# ARTMAP ARTIFICIAL NEURAL NETWORKS WITH FUZZY LOGIC. THEIR APPLICATION TO STUDY THE WAVE CONDITIONS AT SINES PORT, PORTUGAL

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**Abstract**

*The forecast of sea waves has been analyzed, in the literature, using various methodologies. Currently, there are a number of techniques that have shown satisfactory results, which are based on empirical formulations, numerical and physical modeling. However, there is still a large gap for research in the use of numerical modeling, especially when the models employed become very complex or with a large amount of variables. Thus, the scope of this work is to present a neural network system of the ART (Adaptive Resonance Theory) type with Fuzzy Logic techniques to determine wave conditions at the Portuguese coast (Sines Port).*

## 1. Introduction

Coastal zones are very attractive regions for human settlement. Associated to man's occupation of these areas is the attempt to minimize the natural hazards, with structures being designed to ensure quality of life and safety to neighboring populations.

Dornelles (2007) showed that protection structures such as dikes, dams, polders, jetties, breakwaters, spurs, etc., are always designed for a particular return period of wave or flood events, and for situations beyond the projected period, losses are amplified because in the "protected" areas the occupation is intensified due to the false perception that sea waves or flooding will never reach that region.

So, the knowledge of the local wave climate is essential for a more supported coastal management. In order to meet these needs it is important to uprightly simulate real cases for the planning of current or emergency situations. Numerical hindcast and wave propagation models represent a powerful tool to address problems in coastal engineering and in environmental studies, such as water management. They give an important contribution in this context, due to their quickness, flexibility, and wide application range. Although these characteristics allow the easy simulation of several scenarios, the models are computationally demanding and have their own limitations because they cannot simulate all physical phenomena present in the complex process of generation, propagation and dissipation of waves from offshore to the coastline. Physical modeling can analyze these phenomena, but it is expensive, time consuming, requires very specific infrastructure and equipment and a high experience by those performing the tests and analyzing their results. Therefore, it has been demonstrated (Londhe and Deo, 2004) that techniques based on Artificial Neural Networks have been taken up with great approval by their users. These network tools have proven very useful in the practice of engineering, but still have limitations mainly related to the lack of generalization.

Thus, this paper presents the application of ARTMAP Artificial Neural Networks, with Fuzzy Logic techniques, to try to excel the complexity of wave prediction models.

## 2. ART Artificial Neural Networks

Several types of ANNs have been proposed for different kinds of application. A quite popular

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ANN in the field of pattern recognition is a multilayer network using the backpropagation learning algorithm.

Simeón (2008) showed that while this model fits reasonably capabilities mentioned about the brain units, it presents problems related to the memory requirements as a mental faculty: incremental learning and the two classifications of short and long term memory. Once trained, if a new example is presented, on its own, to the network, previous information may be lost in the process. Therefore, this work will examine another type of networks, namely ART networks.

Carpenter et al (1987) showed that the ART (Adaptive Resonance Theory) networks seem to satisfactorily meet these requirements. Recognition layer (Y) classifies the input, providing the neuron with higher value in the activation function (Figure 1).

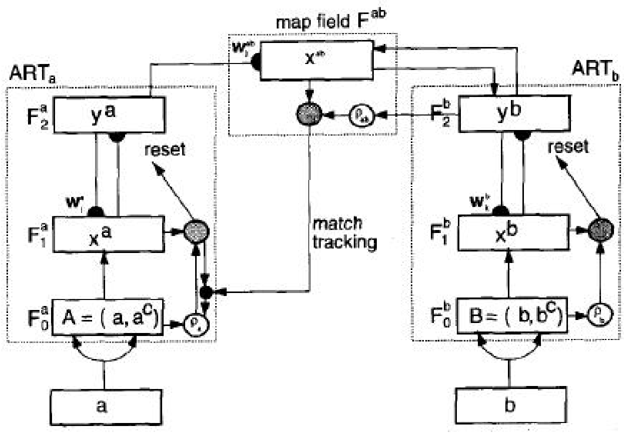


Figure 1. Adapted model of Fuzzy ARTMAP (CARPENTER et al., 1992).

Incorporating elements of fuzzy logic in the classic ART model allowed the analog treatment of imprecision, characteristic of the way language represents the world. Carpenter et al (1991) showed that the models known as Fuzzy ART have such characteristics. The proposal to build an artificial entity being with memory consists, thus, in building a model of this nature.

FAM (Fuzzy ARTMAP) model development, illustrated in Figure 1, allowed adaptation of ARTMAP network for using analog patterns both of input and output. The Fuzzy ARTMAP network is a generalization of the binary ARTMAP network. It is capable of incremental supervised learning, updating itself during operation without "forgetting" what has learned previously. The Fuzzy ARTMAP network can be used for classification and/or association of binary patterns and/or analog input and output with arbitrary dimension. This model consists of two Fuzzy ART modules, $ART_a$ and $ART_b$, connected by an intermediate modulus Fab. Operations performed internally in the propagation of signals are changed to the operations defined by fuzzy logic, working with fuzzy sets and operators.

The modules $ART_a$ and $ART_b$ perform the recognition of input values and of the desired output values, respectively. The interconnect module is used in training to map input and output.

### 3. Study Area

The Port of Sines is located on the Southeast of Europe, on the west coast of Portugal, 58 nautical miles south from Lisbon, on the cross of the main international maritime routes – East-West and North-South (Figure 2).


Figure 2. Port of Sines.

Being a modern port (1978), with excellent maritime access, without restrictions, it is one of the major trade and economic gateways of the Iberian Peninsula so that is considered a port of great geographic and strategic importance to Portugal and Spain.

It is an open deep water sea port, sheltered by two main breakwaters (the west and the east breakwaters), which protect five main terminals: liquid bulks, petrochemical products, multipurpose, LNG and container. Due to its modern specialized terminals, the port is able to handle the different types of cargoes, leading the Portuguese port sector in the volume of cargo handled (mainly bulk cargos, both liquid and solid), and offering unique natural characteristics to receive any type of vessels.

The Sines Port presents a high growth potential, in order to become a reference port at an Iberian, European and worldwide level. In fact, the port and its support Industrial and Logistics Zone, with more than 2,000 ha, is already a worldwide extent logistic platform, able to receive the main players of port, maritime, industrial and logistic sectors.

To characterize the wave conditions offshore the Sines Port, data from the directional wave-buoy "Sines 1-D" are available from *Instituto Hidrográfico*, Portugal. The buoy is located offshore the port (37º55'N and 08º55'W) at a water depth -93 m (CD). In normal conditions, the wave parameters, such as the significant wave height (HS), the mean wave period (TZ) and the wave direction (DIR), are produced every 1 hour, based on 20 minutes duration wave buoy measurements. To predict the wave characteristics at the coast, the wave propagation model SWAN (Booij et al., 1999) is forced by the buoy data. The results (HS, TZ, DIR) near the coast, located at a depth -40 m (CD), were obtained from May 1988 to December 2002. Table 1 presents an overview of both buoy data and the corresponding SWAN results.

Table 1. Statistical wave parameters at "Sines 1-D" wave buoy and at near coast.

| **Local \ Parameters** | | **Maximum** | **Average** | **Minimum** | **Standard Deviation** | **More frequent** |
|---|---|---|---|---|---|---|
| | **HS (m)** | 7.35 | 1.60 | 0.27 | 0.899 | [1.0 - 2.0] (48.05%) |
| **Buoy** | **TP (s)** | 19.8 | 8.8 | 4.2 | 2.325 | [6.0 - 7.0] (17.78%) |
| | **DIR (º)** | 358 | 299 | 5 | 18.609 | [300 - 310] (32.68%) |
| | **HS (m)** | 11.09 | 1.54 | 0.07 | 0.93 | [1.0 - 2.0] (48.26%) |
| **P** | **TP (s)** | 18.90 | 8.86 | 4.17 | 2.26 | [9.0 - 10.0] (22.27%) |
| | **DIR (º)** | 352.7 | 302.8 | 71.79 | 24.7 | [310 - 320] (32.34%) |

## 4. Methodology

A Fuzzy ARTMAP algorithm was developed with graphical treatment in Microsoft Excel$^{R}$. The gaps in the database were eliminated (missing data). The processor used was an Intel Core i7 2.2

GHz - 8 GB RAM. The network parameters adopted were: β = 1.0 (fast training rate), α = 0.1 (category choice parameter), $\rho_a = \rho_{ab} = 0.95$ (monitoring parameter – $ART_a$ and $InterART_{ab}$ Module), $\rho_b = 1.0$ (monitoring parameter $ART_b$), ε = 0.001 (increase in the monitoring parameter ARTa). The offshore wave height and period from the wave buoy were used as input values, whereas the output values were the wave height and period, respectively, determined at the coast (Point P) by using the SWAN model. The network was trained with a data period of one year (2010), approximately 3,000 values. Subsequently, a test was performed for a few random months included in the spring, summer, autumn and winter. With the same training, a random test was carried out for the two weeks of 10/05/2010 to 16/05/2010 and 10/11/2010 to 16/11/2010, and for a day (09/07/2010). The results are shown in the next section.

## 5. Results

This section presents, in graphical form (Figures 3 to 9), the results obtained for each studied case, for the 2010 training year. The training time was 1,112.13 s.

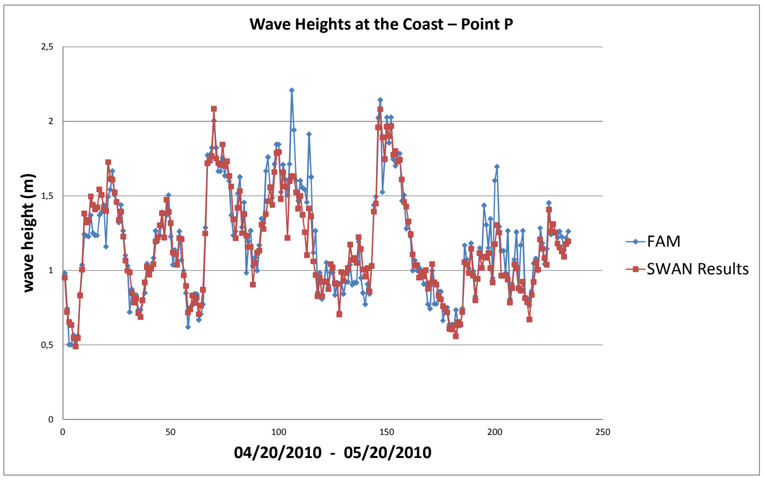


Figure 3. Comparison of Fuzzy ARTMAP predictions with the SWAN results at the coast: SPRING (period chosen: 20/04 to 20/05).

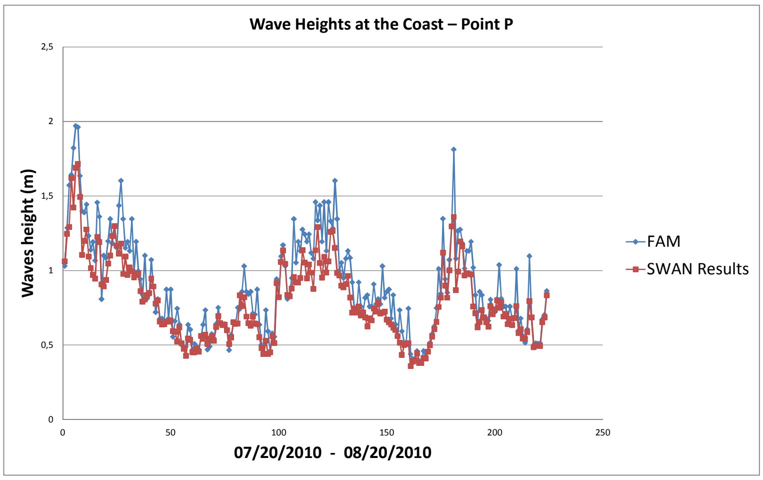


Figure 4. Comparison of Fuzzy ARTMAP predictions with the SWAN results at the coast: SUMMER (period chosen: 20/07 to 20/08).

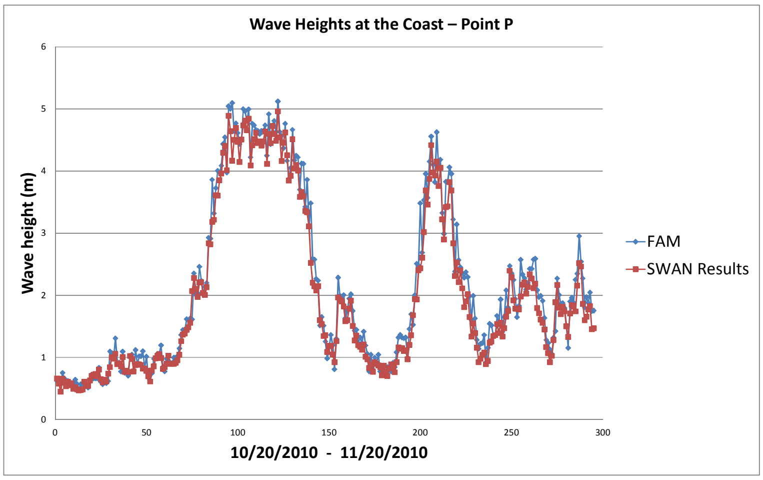


Figure 5. Comparison of Fuzzy ARTMAP predictions with the SWAN results at the coast: AUTUMN (period chosen: 20/10 to 20/11).

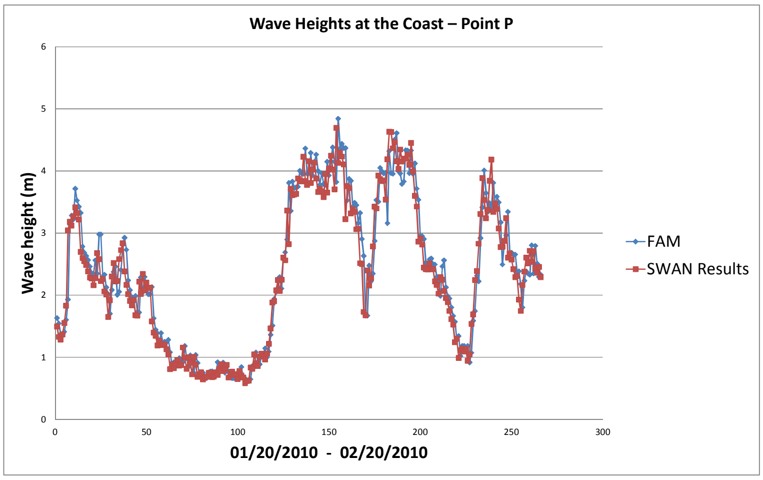


Figure 6. Comparison of Fuzzy ARTMAP predictions with the SWAN results at the coast: WINTER (period chosen: 20/01 to 20/02).

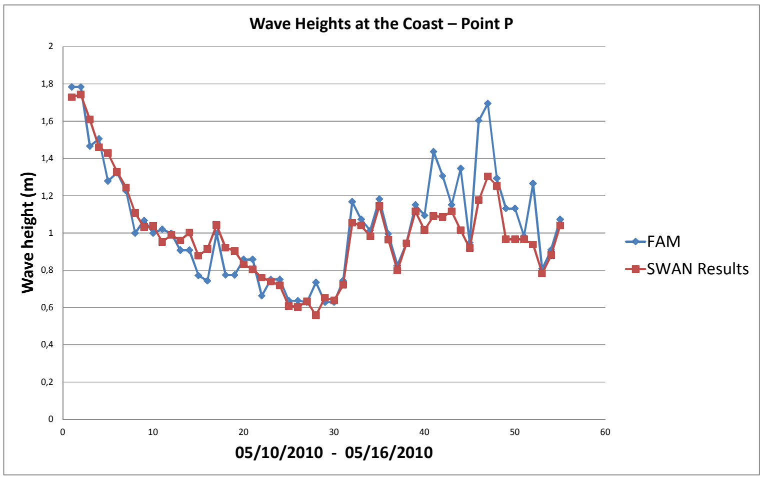


Figure 7. Comparison of Fuzzy ARTMAP predictions with the SWAN results at the coast: WEEK 1 (10/05 to 16/05).

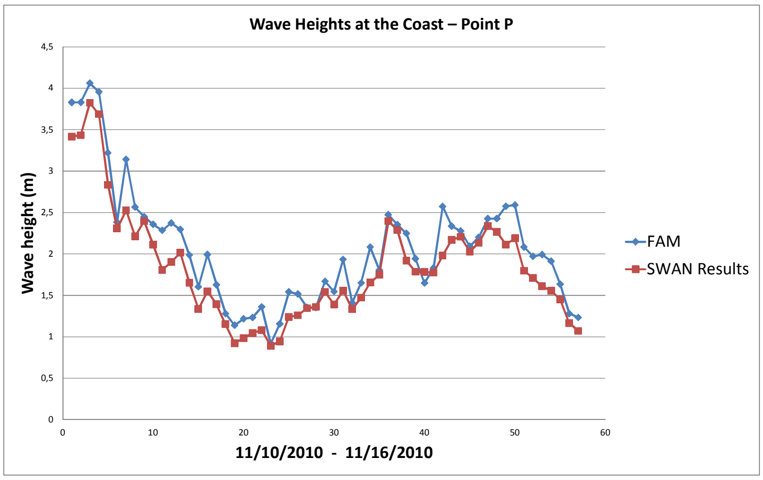


Figure 8. Comparison of Fuzzy ARTMAP predictions with the SWAN results at the coast: WEEK 2 (10/11 to 16/11).

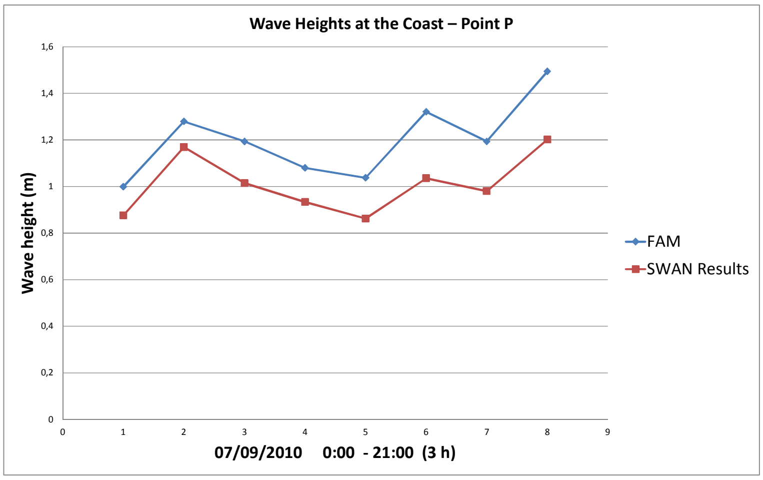


Figure 9. Comparison of Fuzzy ARTMAP predictions with the SWAN results at the coast: 09/07/2010.

Next, Table 2 contains, for each studied case, the calculated values of the mean absolute percentage errors (MAPE) and of the maximum errors (E).

Table 2. Mapping errors and computational time for each studied case.

| CASE | MAPE (%) | MAXIMUM ERROR (%) | COMPUTATIONAL TIME (s) |
|---|---|---|---|
| SPRING | 7.8 | 36.9 | 0.42 |
| SUMMER | 13.2 | 45.5 | 0.44 |
| AUTUMN | 9.6 | 42.9 | 0.52 |
| WINTER | 10.6 | 52.1 | 0.47 |
| WEEK 1 | 9.0 | 36.2 | 0.10 |
| WEEK 2 | 13.7 | 30.0 | 0.10 |
| DAY 09/07 | 18.9 | 27.6 | 0.04 |

## 6. Discussion and Conclusions

In terms of results, we observed that:

- the ARTMAP results presented in all cases appear to be slightly overestimating the SWAN results (on the safe side);

- the training time with approximately 3,000 data points (a full year) is very low (less than 20 minutes), which favors a future real time treatment;
- the computational time for each case is even lower (less than 1 second);
- the predictions provided by the network in all cases follow the trend of the wave heights at the coast, showing a good fit to the SWAN results.

Future developments of the ARTMAP network will encompass a broader sensitivity analysis of its parameters. The network will also be trained using a 10-year buoy wave data period (instead of solely the 2010 data) followed by an analysis of its results for different years from those already trained. Finally, this work is in its early stage and it is expected that, with further developments to the ARTMAP network, it will be possible to use it embedded in a real time warning system, including the analysis of other variables.

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