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# *Study Of The Evolution And Modeling Of Aeolians Dunes*

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**Abstract – The objective of this work is to study the influence of sediment supply on the evolution and formation of sand dunes on a horizontal plane. The study on dune fields is complemented by work on an isolated dune or sand pile. Numerical simulations are conducted using ANSYS Fluent software, which employs the finite volume method of the Eulerian model. We have adopted a simplified approach by varying three characteristic parameters in our simulations: wind speeds, sand densities and their sizes. The results show that, without the addition of external sand, the duration of dune formation is determined by the amount of sand lost. The height of the dunes gradually decreases until their disappearance. High wind speeds intensify erosion: fine grains are easily lifted and transported in suspension, while larger grains primarily move by saltation and creep. This dynamic leads to a great diversity of dune shapes, influenced by sand density and wind intensity. Next, we used artificial intelligence to analyze and model the data from the results obtained during the simulations. To achieve this, the ANFIS neuro-fuzzy system is applied for modeling the height of sand dunes.**

**Keywords – Sand, Isolated dune, Wind, Numerical simulation, Neuro-fuzzy.**

## I- INTRODUCTION

Aeolian dunes are the result of the complex interaction between a granular medium and an air flow [1]. They can take on various shapes depending on the wind conditions and the sand that composes them. There are also climatic, biological, geomorphological, and/or oceanographic conditions such as wind direction and speed, precipitation, vegetation cover, sediment supply, and sand grain size [2] [3] [4]. The movement of sand dunes can cause major problems for human installations such as agriculture, road traffic and even entire towns. It reduces land area and the availability of water resources [5] [6] [7]. Despite the fact that dunes are often grouped together in dune fields, it is essential to understand the behavior of isolated dunes [2]. The objective of this work is to study the evolution of sand dunes. We varied three main parameters in our simulations: wind speed, sand density and grain size. For this study, we conducted several series of numerical simulations starting from an isolated pile of sand. We then established a model of the data obtained from the numerical simulations using the neuro-fuzzy system (ANFIS).

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## II- MATERIALS AND METHODS

### 2.1 MATERIALS

**ANSYS Fluent:** ANSYS Fluent software offers comprehensive modeling capabilities for a wide range of incompressible and compressible fluid flow problems [8]. Sand dunes are simulated using ANSYS Fluent [6].

**MATLAB:** The MATLAB software for large-scale data processing and numerical calculations [9]. It is a scientific calculation software [10] [11], and can also be considered a programming language suitable for scientific problems [12]. We used this software to develop the modeling using ANFIS.

### 2.2 EULERIAN METHODS

#### 2.2.1 Generalized transport equation

The generalized transport equation is used to derive the conservation of mass and momentum equations in ANSYS Fluent [13].To study fluid flow, the following two main equations must be used [14]:

Continuity equation:

$$\frac{\partial \rho}{\partial t} + \nabla.(\rho u) = 0 \tag{1}$$

Equation of momentum:

$$\rho\left(\frac{\partial \vec{u}}{\partial t} + \vec{u}.\nabla\vec{u}\right) = -\nabla p + \nabla.\tau + \rho\vec{g} + \rho\ (\vec{F_l} + \vec{F}_D) + S_u \tag{2}$$

Where $p$ is the static pressure, $\tau$ is the viscous shear stress tensor, g is the gravitational force, $\vec{F_d}$ is a driving force, $\vec{F_l}$ represents the lift force, and $S_u$ are the source terms specific to an application [13].

#### 2.2.2 Description of isolated dune

The numerical simulation of isolated dunes or sand heap incorporates morphodynamics on a non-erodible substrate subjected to unidirectional wind. This sand pile is then defined solely by the position of its top x and its height h.

A dune can be completely described by two continuous variables x (y; t) and h (y; t), where y represents the position of the dune and t is the time [15]. And L is the total length of a sand dune. Figure 1 illustrates the problem we are interested with. The objective is to study the profile of an isolated two-dimensional dune as a function of its mass and characteristic wind speed.

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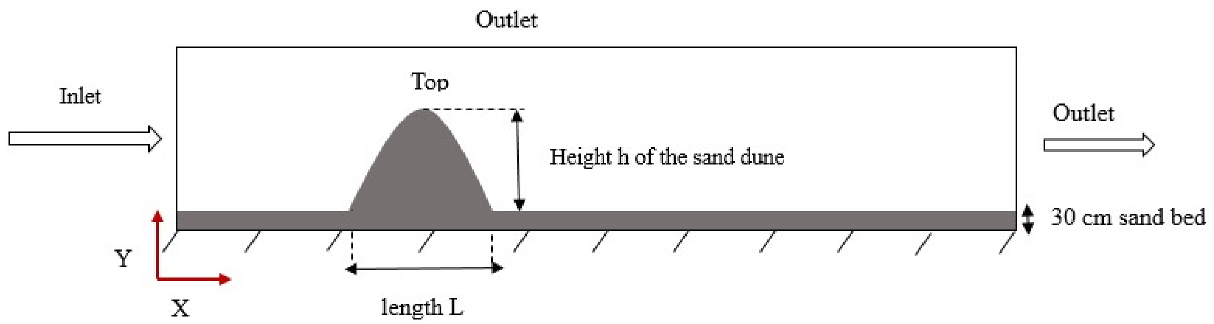


*Figure 1: Initial state of isolated dune*

Table 1 gives the various parameters used in the simulations, with two variables playing a major role in shaping the dune structure: the physical properties of the granular medium and the characteristics of the airflow.

*Tableau 1: Parameters of stratified flow in a rectangular pipe*

| Parameter | Value | Unit |
|---|---|---|
| $\rho_{wind}$ | 1,225 | $Kg/m^3$ |
| $\mu_{wind}$ | $1,7894\ .10^{-5}$ | Kg/m. s |
| $\rho_{sand}$ | 2600 à 2900 | $Kg/m^3$ |
| $\mu_{sand}$ | $1,72.10^{-5}$ | Kg/m. s |
| $D_{sand}$ | 0,1 à 0,5 | mm |
| Wind speed | 6,67 à 30 | m/s |

Where $\mu_{wind}$ is the dynamic viscosity of wind, $\rho_{wind}$ is the density of wind, $\mu_{sand}$ is the dynamic viscosity of sand , $\rho_{sand}$ is the density of sand and $D_{sand}$ is the grain diameter of the sand.

## III- RESULTS AND INTERPRETATION

Figure 2 represents the development of sand dunes that initially have a conical sand pile shape, with a sand grain diameter of 0.5 mm and a density of 2600 kg/m³, under the influence of a constant wind of 30 m/s. The different time steps represented are t = 0 s; t = 0.5 s; t = 1 s; t = 1.5 s; t = 2 s; t = 4 s; and t = 6 s, showing the flow from left to right (front view). We observe areas of deformation on the sand pile, leading to its fragmentation. On the one hand, the sand pile flattens and elongates, with a deposit of grains on top. Thus, the sand is eroded on one side of the sand pile and deposited on the other, allowing the sand pile to move while adapting its shape to the wind flow. A generalized erosion occurs, leading to the gradual disappearance of the sand pile, while a deposition zone may appear. It is observed that where there is a loss of mass on the sand dune, it can lead to its total disappearance after a certain time. Particles escape, and the dune gradually thins. Its volume decreases to the point that it can completely disappear before exiting the channel.

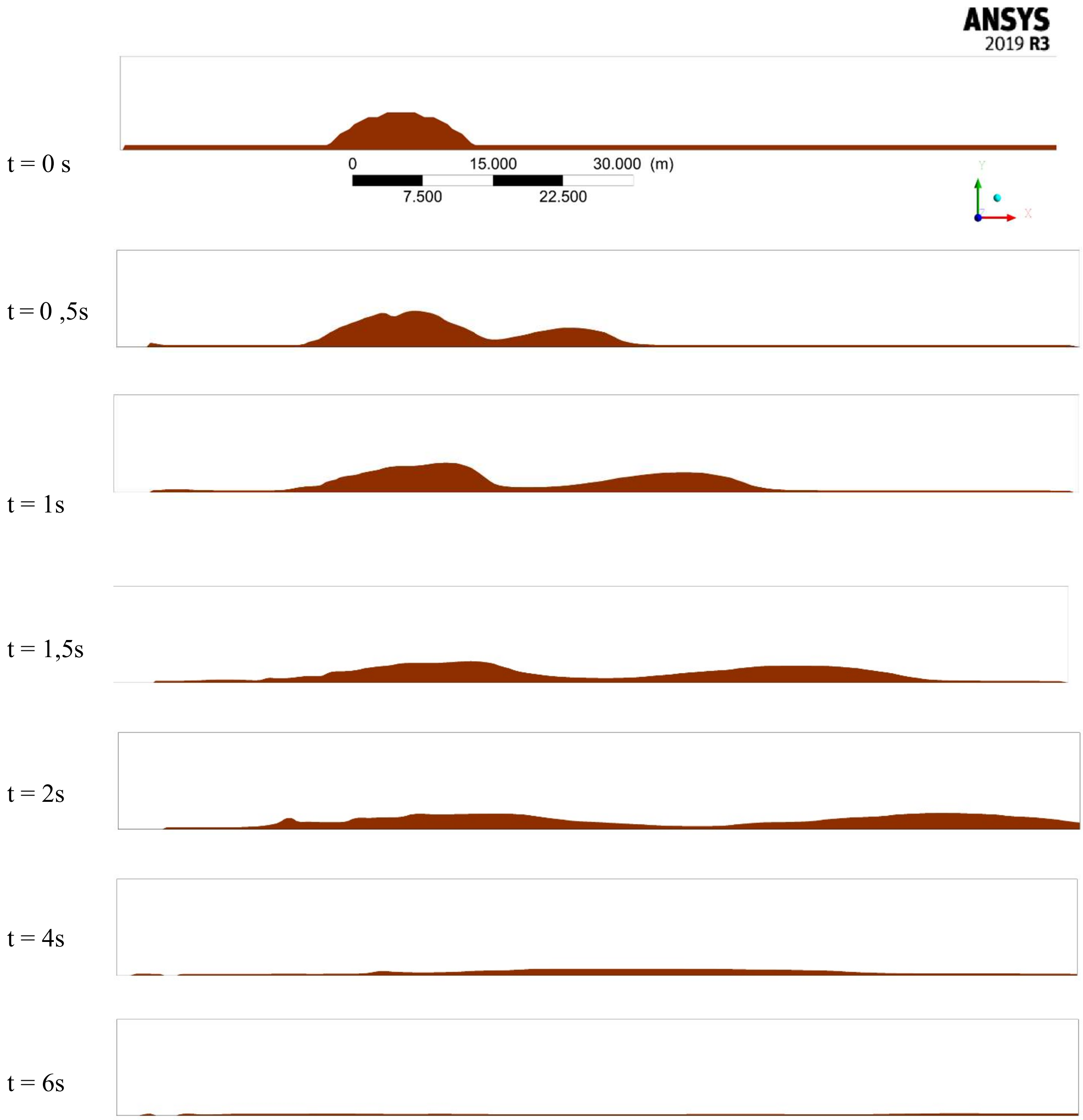


*Figure 2: Evolution of a sand dune from a conical sand pile*

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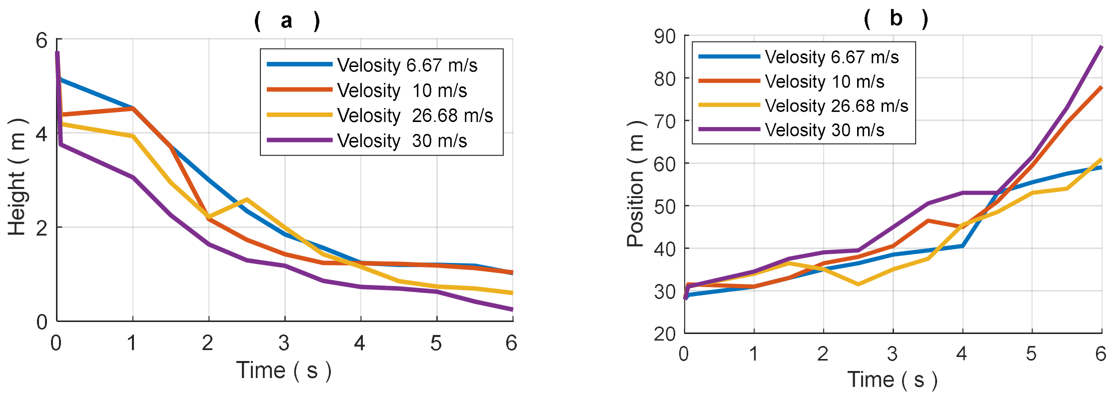
### 3.1 Effect of wind speed variation on the movement of sand dunes

In the results of the following simulations, the wind speed varies from 6.67 m/s to 30 m/s. The sand density is kept constant at 2600 kg/m³, and the grain diameter is set at 0.5 mm. At the initial state, all the dunes have a similar height.

Figure 3(a) represents the evolution of the sand dune height. A general decrease in dune height is observed, regardless of the wind speed. The wind carries away the grains of sand, thereby reducing the height of the dune. The higher the wind speed, the faster the erosion. Dunes exposed to a wind speed of 30 m/s erode much more quickly than those subjected to a wind speed of 6.67 m/s.

Figure 3(b) illustrates the evolution of the sand dune position over time. The higher the wind speed, the faster the dune moves. It is observed that the dune subjected to a wind speed of 30 m/s (purple curve) moves significantly faster than those subjected to lower wind speeds. The distance traveled by the dune increases with wind speed and time. The higher the wind speed, the faster and more significant the movement of the dune.

Figure 3(c) illustrates the evolution of the length of the dune horns over time. A clear progressive increase in the length of the horns is observed. At a high wind speed, the elongation of the horns is rapid but tends to stabilize quickly. On the other hand, at a speed of 6.67 m/s, the elongation of the horns is slower, but it continues over a greater distance and for an extended period. For a wind speed of 30 m/s, the curve shows a parabolic configuration. When the dune exits the study area (or the conduit), its length gradually decreases until it disappears, this reduction being limited by the amount of available sand.



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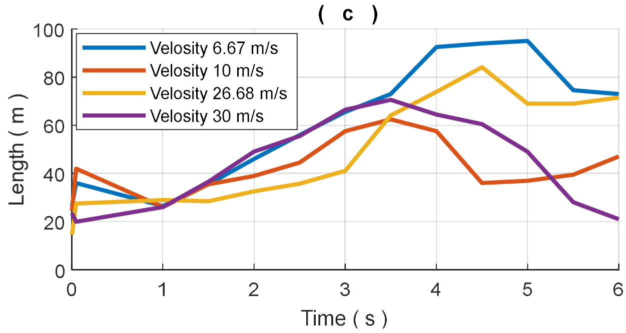


*Figure 3: Temporal evolution of the height, position and length of sand dunes*

### 3.2 Influence of the variation in sand densities on dunes movement

In the results of the following simulations, the sand density is varied from 2600 kg/m³ to 2900 kg/m³, with a constant wind speed of 30 m/s. The grain diameter is set at 0.5 mm.

Figure 4(a) illustrates the temporal evolution of the sand dune height. A general decrease in dune height is observed for all densities. The wind carries away the sand grains, thereby reducing the height of the dune. The sand density does not have a very marked influence on the erosion rate in this numerical simulation. The curves, being relatively close, indicate that dunes of different densities erode at similar rates. The density of the sand therefore has no notable impact on the wind erosion rate of the dunes. Without external sand input, the lifespan of the dunes depends on their sand loss: they gradually erode, lose height, and eventually disappear.

Figure 4(b) illustrates the evolution of the sand dune position. The evolution of the dune position over time is nuanced, with phases of rapid movement alternating with periods of slowing down. These fluctuations are related to complicated interactions between the wind, the grains of sand, and the shape of the dune. There is no direct relationship between sand density and the dune migration speed. The curves show irregular variations, indicating that the distance traveled by the dune appears to vary randomly depending on the density.

Figure 4(c) illustrates the evolution of the sand dune length over time. The different curves indicate that the sand density has an impact on the evolution of the dune length. There is no direct and simple relationship between the density of the sand and the elongation speed of the dune. The curves evolve irregularly, showing rapid increases and decreases. For dunes with a density of 2600 kg/m³, represented in blue, the curve is parabolic. The final length of the dune varies randomly according to the density. The length of the sand dune gradually decreases until it disappears, due to the loss of sand.

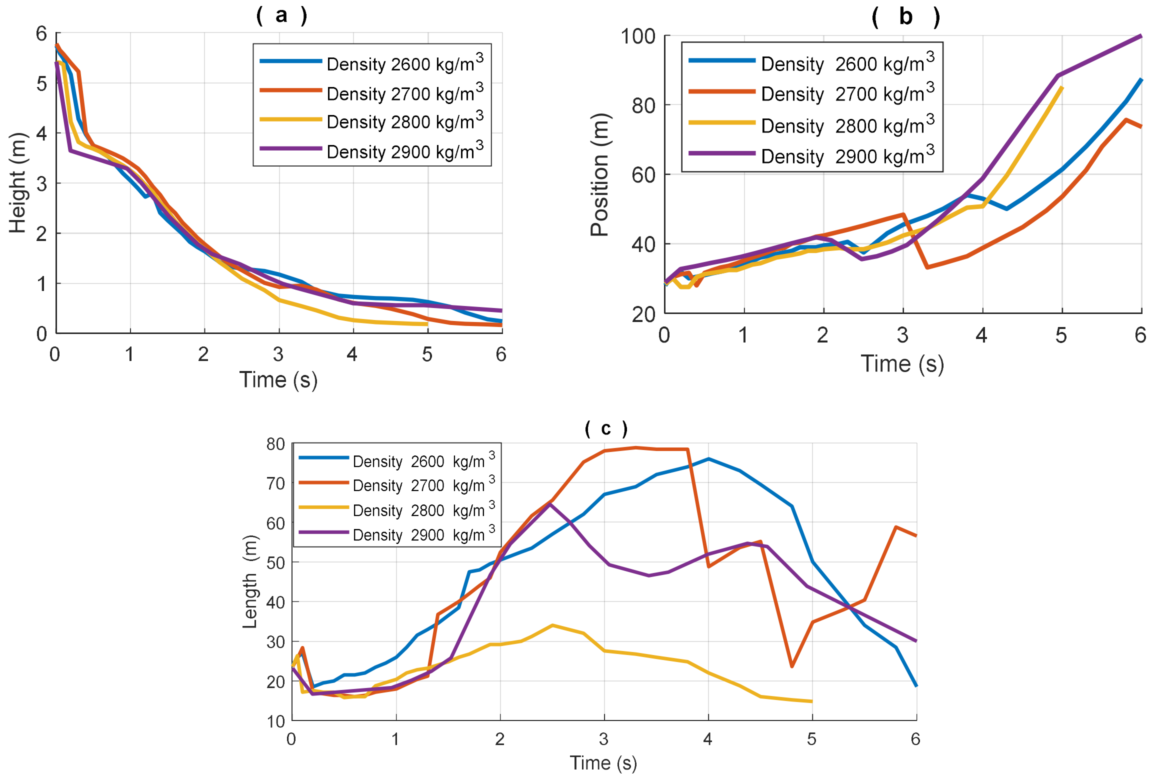


*Figure 4: Temporal evolution of the height, position and length of sand dunes*

### 3.3 Impact of the variation in sand grain diameters on dune movement

In all the results of the following simulations, the sand density is constant at 2650 kg/m³, under the effect of wind blowing at a constant speed of 10 m/s, while the sand grain sizes vary from 0.1 mm to 0.5mm.

Figure 5(a) illustrates the evolution of the sand dune height. Fine grains (diameter D = 0.1 mm) are easily transported by the wind in suspension, which reduces their time of appearance. Intermediate-sized grains (D = 0.2 to 0.4 mm) are large enough to be less easily moved by the wind, but small enough to be set in motion. In contrast, coarse grains (D = 0.5 mm) are more difficult to move.

Figure 5(b) represents the evolution of the sand dune position over time. Dunes composed of larger sand grains (0.4 mm and 0.5 mm) move over longer distances. Finer grains are often suspended and disappear more quickly. This is explained by the fact that fine grains are more easily lifted and transported by the wind, while larger grains are less readily lifted, which favors their movement by saltation and creeping.

Figure 5(c) represents the evolution of the sand dune length. The simulation shows that for fine grains (D=0.1 mm), the dune length remains less stable, because the grains are easily transported by the wind in suspension. For intermediate grains (D = 0.2 to 0.4 mm), rapid growth phases are observed, followed by stabilization or even retreat. In contrast, grains with a diameter of D = 0.5 mm are more difficult to move, which limits the growth of the dune, which then takes an almost parabolic shape.

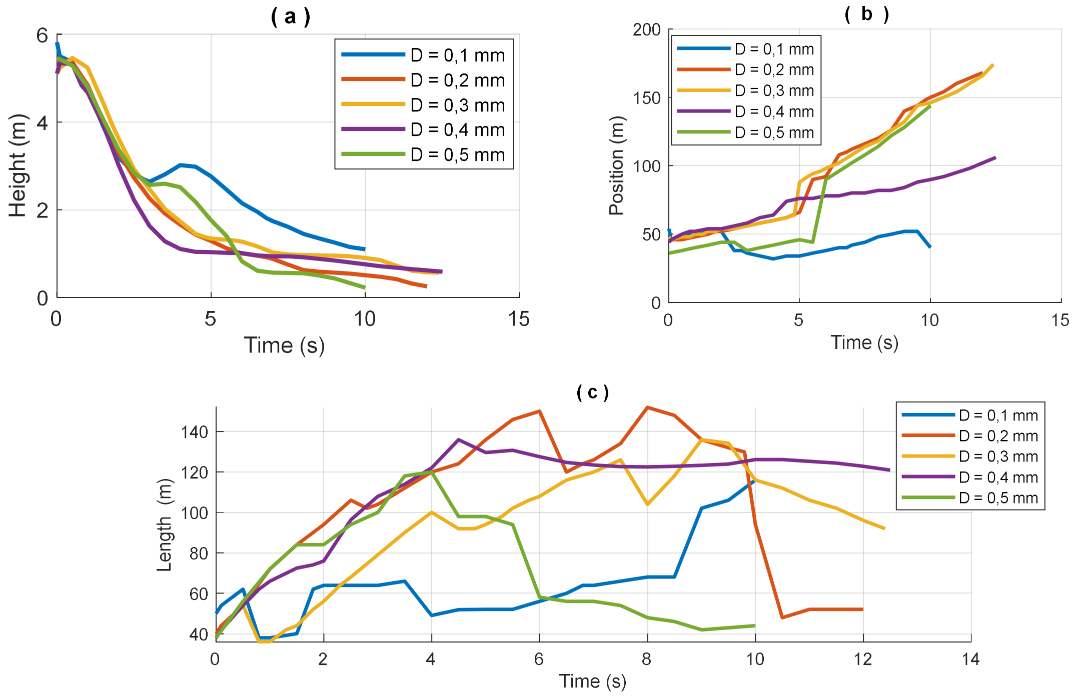


*Figure 5: Temporal evolution of the height, position and length of sand dunes*

## IV- MODELING OF SAND DUNE HEIGHT USING NEURO-FUZZY ARTIFICIAL INTELLIGENCE (ANFIS)

We modeled sand dune heights using wind speeds ranging from 6.67 m/s to 30 m/s. The sand used had a density of between 2600 kg/m³ and 2900 kg/m³, with diameters ranging from 0.1 mm to 0.5 mm.

### 4.1 Structure of the ANFIS network

Figure 6 represents the structure of the ANFIS network with six (6) input data as functions members: wind speed, sand dune position, sand dune length, sand grain diameter, sand density, and simulation time. And one (1) output, which is the height of the sand dune.

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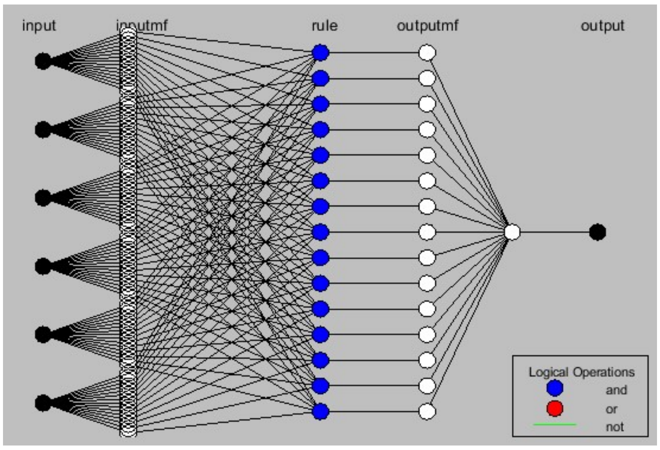


*Figure 6: ANFIS network structure with six (6) inputs and one (1) output*

### 4.2 Modeling of Sand Dune Height

Figure 7(a) compares the raw data of maximum sand dune heights (in black) with the data predicted by the model after training (in red). 75% of the data is used for this step. The comparative analysis reveals an excellent quality of the predictions on training (Target represents the actual data of sand dune heights and Output represents the models). Figure 7(b) represents that the mean squared error (MSE) and the root mean squared error (RMSE) of the maximum sand dune height is 0.149, which are relatively low, which indicates that the model presents an overall satisfactory performance. Figure 7(c) illustrates the distribution of prediction errors (error variation) is centered around zero, which confirms the good performance during the training phase.

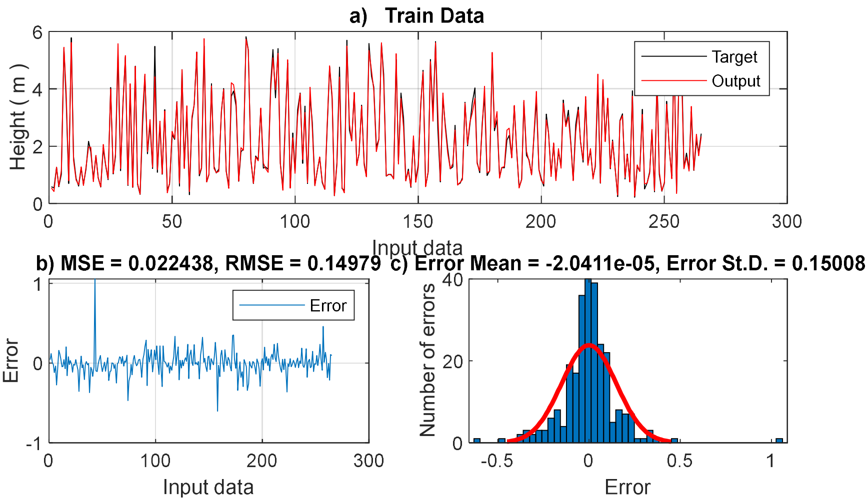


*Figure 7: Representation of data learning*

The figure 8(a) represents the results of the test phase using the remaining 25% of the data. By comparing the actual and predicted values, the overlap of the red and black curves reveals the quality of the model, indicating its performance during the test phase. From figures 8(c) and 8(b), we find minimal error values concentrated around zero, which confirms the good performance of the modeling test. The low standard deviation indicates better precision of the model.

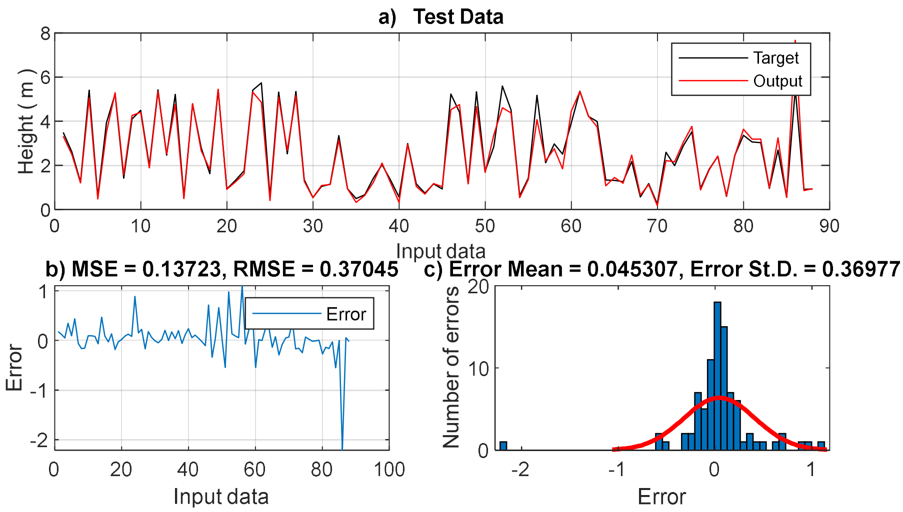


*Figure 8: Representation of the model test*

Figure 9(a) represents the model results on the entire dataset: both training and test data, in order to measure the performance of the model on the whole dataset. A good model is characterized by a close match between the predictions (outputs) and the actual values (targets). By analyzing the curves from the training phase and the test phase, we were able to assess that the model is acceptable and likely to generalize to unseen data. Figure 9(b) represents how the error varies with the provided data. Figure 9(c) shows that the average error is very close to zero, which confirms the good performance of the obtained model. The histogram indicates that most of the errors are close to zero, which suggests that the model is accurate. In other words, the model is highly effective at predicting the position of the maximum height of the sand dune.

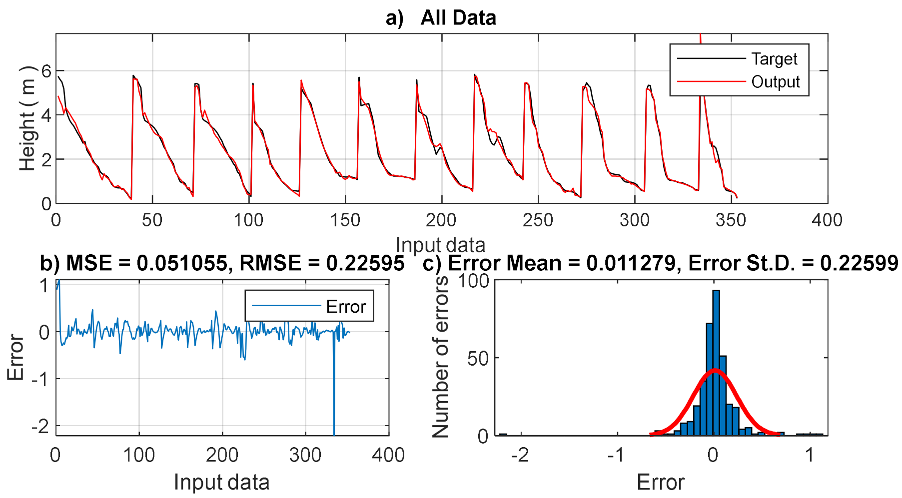


*Figure 9: Representation of the training and test set*

Figure 10 shows the strong correlation between the predicted values and the actual values, suggesting that the model used is highly effective and can be confidence used for new predictions. For the three datasets, the correlation coefficient R is very close to 1. This reveals an almost perfect linear correlation between the predicted values and the actual values. The model is therefore effective in predicting the height of sand dunes.

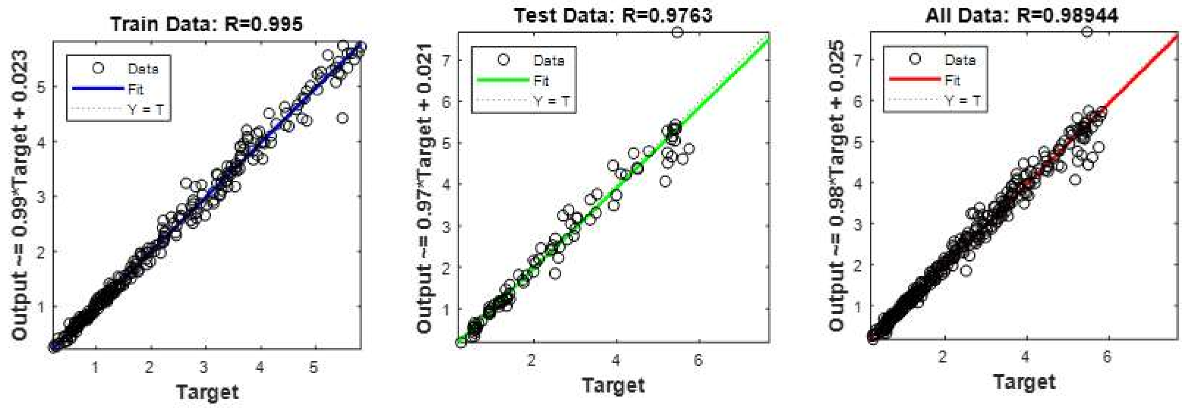


*Figure 10: Correlation between calculated height output and model height output: training test and dataset*

## V- CONCLUSION

The objective of this work was to study the morphodynamics of sand dunes: height, length, and position of the dunes. Once the sediment is set in motion, it can move in different modes: creep, saltation, and suspension. Two variables play a major role in the shape of dune structures: the abundance of sediment and the characteristics of the flow: intensity and direction of the wind. Based on this result, it is found that the evolution of sand dunes is indeed influenced by wind speed, but the relationship is not necessarily proportional. Length and height do not follow the same evolutions. The movement of grains in a fluid depends on both their size and density, as well as the physical characteristics of the wind. Indeed, the grains located at the top of the dune move at a higher speed than those at ground level. The higher the wind speed, the faster the erosion, which leads to a decrease in the height of the dunes. The dune weakens until it disappears. We then modeled the results of the simulations using a neuro-fuzzy system. The correlation coefficient R is very close to 1, indicating that the model is effective in predicting the height of sand dunes.

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