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Modelling the onset and end dates of monsoon circulation in Northern Madagascar

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Abstract

This article presents a method for modelling the onset and end dates of the monsoon season in Northern Madagascar. The method relies on an Artificial Neural Fuzzy Inference System (ANFIS) based on artificial intelligence, which utilizes daily zonal wind data at 925 hPa and a moving average smoothing technique to estimate the onset and end dates of the monsoon. The average period of the monsoon season in this region ranges from December 29th to March 5th. The onset and end dates of the monsoon season serve as inputs to the ANFIS model, which consists of four inputs and one output. To improve forecast accuracy, forecast accuracy, the model results are compared to observation data and validated using the root mean square error (RMSE) criterion.

Keywords

Artificial intelligence, Moving average, Modelling, Monsoon, ANFIS, RMSE

1. Introduction

The monsoon is a seasonal wind system that affects tropical and subtropical regions of the globe, resulting from temperature differences between the oceans and land. During the summer, land heats up more rapidly than the oceans, creating a low-pressure area over the land. The warm and humid air from the oceans is then drawn towards the land, generating monsoon winds and abundant precipitation [1]. In Madagascar, the monsoon plays a crucial role in the island's climate by bringing vital rainfall for agriculture, wildlife, and flora. However, these heavy rainfall events can also lead to flooding and landslides [2]. Therefore, it is important to determine the start and end dates of the monsoon season to establish agricultural calendars and mitigate potential hazards. This article describes the modelling of the onset and cessation dates of the monsoon season in Northern Madagascar using an artificial intelligence-based method, specifically the hybrid ANFIS network. The first section presents the study area and the data used, followed by an explanation of the methodologies employed to achieve the obtained results.

2. Methods

2.1. Study area

The study area is located in the northern region of Madagascar and is delimited as illustrated in figure 1 below

2.2. Database

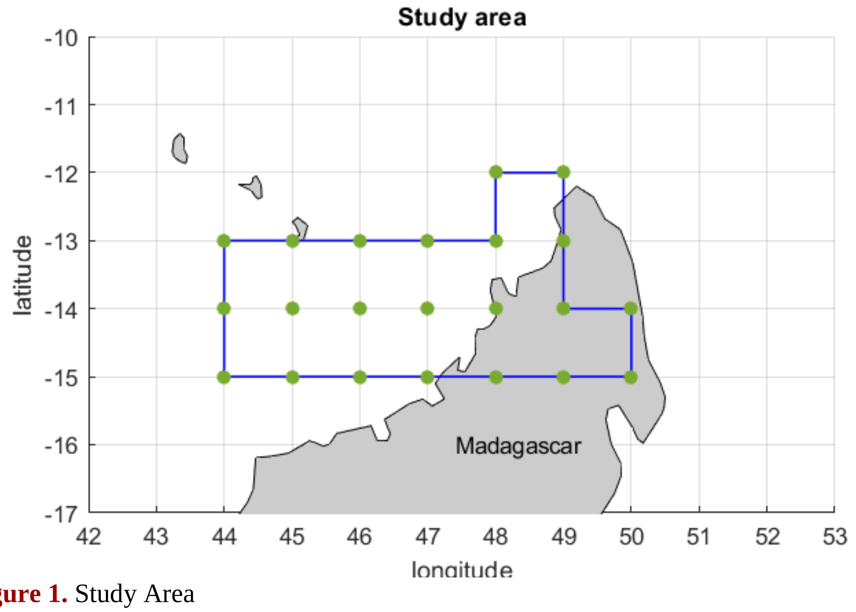

Figure 1. Study Area

The data used for this study are 925 hPa wind field data provided by the ECMWF (European Centre for Medium-Range Weather Forecasts) with a grid resolution of 1° x 1°. The dataset covers the period from 1979 to 2017.

2.3. Moving Average Smoothing [3]

The moving average smoothing method is a non-parametric technique that aims to capture the underlying trend of the data while reducing the influence of outliers. This method is defined as follows:

$$\overline{X}_{(j+1)}(q) = \frac{1}{q}\sum_{i=1}^{q} X_{(j-i)} \quad (1)$$

2.4. Hybrid Network: ANFIS

ANFIS is an inference system that combines the learning capabilities of artificial neural networks with the knowledge representations of fuzzy inference systems to solve complex modelling and prediction problems [4]. The ANFIS network is composed of five main layers [5]:

- The first layer corresponds to the input nodes that receive the input data.
- The second layer consists of membership nodes, which apply relevance functions to the input data.
- The third layer is formed by rule nodes that combine the relevance functions to generate fuzzy rules.
- The fourth layer consists of consequence nodes that calculate the contribution of each rule to the overall system output.
- The fifth layer is the output node, which combines all the rule contributions to produce the final output of the system.

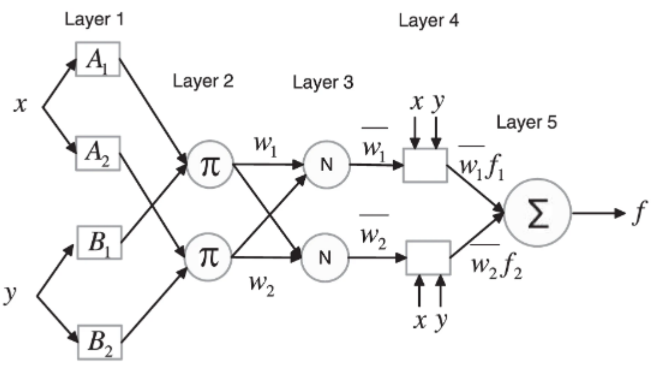

Figure 2. Architecture of Anfis [6]

The ANFIS network has a supervised learning mechanism to adjust the model parameters. The learning is usually done by using a combination of backpropagation and gradient descent methods [7].

3. Results

3.1. Determination of the Onset and End Dates of the Monsoon Circulation

To analyze the data of the 925 hPa zonal wind field and identify the monsoon periods in the study area, we employed a thirty-day moving average method. The onset and end dates of the monsoon circulation were determined based on a sudden change in the direction of zonal wind velocities, transitioning from negative to positive (or vice versa) throughout the year. Specifically, we identified the onset (or end) date when the zonal wind velocity became positive (or negative), as illustrated in Figure 3.

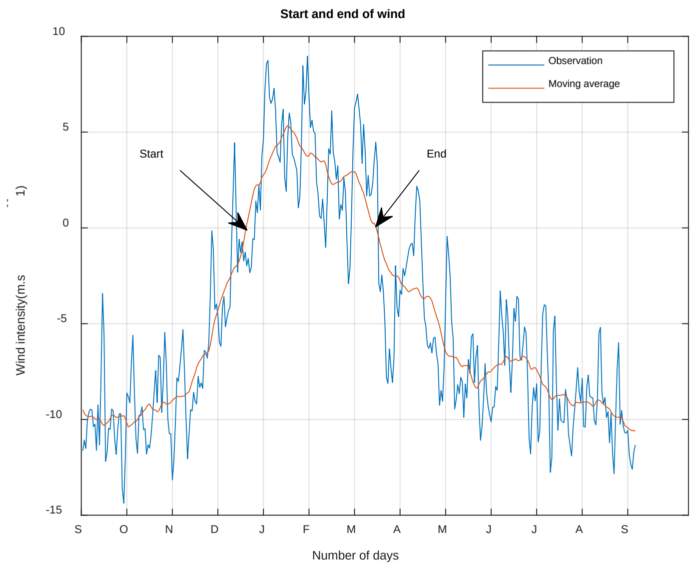

Figure 3. Determination of the onset and end of the monsoon circulation

Figure 4 shows the evolution of the monsoon onset and termination dates in the study area from 1979 to 2017. There is a decreasing trend in the monsoon start date over the years, while the monsoon end date tends to increase. In other words, the onset of the monsoon is getting earlier and earlier, while the end of the monsoon is delayed.

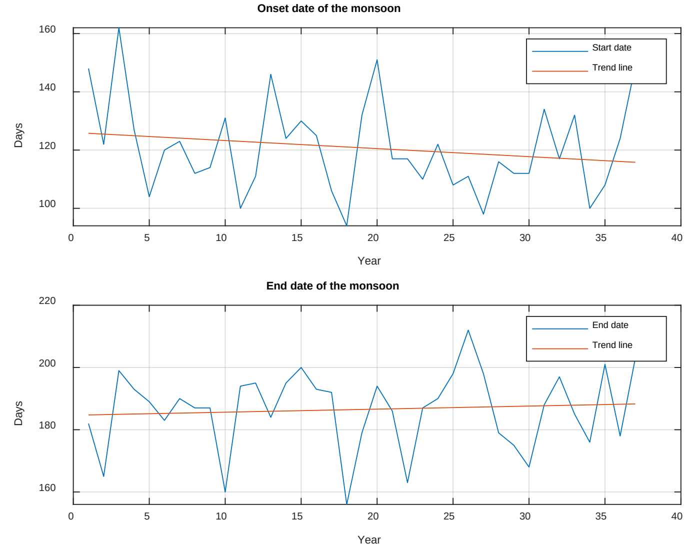

Figure 4. Start and end dates of the monsoon circulation between 1979-2017

3.2. Hybrid Network Modeling: ANFIS

The ANFIS model used in this study is of the Sugeno type, with input data including the onset and end dates of the monsoon obtained earlier.

3.2.1. Modelling the onset date of the monsoon circulation

3.2.1.1. Model Architecture

Figure 5 depicts the graphical representation used to model the onset of the monsoon circulation using the ANFIS model. This mapping consists of four inputs, one output, and thirty-one rules. It should be noted that each of the inputs is subdivided into 31 fuzzy subsets.

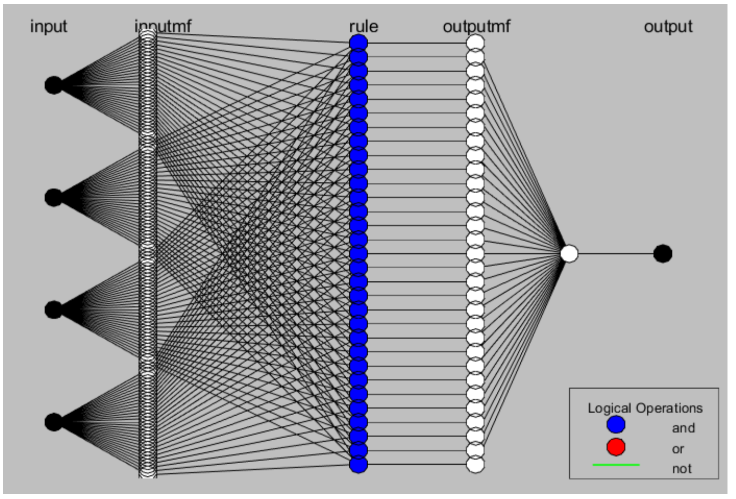

Figure 6. Architecture of the Anfis model

The membership functions associated with this model are shown in the following Figure 6.

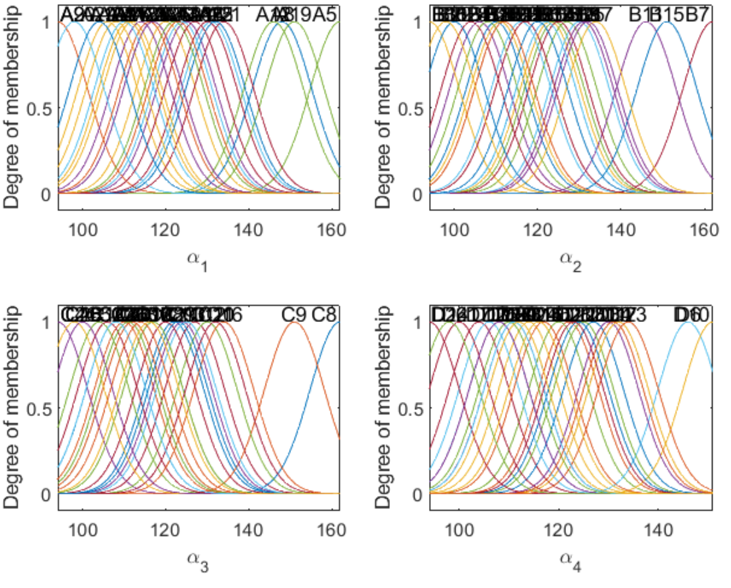

Figure 5. Membership function associated with the Anfis model

3.2.1.2. Fuzzy rules

After 200 iterations, thirty-one fuzzy rules were obtained, some of which are presented below:

- *'1. If (α_1 is A1) and (α_2 is B1) and ($\alpha_3$is C1) and (α_4 is D1) then (ω is M1) '*
- *2. If (α_1 is A2) and (α_2 is B2) and ($\alpha_3$is C2) and (α_4 is D2) then (ω is M2) '*

....

- *'30. If (α_1 is A30) and (α_2 is B30) and ($\alpha_3$is C30) and (α_4 is D30) then (ω is M30) '*
- *'31. If (α_1 is A31) and ($\alpha_2$is B31) and ($\alpha_3$is C31) and (α_4 is D31) then (ω is M31) '*

3.2.1.3. Model Validation

The curve of the ANFIS model is presented in Figure 7, and its root mean square error (RMSE) is 0.75. This value indicates that the model performs excellently**.**

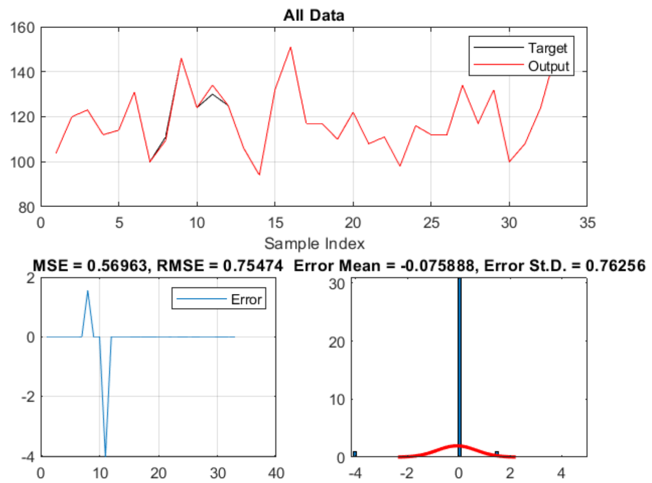

Figure 7. Model validation

3.2.1.4 Monsoon Onset Date Forecast

According to Figure 8, the ANFIS model predicts that the monsoon will begin in the study region on December 25th of the following year, specifically in 2018.

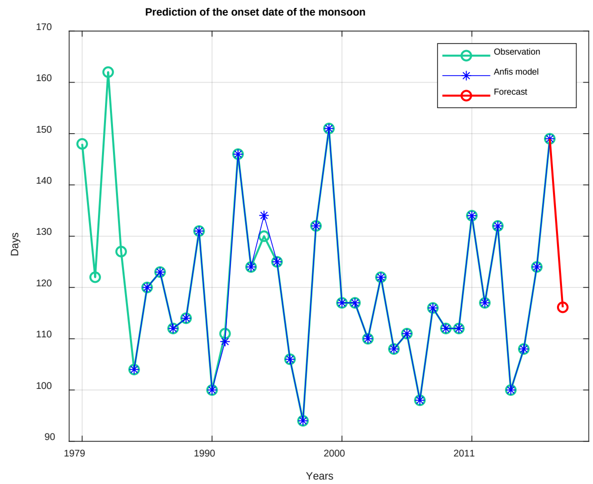

Figure 8. Prediction of the start date of the monsoon circulation with RMSE 0.75

3.2.2. Medelling of the end date of the monsoon cycle

3.2.2.1. Model Architecture

Figure 5 depicts the graphical representation used to model the onset of the monsoon circulation using the ANFIS model. This mapping consists of four inputs, one output, and thirty-one rules. It should be noted that each of the inputs is subdivided into 31 fuzzy subsets.

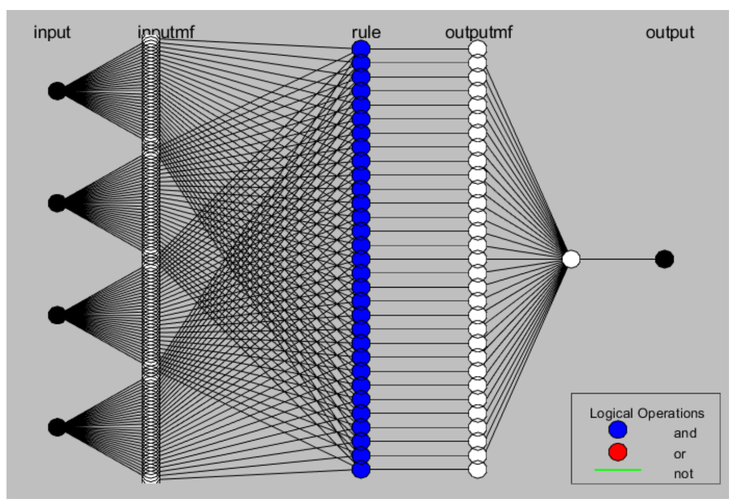

Figure 9. Architecture of the Anfis model

The membership functions related to this model are shown in the following figure 10:

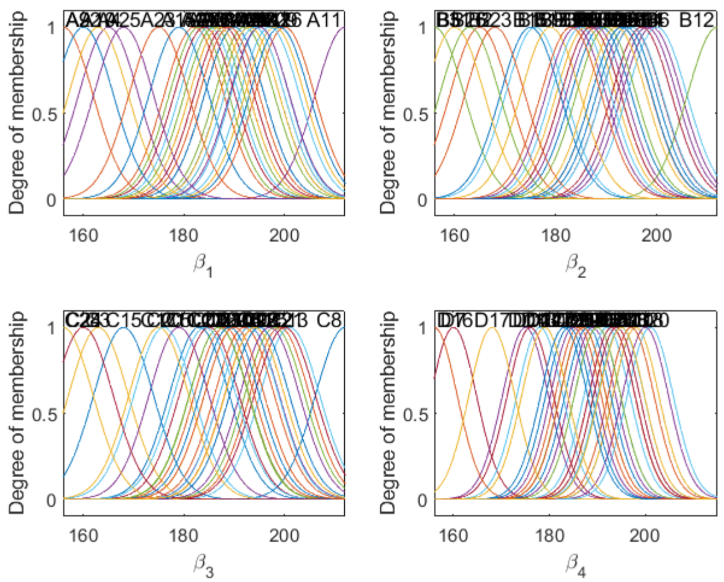

Figure 10. Membership function associated with the Anfis model

3.2.2.2. Fuzzy rules

After 200 iterations, thirty-one fuzzy rules were obtained, some of which are presented below:

- *'1. If (β_1 is A1) and (β_2 is B1) and (β_3 is C1) and (β_4 is D1) then (ω is M1) '*
- *2. If (β_1 is A2) and (β_2 is B2) and (β_3 is C2) and (β_4 is D2) then (ω is M2) '*

....

- *'30. If (β_1 is A30) and (β_2 is B30) and (β_3 is C30) and (β_4 is D30) then (ω is M30) '*
- *'31. If (β_1 is A31) and (β_2 is B31) and (β_3 is C31) and (β_4 is D31) then (ω is M31) '*

3.2.2.3. Model Validation

Figure 11 shows the value of the RMSE of the Anfis model obtained, which is 1.43. This value is an indicator of the quality of the model, and in this case, it indicates that the model is excellent.

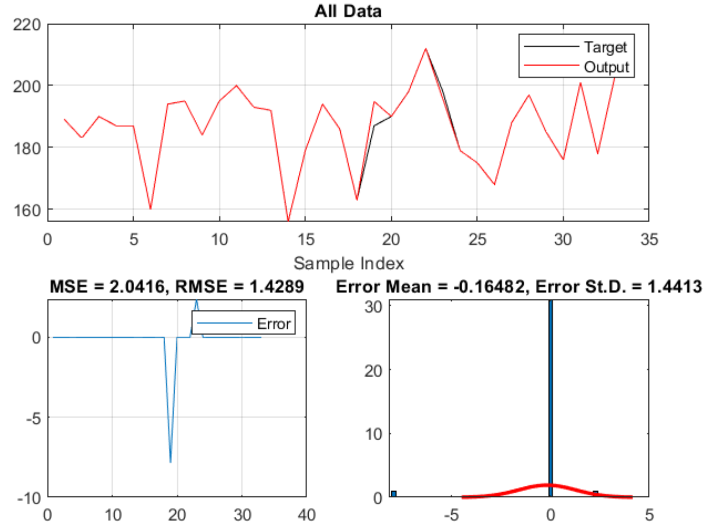

Figure 11. Model validation

3.2.2.4. Prediction of the end date of the monsoon circulation

The figure 12 below shows the forecast of the end date of the monsoon circulation in the study area. The probable date for the end of the monsoon is March 26th.

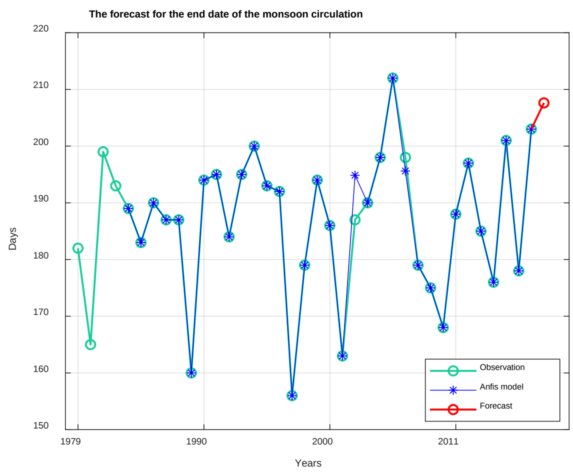

Figure 12. Prediction of the end date of the monsoon circulation with RMSE 1.43

4. Discussion

It is important to note that different variables have been used by the authors to define the onset of the monsoon, such as the use of wind (Holland, 1986), rainfall accumulations (Matsimoto, 1997; Wang and LinHo, 2002; Zhang et al., 2002; Fontaine B. and Louvet S., 2006), a combination of wind fields, rainfall, or other parameters (Lau and Yang, 1997; Qian and Lee, 2000; Yihui et al., 2001), and even the reversal of the meridional temperature gradient (Li and Yanai, 1996; Mao, Chan, and Wu, 2004) [8].

In this study, different climatic variables were examined, and it was concluded that the use of the zonal component of the wind was the most appropriate variable for determining the onset and the end of the monsoon in the study area. However, it should be noted that each method has its advantages and limitations depending on the study area and the data available. It is therefore important to choose the most appropriate method and variable for the context of the study.

5. Conclusion

In summary, this article has allowed us to gain a better understanding of the onset and end dates of the monsoon in Northern Madagascar, as well as accurately predict these dates. The results obtained through the moving average method have revealed that the average duration of the monsoon circulation is about 73 days, occurring between December 29th and March 5th. Furthermore, the ANFIS model with four inputs, thirty-one rules, and one output has shown remarkable performance with low RMSE values, enabling reliable prediction for the future.

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