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Modeling Annual Salinity in the Central Mozambique Channel as a Function of Four Parameters (Rainfall, Evaporation, Pressure and Ocean Temperature) Using Fuzzy Logic

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ABSTRACT : *The salinity of sea water is a function of rainfall, evaporation, pressure, sea surface temperature (SST), solar radiation, wind speed, ... In this study, we will try to model by fuzzy logic the salinity as a function of the annual average of these first four variables. The study area is located in the central part of the Mozambique Channel bounded by*
$19^{o}9^{/}36^{//} \leq$ Latitude $\leq 23^{o}9^{/}36^{/}$ and $35^{o}\ 30^{/} \leq$ Longitude $\leq 43^{o}30^{/}$. After calculation we found the following result:
S =34.0008 - 16.6607*Rainfall - 22.9204*Evaporation + 0.5989 Rainfall*(SST) + 0.0224 Evaporation*Presure
with an RMSE (Root Mean Square Error) equal to 0.024. This shows that we have a good model.

Key words : *Salinity - Rainfall - SST - Evaporation - Pressure*

I. Introduction

The water cycle is driven by the evaporation of sea water which then precipitates as rain, snow, hail, etc., either directly over the oceans or over land. The fresh water then runs off and returns to the oceans at varying rates. As a result, the water cycle causes an increase in salinity in areas of evaporation (concentration of salts) while while increased freshwater inflow reduces it in areas of high precipitation. This phenomenon is at the origin of the differences in salinity between the different seas and oceans. Researchers have found that ocean salinity can serve as a reliable indicator of evaporation and Rainfall. Ocean salinity could therefore be a tool to validate climate change models and remove uncertainties in the water cycle.

II. Data and Study area

In the present work, data of the five parameters (rainfall, evaporation, pressure, sea surface temperature (SST) and salinity) are used to further our study.

<u>Data</u>

The monthly salinity data are taken from the NOAA (National Oceanographic and Atmospheric Administration) website. These data are available in the site:

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<http://www.esrl.noaa.gov/psd/data/gridded/data.godas.html>. These data have a netcdf or ".nc" extension and a spatial resolution of 1°×0.33° and they a three-dimensional matrix of which the third is the month: 468 months from January 1980 to December 2018. The unit of salinity is the PSU or Practical Salinity Unit which is equivalent to g/kg. In our case, the data to be studied are the salinities collected in the first fifteen (15) meters of depth.

The data of rainfall, evaporation, pressure and ocean surface temperature (SST) are daily reanalysis data from the ECMWF (European Centre for Medium-Range Weather Forecasts) site and having as extension NETCDF (Network Common Data Form) or "nc", available online at the synoptic scale "http://www.ecmwf.int" with a grid of 1° x 1°, covering the period of 14610 days or well 40 years (from January 1, 1979 to December 31, 2018). Our data initially have a large three-dimensional matrix, the first of which is latitude, the second longitude, and the third time. We work with MATLAB and XLSTAT.

Study area

Our study area is in the central part of the Mozambique Channel bounded by:
in latitude $19^{o}9^{/}36^{//} \le$ Latitude $\le 23^{o}9^{/}36^{/}$, in longitude $35^{o}30^{/} \le$ Longitude $\le 43^{o}30^{/}$

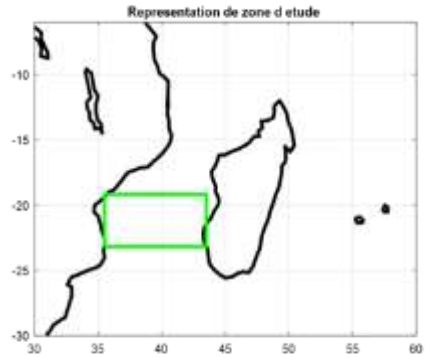

Figure 1: The study area.

III. Annual salinity modeling using fuzzy logic

The mapping is shown in Figure 2. After various attempts to combine the input climate variables (rainfall, evaporation, SST, and pressure) to have a good resolution of the output salinity, the following multiple linear combination gives us the best results:

a) Rainfall abbreviated as Rai ;

b) Evaporation in short Evap ;

c) Rainfall * (SST) in short Rai* SST;

d) Evaporation * Pressure in short Evap*Press

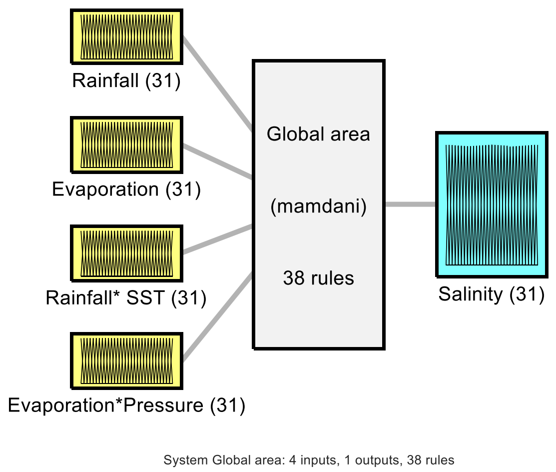

Figure 2 : Mapping of the annual salinity model

The multiple regression expression is then written :

S = ξ - α1*Rai - α2*Evap + α3*Rai*(SST) + α4*Evap*Press

ξ = a constant

The membership function of the input variables

The universe of discourse and number of partitions of each climate variable are shown in Table 1.

Table 1: Universe of discourse and number of partitions of the variables used

Variables	Universe of discourse	Number of partitions
Rainfall	U_P = [-1,2656 -0,0219]	31 partitions (P1, P2, ………P31)
Evaporation	U_E = [1, 3179 5,1930]	31 partitions (E1, E2, ………E31)
Rainfall x SST	U_R = [0,018 8 1,1908]	31 partitions (R1, R2, ………R31)
Evaporation x Pressure	$U_{T=}$ [-5,1872 - 1,1300]	31 partitions (T1, T2, ………T31)
Salinity	U_S = [-0,072 0,0426]	31 partitions (S1, S2, ………S31)

The fuzzification of input and output variables

During the fuzzification step, each input and output variable is associated with fuzzy subsets. This is a transformation of the numerical values into fuzzy values of the linguistic variables using the time series of Rainfall, Evaporation, Pressure, Ocean Temperature, Salinity, as well as the fuzzy values corresponding to these variables, for the entire 39 years of the study.

The creation of the fuzzy rules

This step aims at determining the relationships between the input and output set. The adopted rules appear according to the orders of the chosen model. In our case, we retain the model of order 1 and we group these rules by its antecedents. Thus, we obtain 37 fuzzy inference rules. We have below some examples of the rules applied in the area:

1. If (Rainfall P23) and (Evaporation is E9) and (Rainfall x SST is T10) and Evaporation x Pressure is R23) ...... Then (Salinity is S20)

2. If (Rainfall P11) and (Evaporation is E9) and (Rainfall x SST is T21) and (Evaporation x Pressure is R23) ...... Then (Salinity is S19)

....

37. If (Rainfall P21) and (Evaporation is E20) and (Rainfall x SST is T12) and (Evaporation x Pressure is R12) ...... Then (Salinity is S25)

38. If (Rainfall P24) and (Evaporation is E7) and (Rainfall x SST is T8) and (Evaporation x Pressure is R22) ...... Then (Salinity is S23)

The defuzzification is obtained by using the center of gravity.

Calculation of forecast error

Root Mean Square Error (RMSE) is a standard way to measure the error of a model in predicting quantitative data. Ceremoniously it is defined as follows:

$$RMSE = \sqrt{\sum_{i=1}^{n} \frac{(\hat{y}_i - y_i)^2}{n}}$$

$\hat{y}_1, \hat{y}_2, \ldots, \hat{y}_n$ is predicted of the values

$y_1, y_2, \ldots, y_n$ is obs

n is the number of observations

Often RMSE values are difficult to interpret because one is not able to tell if a variance value is small or large. To overcome this effect, it is more interesting to normalize the RMSE so that this indicator is expressed as a percentage of the mean value of the observations.

IV. Results

As we said in the previous paragraph, the multiple linear regression method is written as follows:

S = ξ - α1*Rai - α2*Evap + α3*Rai*(SST) + α4*Evap*Press

With:

ξ = a constant

The result of the multiple linear regression gives:

S =34.0008-16.6607.Rai-22.9204.Evap+ 0.5990.Rai*(SST) + 0.0224 Evap*Press

Figures 3, 4, 5, 6 represent the respective membership functions of Rainfall, Evaporation, Rainfall *SST and Evaporation *Pressure in input.

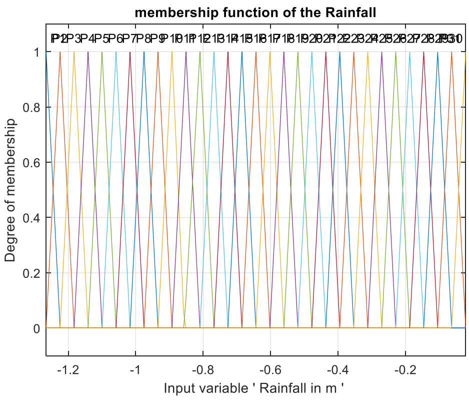

Figure 3: Membership function of of the "Rainfall" input

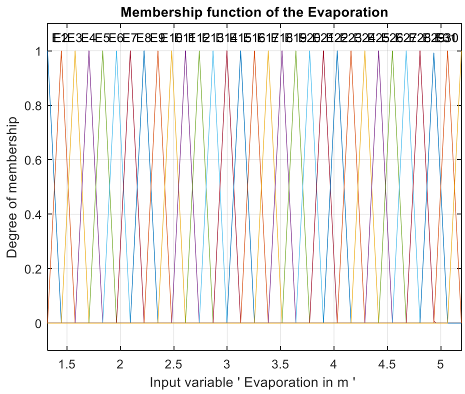

Figure 4: Membership function of the "Evaporation" input

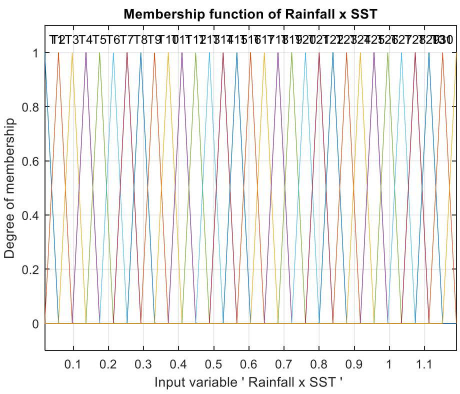

Figure 5: Membership function of "Rainfall*SST" as input

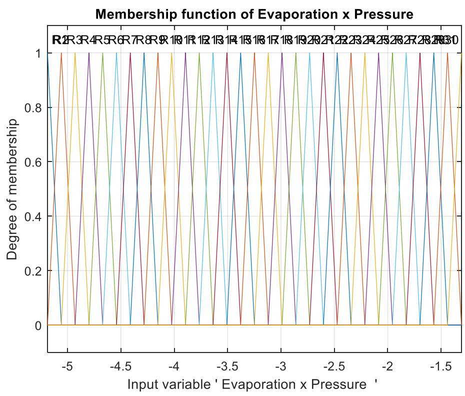

Figure 6: Membership function of the "Evaporation*Pressure" input

Figure 7 gives the function of the membership, at the output, of the Salinity.

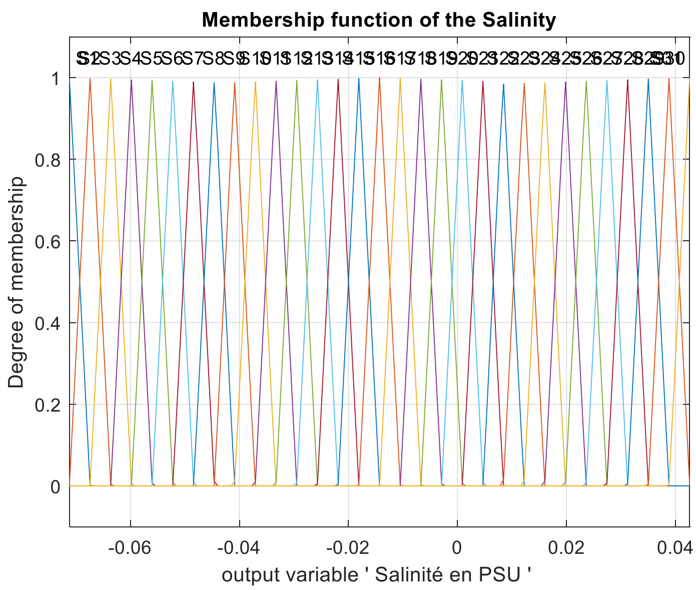

Figure 7: Membership function for "Salinity»

We see that these membership functions all contain 31 triangles.
Figure 8 gives three annual curves of salinity:
- In black that of the original salinity data;
- In blue that of the model;
- In purple the forecast.

The RMSE is 0.024. This shows that the model is good.

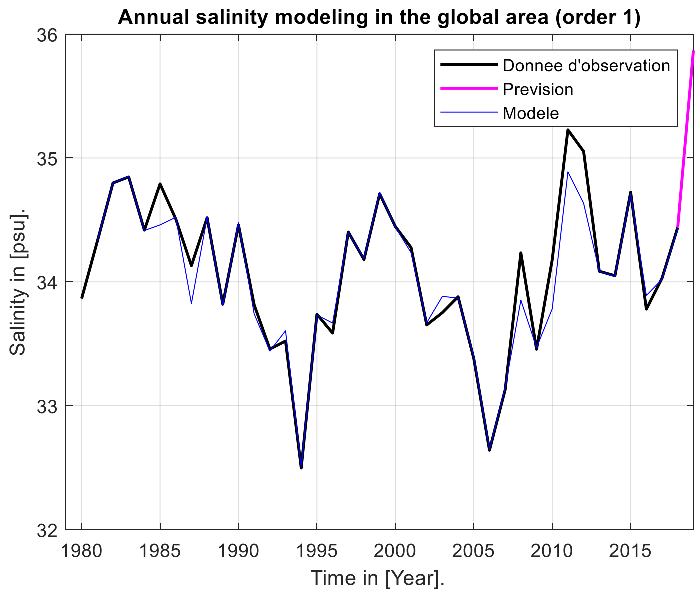

Figure 8 : Modeling of annual salinity

V. Conclusion

The fuzzy inference method can translate a qualified operator control strategy to a set of « if... then » linguistic rules that is easily interpretable. We used fuzzy control to model annual salinity data as a function of several climate variables including Rainfall, evaporation, Pressure and ocean surface temperature. But this fuzzy logic modeling is only feasible by the 2 to 2 composition of climate variables in this case with the products of Rainfall*SST and Evaporation *Pressure.

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