METEOROLOGICAL VARIABLES IN CORRELATION WITH CYCLONE FORMATION IN THE SOUTHWESTERN BASIN OF THE INDIAN OCEAN

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ABSTRACT

The field of meteorological variables shows a significant variation from 3 days before cyclogenesis. The study of the evolution of these meteorological variables shows that 11 parameters are in linear correlation with the cyclogenesis in the South-West Indian Ocean basin.

Keyword: *climatological mean, standard deviation, coefficient of variation, correlation coefficien, inversion*

1. INTRODUCTION

The precyclogenesis phase begins with an atmospheric disturbance. An initial disturbance may or may not evolve into a tropical depression, then a tropical storm and finally a tropical cyclone when the wind speed reaches 64 knots or 33 $m.s^{-1}$ **[1].** The purpose of this article is to find a rational way which initial structure of the field of meteorological variables leads to such a disturbance ? **Figure 1** shows the area of high cyclonic activity in the Southern Indian Ocean basin **[2].** It is delimited by latitudes -7° to -18° and longitudes 52° to 103°, included in the blue colored rectangle.

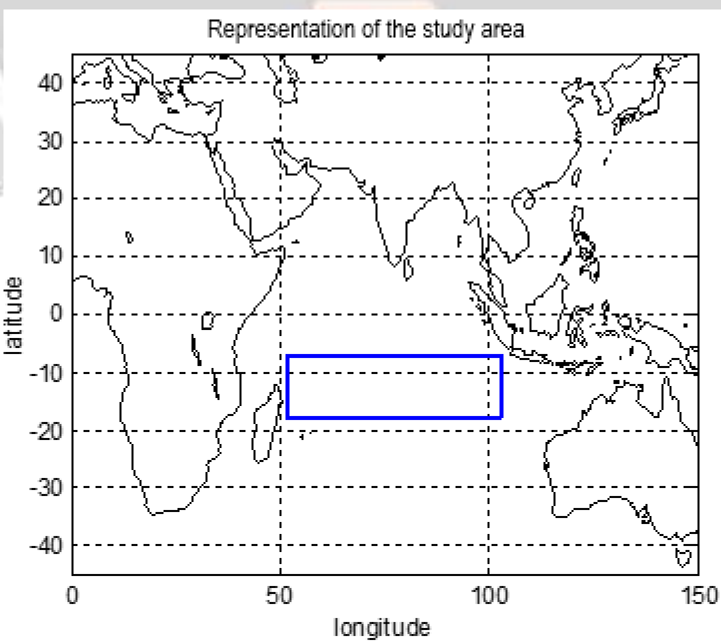

Figure 1: Representation of the study area

2. METHODOLOGIES

2.1 Data

The data used in this article are from ERA-Interim for the period 1989 to 2010. This is meteorological reanalysis data from the European Centre for Medium-Range Weather Forecasts (ECMWF/ECMMT)

2.2 Methods

Preliminary tests on the meteorological variables of the study area (oceanic or over-ocean data) processed in this work have shown that these variables are long memory effects. These results justify the use of climatological means to describe the general behaviour of meteorological variables before cyclones formation using descriptive statistics**.** **Descriptive statistics** such as the empirical mean, the empirical standard deviation, the coefficient of variability, the linear correlation coefficient, and particularly the climatological averages are used to describe the trend of the phenomenon. **[3], [4], [5], [6]**

- For a statistical series (x_i, n_i) of size n with a time depth of several years, we have :

empirical mean : $\bar{x} = \dfrac{\sum_i^n x_i}{n}$

empirical variance : $s^2 = \dfrac{\sum_{i=1}^n \left(x_i - \bar{x}\right)^2}{n}$

empirical standard deviation: $s = \sqrt{\dfrac{\sum_{i=1}^n \left(x_i - \bar{x}\right)^2}{n}}$;

coefficient of variability (percentage) : $cv = \dfrac{s*100}{\bar{x}}$

- For two statistical series $k = (x_k, n_k)$ and $h = (x_h, n_h)$ of the same size n with a time depth of several years, the linear correlation coefficient is given by:

$$r(k,h) = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{x_{ik} - \bar{x}_k}{s_k}\right)\left(\frac{x_{ih} - \bar{x}_h}{s_h}\right) \text{ where } \begin{cases} \bar{x}_k : \text{mean of k} \\ s_k : \text{standard deviation of k} \end{cases} \begin{cases} \bar{x}_h : \text{mean of h} \\ s_h : \text{standard deviation of h} \end{cases}$$

3. RESULTS AND DISCUSSIONS

3.1. Study of meteorological variables behavior before cyclogenesis

3.1.1 Variation of the climatological mean of OLR before cyclogenesis

Figures 1 to 7 represent the climatological mean variation of the meteorological variables at the cyclone baptism points from 15 days prior to the day of cyclogenesis. These figures show that a noticeable variation can be observed as early as 7 days before the day of the cyclone's baptism, the most significant occurring at three days before the cyclogenesis.

- The climatological mean of the OLR begins to decrease from 10 days before the day of cyclogenesis with an mean decrease of 8.72 $W.m^{-2}.day^{-1}$. This decrease is significantly increases from 3 days prior to the day of cyclogenesis reaching the mean 20.6 $W.m^{-2}.day^{-1}$, ie 2.36 times compared to the whole (**Figure 1**).

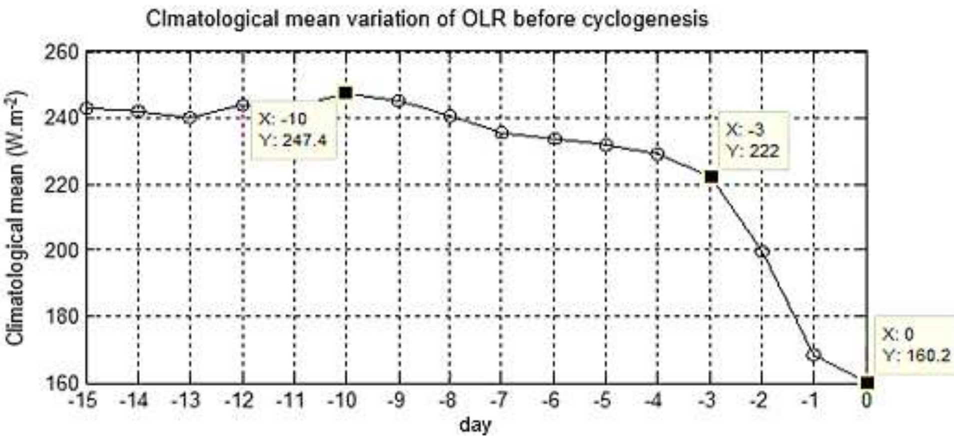

Figure 1 : variation of the climatological mean of OLR before cyclogenesis

3.1.2 Variation of the climatological mean of OLR before cyclogenesis

The mean climatological of mean sea level pressure has been decreasing since 15 days before the day of cyclogenesis. The mean decrease is in the order of -0.22 $hPa.day^{-1}$. This decrease increases from 6 days to 2 days before cyclogenesis with mean of -0.25 $hPa.day^{-1}$. This decrease increases significantly from 2 days before the day of cyclogenesis reaching a mean about 0.9 $hPa.day^{-1}$ or nearly 4 times compared to all. (**Figure 2**)

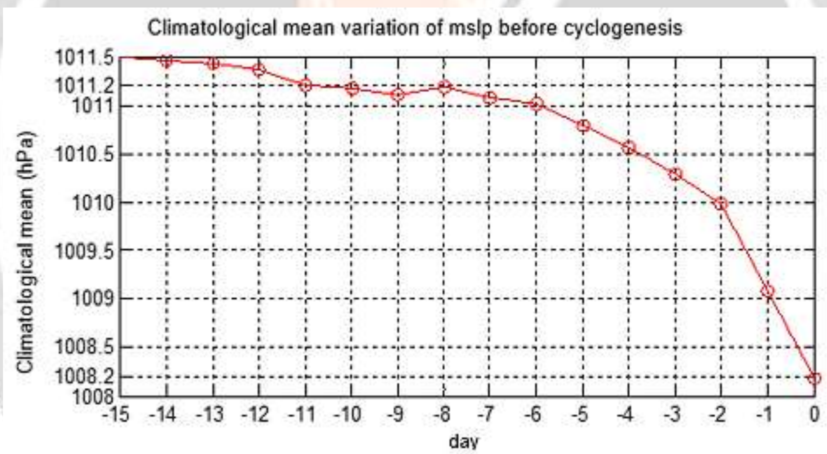

Figure 2 : variation of mean climatological of mean sea level pressure before cyclogenesis

3.1.3 Variation of the climatological mean wind at 850 hPa, 700 hPa and 200 hPa

The climatological mean of wind speeds on the 850 hPa and 700 hPa levels vary almost similarly, whereas the one on the 200 hPa level varies relatively little. The linear correlation coefficient between wind variation on the 850 hPa and 700 hPa levels is 0.9697 with a zero no correlation probability.

- The variation on 700 hPa level is generally one day behind the variation on 850 hPa level. This variation shows a relatively significant increase from 3 days (mean 0.56 $ms^{-1}.day^{-1}$) for the wind on 850 hPa level and from 2 days (mean 0.40 $ms^{-1}.day^{-1}$) for the wind on 700 hPa level before cyclogenesis.
- The climatological mean wind speed on 200 hPa level remains **higher than** on the 700 hPa level for 15 days before until 2 days before cyclogenesis. A day before cyclogenesis, the phenomenon is reversed. **This meteorological phenomenon may be a precursor to cyclogenesis.**
- Unlike winds on 700 hPa and 850 hPa levels, the climatological mean wind on 200 hPa level decreases from 2 days before cyclogenesis (mean 0.22 $m.s^{-1}$ day^{-1}). (**Figure 3**)

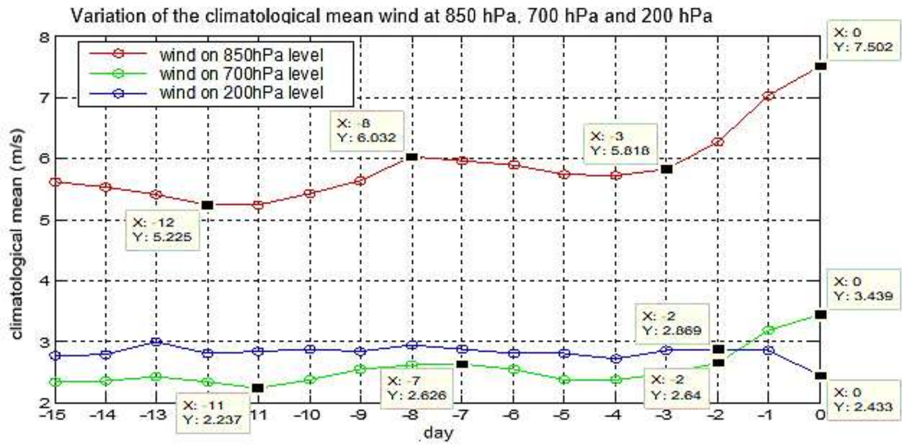

Figure 3 : variation of the climatological mean wind at 850 hPa, 700 hPa and 200 hPa

3.1.4 variation of the climatological mean of wind shear between levels 850 hPa, 700 hPa and 200 hPa before cyclogenesis

The climatological mean of the vertical wind shear between the 700 hPa and 200 hPa levels and the 850 hPa and 200 hPa levels vary almost similarly.

- Their linear correlation coefficient is 0.9843 with a zero no correlation probability. These climatological mean increase respectively from 0.120 $m.s^{-1}.day^{-1}$ and 0.428 $m.s^{-1}.day^{-1}$ between 15 and 13 days before cyclogenesis.
- Then, they decrease respectively by 0.056 $m.s^{-1}.day^{-1}$ and 0.150 $m.s^{-1}.day^{-1}$ between 13 and 6 days before cyclogenesis. A significant decrease of 0.526 $m.s^{-1}.day^{-1}$ and 0.977 $m.s^{-1}.day^{-1}$ is observed from 3 days before the day of cyclogenesis. These last decreases are 10 times more compared to previous decays. (**Figure 4**)
- The climatological mean of the vertical wind shear between the 700 hPa and 850 hPa levels varies relatively little (between 0.1067 $m.s^{-1}$ and 0.4063 $m.s^{-1}$) for 15 days before the day of cyclogenesis. (**Figure 4**)
- From 15 days to 1 day before cyclogenesis, the climatological average of the vertical wind shear between the levels 200 hPa and 850 hPa is higher than that between 200 hPa and 700 hPa. The phenomenon is reversed on the day of cyclogenesis. (**Figure 4**)

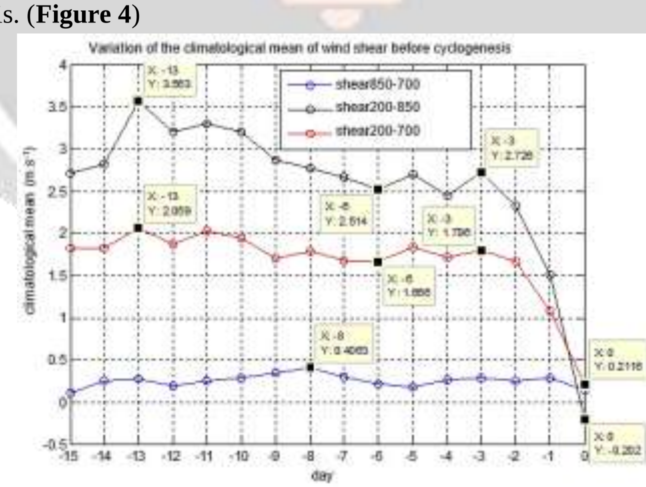

Figure 4 : variation of the climatological mean of wind shear between levels 850 hPa, 700 hPa and 200 hPa before cyclogenesis

3.1.5 Variation of the climatological mean of the specific humidity on 850 hPa and 700 hPa levels before cyclogenesis

The climatological mean of the specific humidities on the 850 hPa and 700 hPa levels vary almost similarly, especially between 6 days before and the day of cyclogenesis. Their linear correlation coefficient is 0.9849 with a zero no correlation probability. A quasi-linear increase is observed between 6 days and 3 days before the cyclogenesis with a rate close to $2x10^{-4}$ $kg.kg^{-1}.day^{-1}$ on both levels. This increase is accentuated from 3 days before the day of cyclogenesis with an mean rate of the order of 4 $x10^{-4}$ $kg.kg^{-1}.day^{-1}$ for the specific humidity level 850 hPa and 7 $x10^{-4}$ $kg.kg^{-1}.day^{-1}$ for the 700 hPa level. (**Figure 5**)

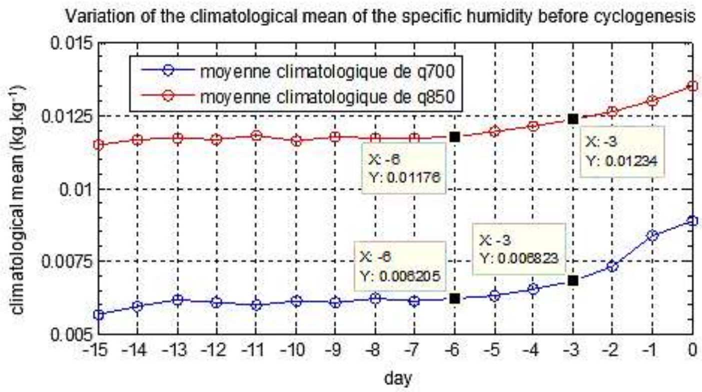

Figure 5 : variation of the climatological mean of the specific humidity on 850 hPa and 700 hPa levels before cyclogenesis

3.1.6 Variation of climatological mean of the sea surface temperature before cyclogenesis

Figure 6 represents the variation of climatological mean of the surface sea temperature. On this figure :

- the climatological mean of the surface sea temperature presents a quasi-gaussian variation in first approximation.
- the climatological mean at 15 days before and at days of cyclogenesis are almost the same and close to 28.58 ° C.
- an mean increase of 0.03 ° $C.day^{-1}$ is observed between 15 and 8 days before the cyclogenesis.
- the maximum of 28.74 ° C is reached at 8 days before the cyclogenesis.
- from 8 days before the day of cyclogenesis, there is a mean decrease of -0.02 ° $C.day^{-1}$. (**Figure 6**)

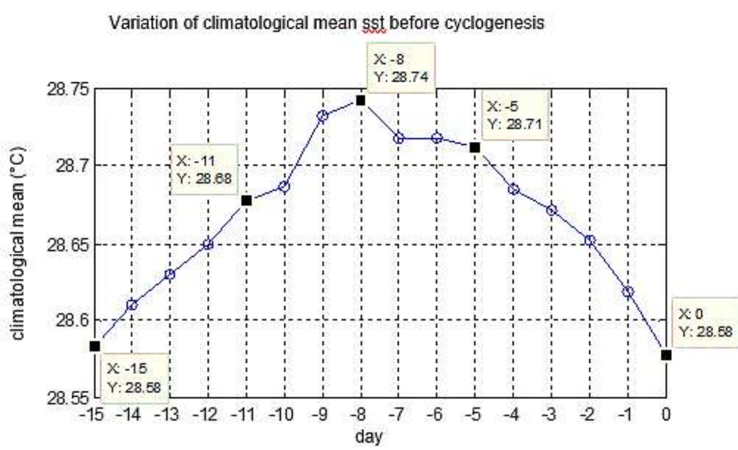

Figure 6 : Variation of climatological mean of the sea surface temperature before cyclogenesis

3.1.7 variation in the climatological mean of vorticity and divergence on levels 850 hPa and 200 hPa before cyclogenesis

Figure 7 represents the variation of climatological mean of divergence and vorticity on different levels.

- The climatological mean of vorticity on 850 hPa level shows a very large variation before cyclogenesis compared to its counterparts. A mean decrease of $-4.84\text{x}10^{-6}$ $s^{-1}.day^{-1}$ occurs between 6 days before and the day of cyclogenesis. This drop is larger over the last 3 days with a mean of -8.34 $\text{x}10^{-6}$ $s^{-1}.day^{-1}$.
- The climatological means of vorticity and divergence on 200 hPa level are almost 1 day before cyclogenesis. They are very close to 9.5x10-6 s-1 at that day.
- The climatological means of divergence on 850 hPa and 200 hPa levels vary practically in opposite ways from 15 days before to the day of cyclogenesis. Their linear correlation coefficient is -0.9673 with a zero non-correlation probability. A significant mean increase of $2.86\text{x}10^{-6}$ $s^{-1}.day^{-1}$ is observed for divergence on 200 hPa levels and a decrease of $-1.02\text{x}10^{-6}$ $s^{-1}.day^{-1}$ for divergence on 850 hPa levels.

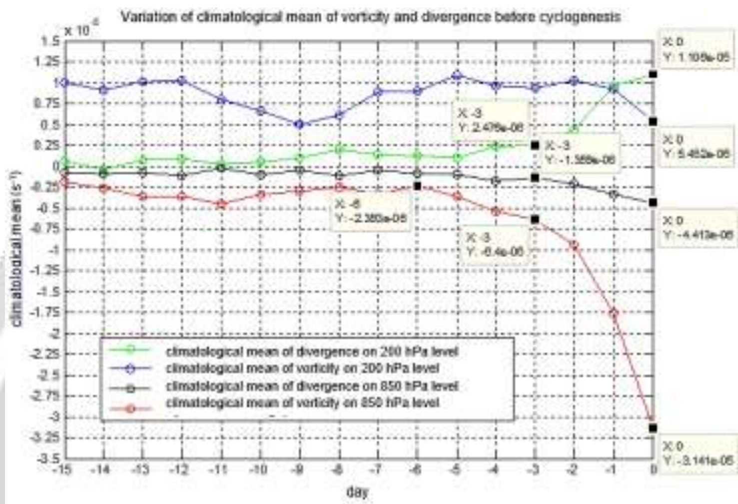

Figure 7 : variation in the climatological mean of vorticity and divergence on levels 850 hPa and 200 hPa before cyclogenesis

3.1.8 Variation and dispersion of real vorticity values before cyclogenesis.

The evolution of the climatological mean suggests the favorable value for the cyclogenesis of each meteorological variable. But the problem is that it is not known exactly because of the dispersion of real values as shown in **Figure 8**. We see on this figure 8 that at 3 days before a disturbance becomes a tropical cyclone, the real vorticity values generally disperse between $-7.161\text{x}10^{-6}$ s^{-1} and $2.375\text{x}10^{-6}$ s^{-1}. The coefficient of variation of this variability is 122.49%, which is almost 8 times greater than the coefficient of variation 15% from which a statistical series has significant variability.

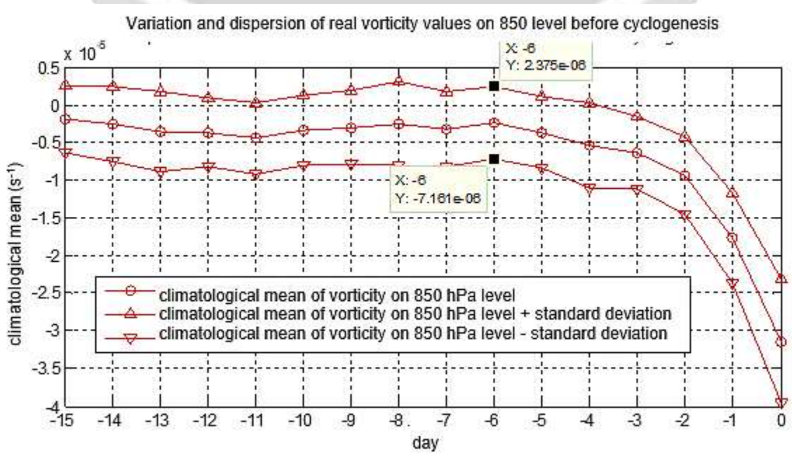

Figure 8 : variation and dispersion of real vorticity values before cyclogenesis.

Given that the cyclone is an extreme phenomenon, the logical approach to solving this problem is to work on the maximum or minimum daily values of meteorological variables. So what is the extreme value of each variable really correlated with cyclogenesis ?

3.2 Number of parameters correlated with cyclone formation

3.2.1 Procedure

To select weather variables and extreme values that may reveal clues, the approach taken is to :

- note the variation in the daily values of each meteorological variable at the baptism point of each cyclone that formed in the cyclogenesis region during cyclonic periods, from 15 days before to the day of cyclogenesis;
- calculate the climatological mean variation of each variable at the baptism points of all cyclones that formed in the cyclogenesis region during this period;
- identify in the study area, from 15 days before to the day of cyclogenesis, the location of the maximum and minimum of the variable under consideration.
- calculate the climatological mean of variation of these maximums and the mean of variations of these minimums from 15 days before to the cyclogenesis day of all cyclones that developed in the cyclogenesis region during this period.
- look for linear correlation coefficients between the climatological means of value variations at the point of cyclone formation and at the point of maximum or minimums. At the same time, the probabilities of non-correlation are calculated to confirm the validity of the correlation found.

3.2.2 validity of results

The results are summarized in **Table 1**.

- the minimum of the **OLR** is more correlated with cyclogenesis than its maximum;
- the **minimum mean sea surface pressure** is more correlated with cyclogenesis than its maximum;
- the **maximum specific humidity at 850 hPa and 700 hPa** are more correlated with cyclogenesis than their minimum.

These results are consistent with the pre-existence condition of a disturbed area of moisture above 40% and high instability. In this area, we observe a cloud cluster or a grain line, which is a cloud band made up of stormy clouds, or a tropical wave, which is a tropical disturbance associated with a low- and medium-low-lying axis of the troposphere. **[9]**

- the minimum **wind divergence at 850 hPa is positively correlated with cyclogenesis**;
- the maximum **wind divergence at 200 hPa is positively correlated with cyclogenesis**.

These results are appropriate with developments in favour of the cyclogenesis of the convergence and divergence of the wind, which requires :

  - **strong wind convergence of low atmospheric levels** : what is expressed is the **minimum amount of wind divergence on 850 hPa level**;
  - **a strong divergence of winds at altitude** : this is expressed as **the maximum divergence of wind on 200 hPa level**.

- the **minimum of vorticity on 850 hPa level** in correlation with cyclogenesis.

This result is consistent with the **favourable evolution of vorticity for cyclogenesis**, whose **negative value in the southern hemisphere is favourable for cyclonic developmen**t : this is expressed by the minimum vorticity on 850 hPa level.

- The **vertical wind shear minima between 200 hPa and 850 hPa and 200 hPa and 700 hPa is positively correlated with cyclogenesis**.

This result is consistent with the theory of cyclogenesis because tropical cyclones require low vertical wind shear so that the warm heart can remain above the centre of the circulation in altitude : this is expressed by **the minimum vertical shear between the 200 hPa and 850 hPa levels and between the 200 hPa and 700 hPa levels in positive linear correlation with cyclogenesis**. **[10]**

Table 1 : Correlation coefficient table

Meteorological variables	Minimum		Maximum	
	Correlation	Probability of non-correlation	Correlation	Probability of non-correlation
OLR	**0.9456**	**0.0000**	0.7259	0.0015
sst	0.5151	0.0411	0.6782	0.0039
mslp	**0.9499**	**0.0000**	0.8522	0.0000
q850	0.2423	0.3659	**0.9534**	**0.0000**
q700	0.4238	0.1019	**0.9305**	**0.0000**
vo200	0.4381	0.0896	-0.1330	0.6235
div200	-0.8066	0.0002	**0.9091**	**0.0000**
vo850	**0.9217**	**0.0000**	-0.5321	0.0339
div850	**0.8851**	**0.0000**	-0.8025	0.0002
wind850	0.5140	0.0417	**0.9272**	**0.0000**
wind700	0.3155	0.2339	**0.8653**	**0.0000**
wind200	0.1328	0.6239	-0.0355	0.8960
vertical shear between the 700hPa and 850hPa wind levels	0.6078	0.0125	-0.4152	0.1098
vertical shear between 200hPa and 850hPa wind levels	**0.9289**	**0.0000**	0.4527	0.0783
vertical shear between 200hPa and 700hPa wind levels	**0.9315**	**0.0000**	0.3188	0.2287

Based on the results of the study of the variation of the climatological mean of the meteorological variables before cyclogenesis on the one hand, the study of the correlation coefficients between the extreme values and the values at the baptism points of the cyclones, on the other hand, a meteorological variable likely to be in correlation with the cyclogenesis must be simultaneously :

- a variable whose climatological mean of variation of its extreme values is correlated with the climatological mean of its variations at the baptismal points of cyclones;
- a variable whose extremal value in correlation with the climatological mean of its variations at the baptism points of cyclones is consistent with its behavior before cyclogenesis according to theories.

Accordingly, **the selection is based simultaneously on these two criteria**. Variables fulfilling these conditions, with a linear correlation coefficient greater than 0.85 with a zero non-correlation probability, are selected. The extreme values and meteorological variables satisfying these criteria are :

- ✓ **the minimum mean pressure at sea surface;**
- ✓ **the minimum of the OLR;**
- ✓ **the minimum divergence at 850 hPa level and the maximum at 200 hPa level;**
- ✓ **the minimum vorticity at 850 hPa level;**
- ✓ **the maximum specific humidity at 850 hPa and 700 hPa levels;**
- ✓ **the maximum wind at 850 hPa and 700 hPa;**
- ✓ **the minimum vertical wind shear between the 200 hPa and 850 hPa levels and the 200 hPa and 700 hPa levels.**

Thus, 11 parameters are in linear correlation with cyclone formation in the southwestern basin of the Indian Ocean. These 11 parameters could be used to determine the precursor indices of cyclogenesis in this region.

4. CONCLUSIONS

The field of meteorological variables shows a significant variation from 3 days before cyclogenesis. From 15 to 2 days before cyclogenesis, the climatological mean wind speed on the 200 hPa level remains higher than on the 700 hPa level but at one day before cyclogenesis, the phenomenon is reversed.

The study of the evolution of the meteorological variables showed that 11 parameters are in linear correlation with the cyclogenesis in the South-West Indian Ocean basin :

- the minimum of the mean sea level pressure ;
- the minimum of the OLR ;
- the minimum of the divergence on 850 hPa level ;
- the maximum of the divergence on level 200 hPa ;
- the minimum of vorticity on 850 hPa level ;
- the maximum specific humidity on 850 hPa level ;
- the maximum of the specific humidity on 700 hPa ;
- the maximum wind on 850 hPa level ;
- the maximum wind on 700 hPa level ;
- the minimum vertical wind shear between the levels 200 hPa and 850 hPa ;
- the minimum vertical wind shear between the levels 200 hPa and 700 hPa.

5. REFERENCES

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