PRECURSOR SIGNAL OF CYCLOGENESIS IN THE SOUTH-WEST INDIAN OCEAN BASIN

MAXWELL Djaffard[1], DONA Victorien Bruno[1], RAKOTOVELO Geoslin[1], RATIARISON Adolphe Andriamanga[2]

[1]*Laboratory of Applied Physics and Renewable Energies, Mahajanga University, Madagascar*
[2]*Laboratory of Atmospheric, Climate and Ocean Dynamics, University of Antananarivo, Madagascar*

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.

The normed principal component analysis shows that a structure of the field of these parameters where the first and second eigenvalues are simultaneously greater than 1, can be a precursor sign of cyclogenesis. When this phenomenon occurs for maximum wind on 200 hPa and maximum specific humidity on 700 hPa levels, it is followed by cyclone at 100% of cases within 15 days at the latest.

Keyword: *climatological mean, standard deviation, coefficient of variation, correlation coefficient, eigenvalue, cyclogenesis*

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.

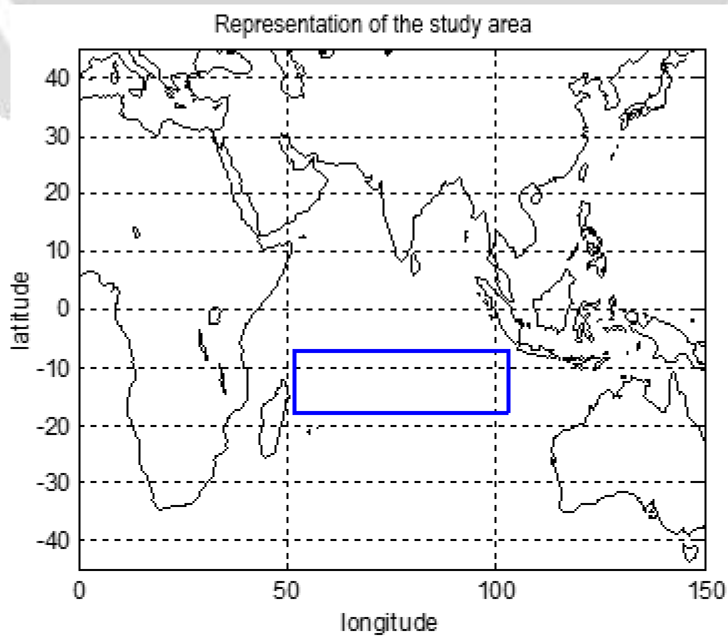

Figure 1: Representation of the study area

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

- **Descriptive statistics** such as the empirical mean, the empirical standard deviation, the coefficient of variability, the linear correlation coefficient, and particularly the climatological averages 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 : $\bar{x} = \frac{\sum_{i}^{n} x_i}{n}$

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

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

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

➢ 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:

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

- **Normalized Principal Components Analysis** to benefit from its ability to provide critical information, with the aim of finding rational precursors of cyclogenesis. **[7], [8]**

➢ Data matrix :

Iinitial data table

$$T = \begin{pmatrix} v_{11} & v_{21} & . & . & . & v_{1(p-1)} & v_{1p} \\ v_{21} & v_{22} & . & . & . & v_{2(p-1)} & v_{2p} \\ . & . & . & . & . & . & . \\ . & . & . & . & . & . & . \\ . & . & . & . & . & . & . \\ v_{(n-1)1} & v_{(n-1)2} & . & . & . & v_{(n-1)(p-1)} & v_{(n-1)p} \\ v_{n1} & v_{n2} & . & . & . & v_{n(p-1)} & v_{np} \end{pmatrix}$$

Cloud point center of gravity

$$G = \begin{pmatrix} x_{G1} = \frac{\sum_{i=1}^{n} v_{i1}}{n} \\ . \\ . \\ . \\ x_{Gp} = \frac{\sum_{i=1}^{n} v_{ip}}{n} \end{pmatrix}$$

Choosing G as the origin leads to the reduced data center table

$$T_{cr}=\begin{pmatrix} \frac{v_{11}-x_{G11}}{s_1} & \frac{v_{21}-x_{G21}}{s_2} & \cdots & \frac{v_{1(p-1)}-x_{G1(p-1)}}{s_{(p-1)}} & \frac{v_{1p}-x_{G1p}}{s_p} \\ \frac{v_{21}-x_{G21}}{s_1} & \frac{v_{22}-x_{G22}}{s_2} & \cdots & \frac{v_{2(p-1)}-x_{G2(p-1)}}{s_{(p-1)}} & \frac{v_{2p}-x_{G2p}}{s_p} \\ . & . & \cdots & . & . \\ . & . & \cdots & . & . \\ . & . & \cdots & . & . \\ \frac{v_{(n-1)1}-x_{G(n-1)1}}{s_1} & \frac{v_{(n-1)2}-x_{G(n-1)2}}{s_2} & \cdots & \frac{v_{(n-1)(p-1)}-x_{G(n-1)(p-1)}}{s_{(p-1)}} & \frac{v_{(n-1)p}-x_{G(n-1)p}}{s_p} \\ \frac{v_{n1}-x_{Gn1}}{s_1} & \frac{v_{n2}-x_{Gn2}}{s_2} & \cdots & \frac{v_{n(p-1)}-x_{Gn(p-1)}}{s_{(p-1)}} & \frac{v_{np}-x_{Gnp}}{s_p} \end{pmatrix}$$

Reduced centered coordinates of the individual u_i :

$$X_{cri}=\begin{pmatrix} \frac{v_{i1}-x_{Gi1}}{s_1} \\ . \\ . \\ . \\ \frac{v_{ip}-x_{Gip}}{s_p} \end{pmatrix}$$

Total inertia of the cloud of individuals :

$$I_G=\frac{1}{n}\sum_{i=1}^{n}\sum_{j=1}^{p}\left(\frac{v_{ij}-x_{Gij}}{s_j}\right)^2=\sum_{j=1}^{p}\left(\frac{1}{n}\sum_{i=1}^{n}\left(\frac{v_{ij}-x_{Gij}}{s_j}\right)^2\right)=\sum_{j=1}^{p}\left(\mathrm{r}\left(v_{ij}\right)\right)$$

Covariance matrix:

$$R=\begin{pmatrix} r(v_{11}) & r(v_{12}) & \cdots & r(v_{1(p-1)}) & r(v_{1p}) \\ r(v_{21}) & r(v_{22}) & \cdots & r(v_{2(p-1)}) & r(v_{2p}) \\ . & . & \cdots & . & . \\ . & . & \cdots & . & . \\ . & . & \cdots & . & . \\ r(v_{(p-1)1}) & r(v_{(p-1)2}) & \cdots & r(v_{(p-1)(p-1)}) & r(v_{(p-1)p}) \\ r(v_{p1}) & r(v_{p2}) & \cdots & r(v_{p(p-1)}) & r(v_{pp}) \end{pmatrix}=\begin{pmatrix} 1 & . & . & . & . & . \\ . & 1 & . & . & . & . \\ . & . & 1 & . & . & . \\ . & . & . & 1 & . & . \\ . & . & . & . & 1 & . \\ . & . & . & . & . & 1 \end{pmatrix}$$

$$so\ trace(R)=p=I_G$$

Eigenvalues and eigenvectors :

$$T_{cr}(V)=\lambda V \text{ where } \begin{cases} \lambda : eigenvalue \\ \text{V : eigenvector} \end{cases}$$

Axes Δ_i passing through G and minimum inertia have for vector director eigenvectors V_i associated with eigenvaluess λ_i such as

$$I_G = \sum_{i=1}^{p} \lambda_i$$

Selection of the principal axes to be chosen

$\sum_{i=1}^{p} \lambda_i = p \Rightarrow \overline{\lambda} = \frac{\sum_{i=1}^{p} \lambda_i}{p} = 1$ therefore we can not consider as significant that the $\lambda_i \geq 1$

3. RESULTS AND DISCUSSIONS

3.1. Study of meteorological variables behavior 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**).

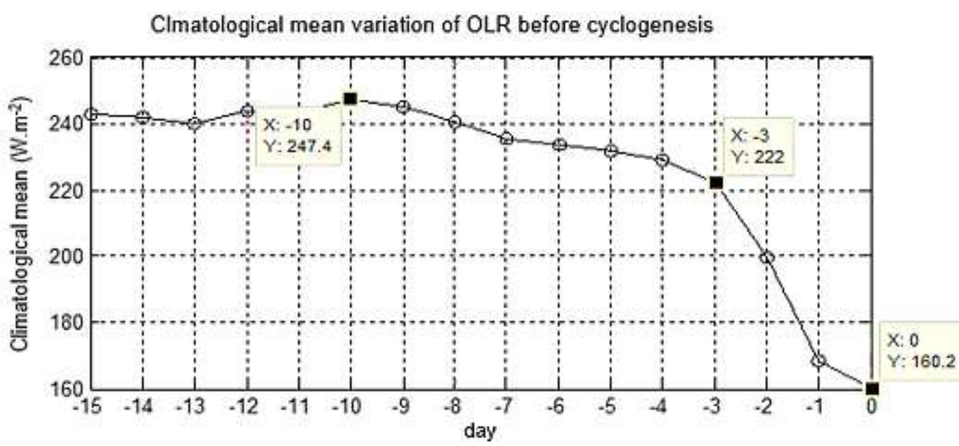

Figure 1 : variation of the climatological mean of OLR before cyclogenesis

- 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**)

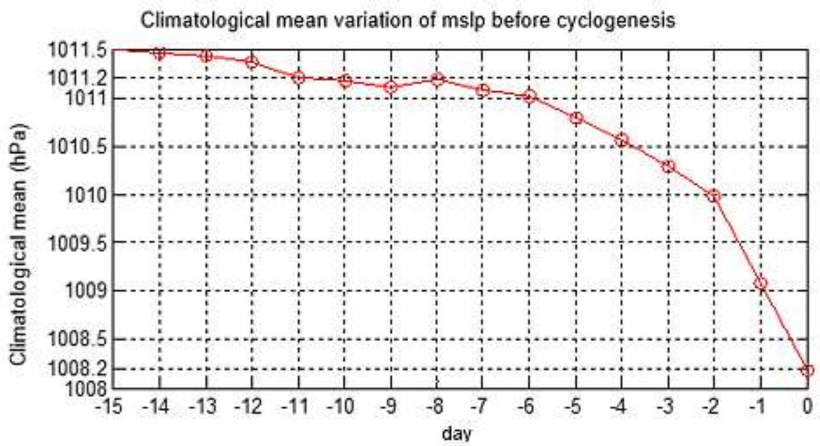

Figure 2 : variation of mean climatological of mean sea level pressure before cyclogenesis

- 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**)

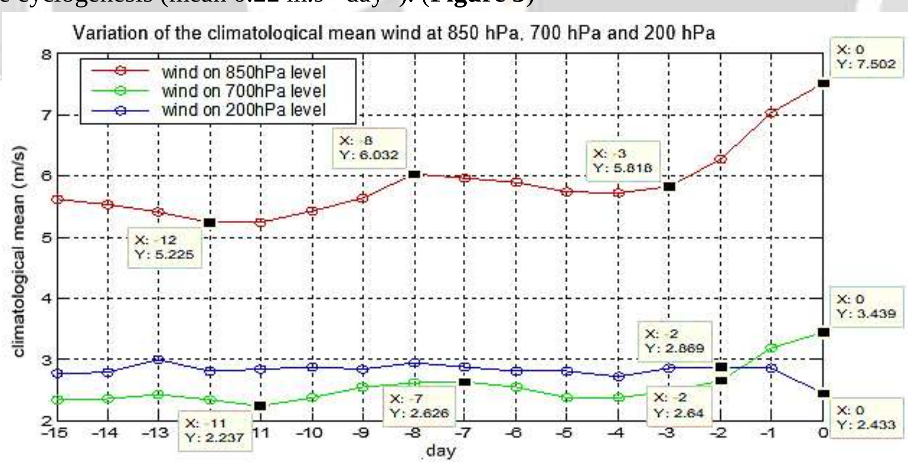

Figure 3 : variation of the climatological mean wind at 850 hPa, 700 hPa and 200 hPa

- 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**)

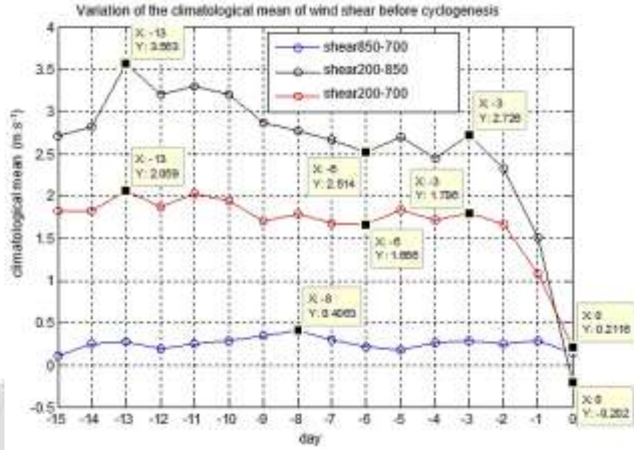

Figure 4 : variation of the climatological mean of wind shear between levels 850 hPa, 700 hPa and 200 hPa before cyclogenesis

- 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 2×10^{-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 4×10^{-4} $kg.kg^{-1}.day^{-1}$ for the specific humidity level 850 hPa and 7×10^{-4} $kg.kg^{-1}.day^{-1}$ for the 700 hPa level. (**Figure 5**)

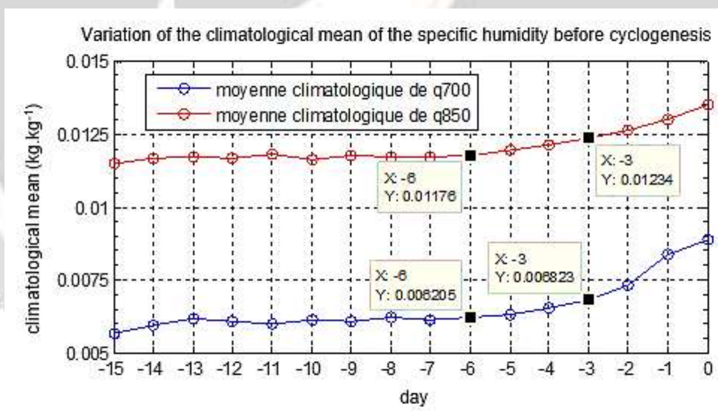

Figure 5 : variation of the climatological mean of the specific humidity on 850 hPa and 700 hPa levels before cyclogenesis

- **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**)

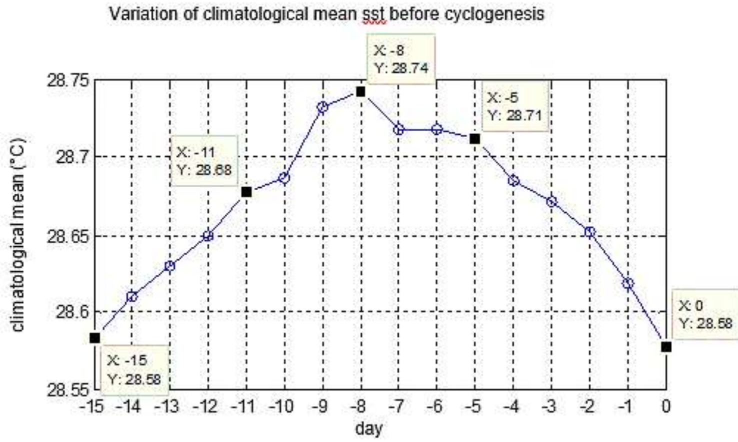

Figure 6 : Variation of climatological mean of the sea surface temperature before cyclogenesis

- **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 -4.84×10^{-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 -8.34×10^{-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 2.86×10^{-6} $s^{-1}.day^{-1}$ is observed for divergence on 200 hPa levels and a decrease of -1.02×10^{-6} $s^{-1}.day^{-1}$ for divergence on 850 hPa levels.

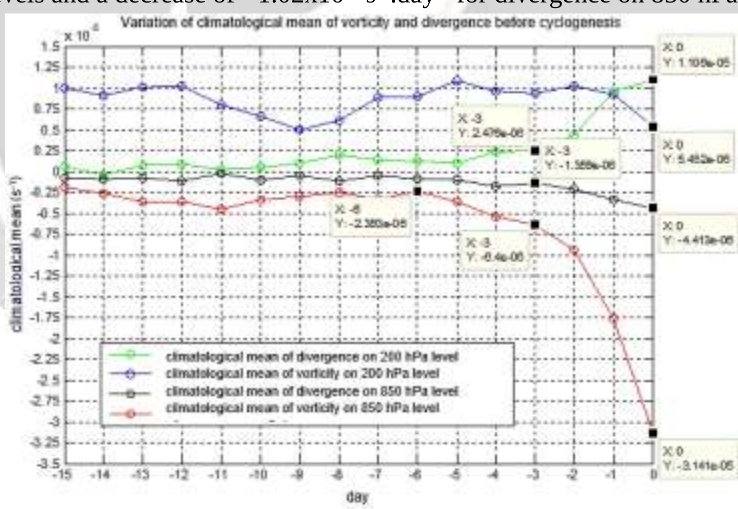

Figure 7 : variation in the climatological mean of vorticity and divergence on levels 850 hPa and 200 hPa before cyclogenesis

The evolution of the climatological mean suggests the favorable value for the cyclogenesis of each meteorological variable. This value is a precursor cyclogenesis index. 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 -7.161×10^{-6} s^{-1} and 2.375×10^{-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.

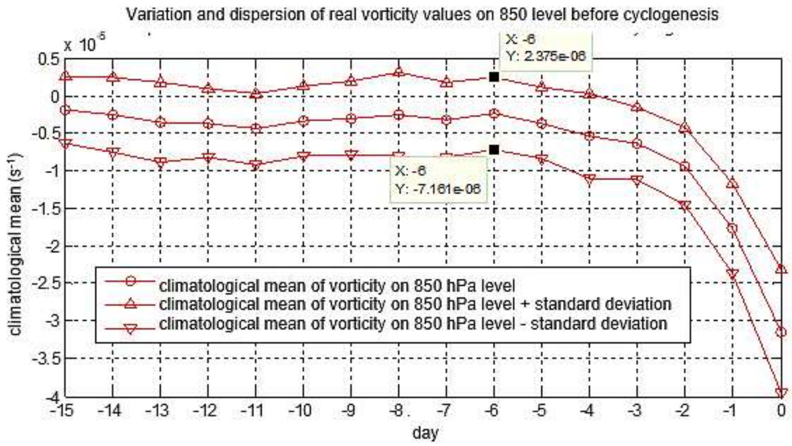

Figure 8 : variation and dispersion of real vorticity values before cyclogenesis.

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 correlated with cyclogenesis ?

To select meteorological variables and extreme values that may reveal the indices, the approach adopted is to :

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

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 reveal a warning signal for 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 selected to be used in the search for cyclogenesis precursor indices. What is the structure of the field of the corresponding meteorological variable and what value relative to this variable are precursor signals for cyclogenesis ?

3.2. Study of the eigenvalue spectrum of selected meteorological variables

3.2.1. Objective and motivation

Numerous research projects, which have been carried out in several socio-economic and scientific fields, have shown that eigenvalues play a decisive role in the behavior of a phenomenon by using certain empirical criteria (Kaiser criterion, elbow criterion, Scree-test criterion) **[11], [12], [13].** This rational scientific approach motivated us to use standardized principal component analysis (given the heterogeneous characteristics of the data to be processed) to predict cyclogenesis. By studying the spectrum of eigenvalues of the variables in correlation with cyclogenesis, we can expect a result to predict the future evolution of the atmosphere which leads to cyclogenesis and to show the existence of a local spatial structure favourable to the precyclogenesis phase.

3.2.2 Behavior of the eigenvalue spectrum before cyclogenesis

We considered cyclone CINDA which was baptized on December 17, 2008 at 6 UTC at latitude -10,3 ° and longitude 67 ° by the C.M.R.S of Météo-France of Reunion.

Figure 9 represents the spectrum of eigenvalues of vertical wind shear between the levels 200 hPa and 700 hPa in the baptism zone of cyclone CINDA before cyclogenesis. Note in this **Figure 9** that the first eigenvalue is always greater than 1 the third eigenvalue is always practically zero. As for the second eigenvalue, it is rarely greater than or equal to 1. Thus the event where the first and the second eigenvalue are simultaneously greater than or equal to 1 seems to be a rare phenomenon. It only appears once in 16 (at 3 days before cyclogenesis), ie 6.25% of cases

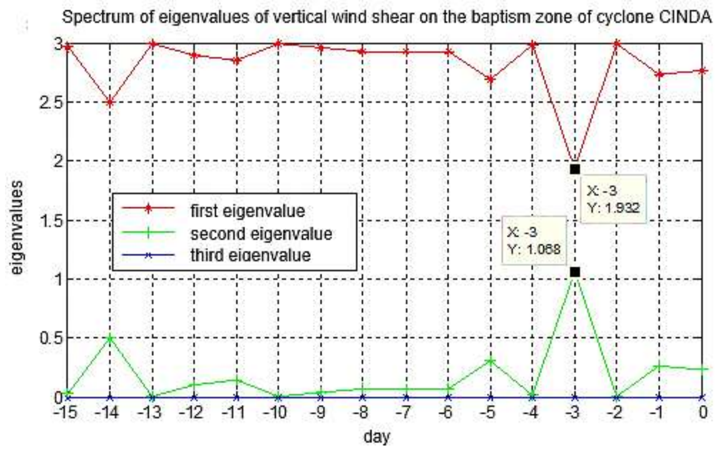

Figure 9 : spectrum of eigenvalues of vertical wind shear between the levels 200 hPa and 700 hPa on the baptism zone of cyclone CINDA

This phenomenon deserves attention because, in normalized principal component analysis, eigenvalues greater than 1 can alone account for more than 99% of the explained variance (almost 100% in this case here because the third eigenvalue is always practically zero). These eigenvalues are associated with the eigenvectors which determine the directions of the factorial axes in a n-dimensional space (n number of eigenvalues greater than 1) explaining almost all the explained variance. Physically, this result suggests the existence of a two-dimensional structure of the vertical wind shear field between the 200 hPa and 700 hPa levels. Factorial axes determine the preferred directions of the evolution of the phenomenon before cyclogenesis. Is this phenomenon relevant or is it just a coincidence ?

Figure 10 represents the climatological mean of the vertical wind shear eigenvalues between the levels 200 hPa and 700 hPa before the cyclogenesis of all cyclones over the study period. We can see that before cyclogenesis :

- the first eigenvalues generally remain greater than 2.4 and the second ones less than 0.6. This shows that this phenomenon is not a coincidence that occurs only in the case of CINDA, but a relevant phenomenon that also manifests itself before all other cyclones.
- the third eigenvalues are still practically nil. This means that the first and second factorial axes retain almost 100% of the information provided by the vertical wind shear between the 200 hPa and 700 hPa levels relative to cyclogenesis.
- the climatological means of the first and second eigenvalues reach their extreme values at 12 days before cyclogenesis. This means that the most probable occurrence of the phenomenon takes place 12 days before the day of baptism of the cyclone for this parameter.

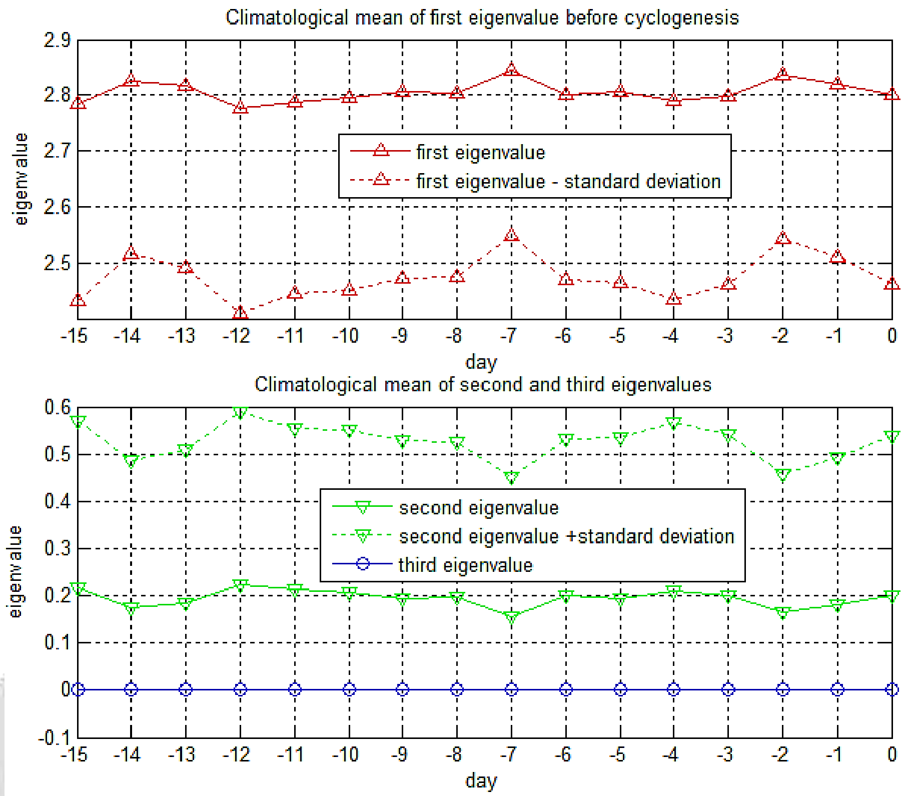

Figure 10 : climatological mean of eigenvalues spectrum of vertical wind shear between the 200 hPa and 700 hPa levels before cyclogenesis

Is this phenomenon true only for vertical wind shear between the 200 hPa and 700 hPa levels before cyclogenesis ?

Figure 11 shows the climatological means of the first eigenvalues spectrum before cyclogenesis for the 11 selected parameters. **Figure 11** shows that the first eigenvalues are generally above 2.55 and that the second eigenvalues are generally below 0.45. It is also clear that the third eigenvalues are always practically nil.

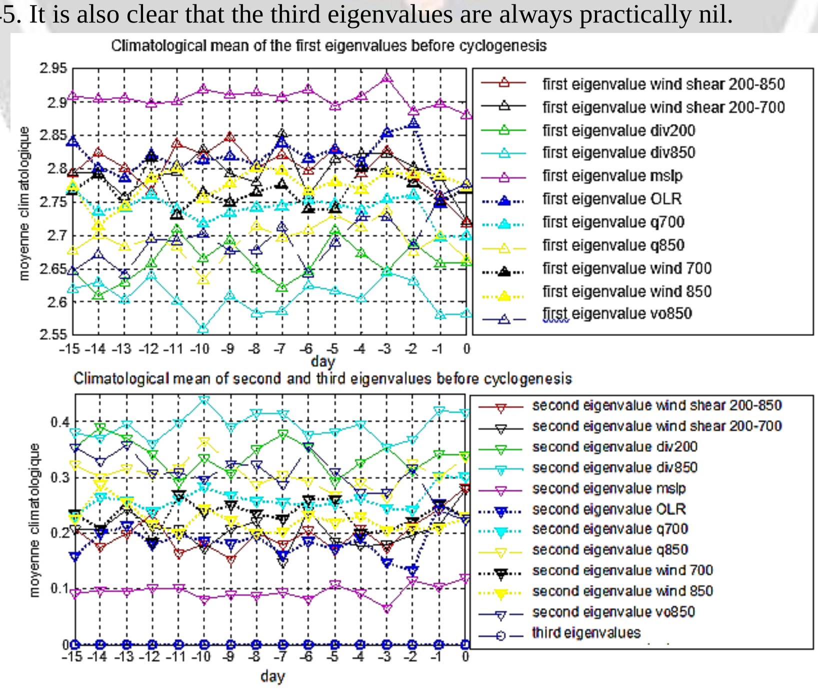

Figure 11 : climatological means of the eigenvalue spectrum before cyclogenesis

Figure 11 shows that the phenomenon of first and second eigenvalues simultaneously exceeding 1 is a particularly rare phenomenon. He deserves our full attention.

Consider all 190 cyclones that originated in the cyclogenesis region between November 16 and April 30 of the southern summers covering the cyclonic periods from 1989 to 2010. Limiting the time between 15 days before and the day of cyclogenesis, **Figure 12** represents the number of cyclones preceded by the phenomenon for all 11 selected parameters. The maximum number is 38, obtained for the divergence at level 850 hPa which were preceded at 5 days before their baptism. There were no cyclones before the phenomenon at 9 days before for vertical wind shear between 200 and 700 hPa, 2 days before the mean sea surface pressure.

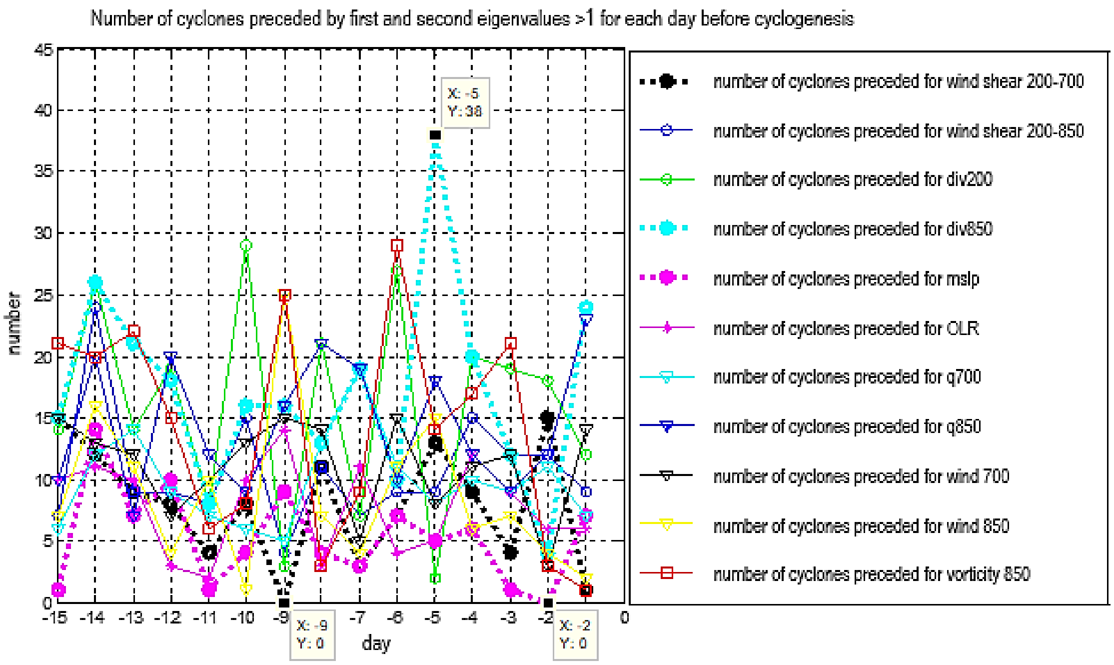

Figure 12 : number of cyclones preceded by the first and second eigenvalues simultaneously greater than or equal to 1 for each day before cyclogenesis

Table 2 summarizes the total number of cyclones preceded by the phenomenon of first and second eigenvalues simultaneously exceeding 1 for each parameter. When the total number is less than 190, this means that there were probably cyclones that were not preceded by this phenomenon. When this number is greater than 190, all cyclones were probably preceded by this phenomenon at least once between 15 and 1 days before cyclogenesis.

Table 2 : Number of cyclones preceded by the phenomenon between 15 and 1 days before cyclogenesis

Parameters	**Total number of cyclones preceded by the phenomenon from 15 days before to 1 day before cyclogenesis**	**Interpretation**
OLR	116	There are at least 74 cyclones that have not been preceded by the phenomenon
mslp	79	There are at least 111 cyclones that have not been preceded by the phenomenon
q850	**218**	All cyclones were preceded by the phenomenon at least once. Some are preceded several times.
q700	147	There are at least 43 cyclones that have not been preceded by the phenomenon
div200	**239**	All cyclones were preceded by the phenomenon at least once. Some are preceded several times.

vo850	**214**	All cyclones were preceded by the phenomenon at least once. Some are preceded several times.
div850	**260**	All cyclones were preceded by the phenomenon at least once. Some are preceded several times.
wind 850	130	There are at least 60 cyclones that have not been preceded by the phenomenon
wind 700	167	There are at least 23 cyclones that have not been preceded by the phenomenon
vertical wind shear between 200hPa and 850hPa levels	160	There are at least 30 cyclones that have not been preceded by the phenomenon
vertical wind shear between 200hPa and 700hPa levels	119	There are at least 71 cyclones that have not been preceded by the phenomenon

Figure 13 shows the percentage cyclone curves preceded by the phenomenon, taking the interval from the relevant day to 1 day before cyclogenesis for each parameter. 100% of cyclones were preceded by the phenomenon considering the interval :

- 12 up to one day for wind divergence on 850 hPa level ;
- 14 up to one day for wind divergence on 200 hPa level, specific humidity and wind vorticity on 850 hPa level.

More than 80% of cyclones were preceded by the phenomenon considering the 15-day interval for wind on 700 hPa level and vertical wind shear between the 200 and 850 hPa levels.

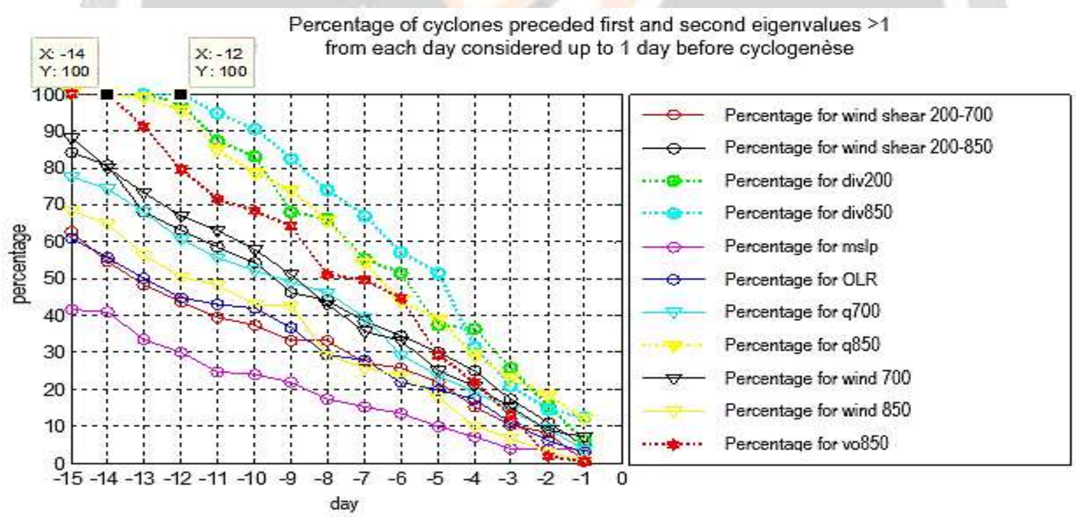

Figure 13 : percentage of cyclones preceded by the phenomenon before cyclogenesis

The problem now is that we do not know a priori the location of the cyclone, so where should we draw the matrix of daily values to treat? To solve this problem, one must take into account the correlations of the selected parameters with the cyclogenesis. The approach is to :

- identify the daily positions of moving points where the values of meteorological variables correlated with cyclogenesis are maximum or minimum according to the results summarized in **Table 1**.
- delimit each time a square area of 2° x 2° (about 226 km x 226 km) centred on the daily position of these extreme values. This distance of 226 km is close to the maximum diameter of the eye of the cyclone (200km) **[1]** which constitutes the central zone of the cyclone. It is likely that the precyclogenesis phase will develop within an area of this size. With a spatial resolution of 1 ° x1 °, the extraction of the data matrix of the daily values in

the square zone thus delimited gives a 3x3 matrix. This will allow later to find factorial axes in a space of restricted dimension physically interpretable and likely to contain the maximum of information on the cyclogenesis.

- research the eigenvalues spectrum of each daily data matrix thus obtained.

Figure 14 shows the percentage curves of first and second eigenvalues simultaneously greater than 1 followed by cyclone up to the relevant day (top) and the relevant day (bottom) within the 15-day interval. For each parameter, the distribution of the percentage on the day in question is between 2.5 and 7.5%. After 15 days, the maximum percentage is 70.73% (obtained for maximum specific humidity at 850 hPa level) and the minimum is 61.61% (obtained for minimum vertical wind shear between 200 hPa and 850 hPa levels)

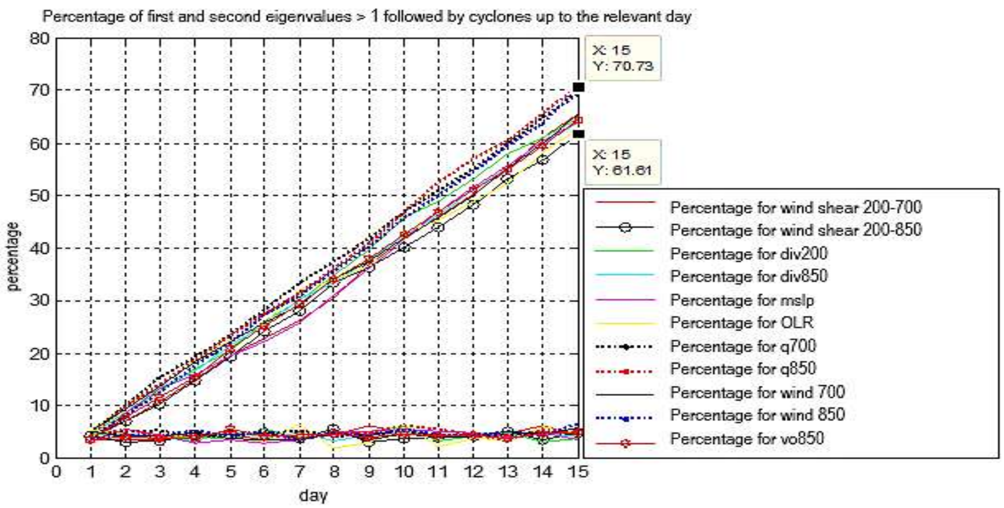

Figure 14 : percentage of first and second eigenvalues simultaneously greater than 1 followed by cyclone

Table 3 summarizes the number of occurrences of the phenomenon of first and second eigenvalues simultaneously greater than 1 for each parameter and the percentage followed by cyclone at the end of 15 days over the cyclone periods from 1989 to 2010. Given the total number of cyclones which is equal to 190, a cyclone could be preceded by this phenomenon more than once during the precyclogenesis phase.

Table 3 : Number of appearances of the phenomenon and percentage followed by cyclone after 15 days

Parameter	Number of occurrences of the phenomenon	Number of appearances followed by cyclone after 15 days	Percentage
OLR	325	204	62,77%
mslp	252	161	63,89%
q850	570	432	**70,73%**
q700	608	421	**69,24%**
div200	742	480	64,69%
vo850	477	307	64,36%
div850	627	401	63,96%
wind 850	541	381	**70,43%**
wind 700	620	406	65,48%
vertical wind shear between 200hPa and 850hPa levels	534	329	61,61%
vertical wind shear between 200hPa and 700hPa levels	558	365	65,41%

Figure 15 is an example where the phenomenon appears 12 and 10 days before the cyclogenesis of cyclone FAVIO, which was christened on February 15, 2007, at latitude -18.85° and longitude and 62.37° at 12 UTC by the Service Météorologique Mauricien.

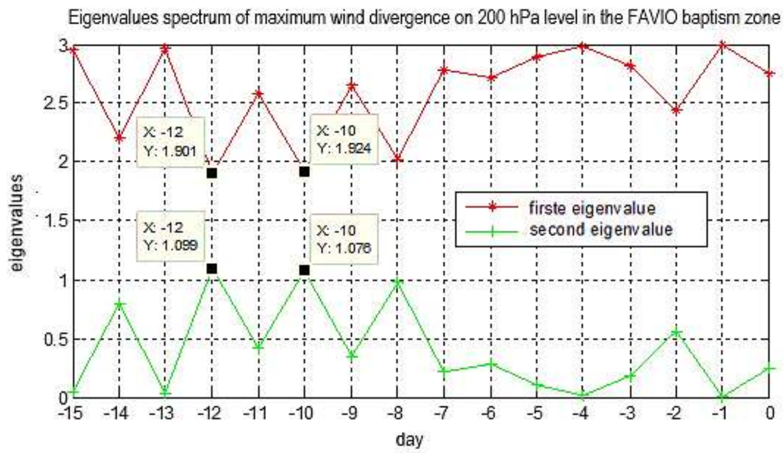

Figure 15 : spectrum of first and second eigenvalues of maximum wind divergence on 200 hPa level

Figure 14 and **Table 3** show that the results obtained with the parameters taken separately are quite low. These results are consistent with the theories on cyclogenesis that conditions must be met simultaneously.

We simultaneously considered the 11 parameters. But this approach has not produced any results. The phenomenon does not occur simultaneously for the 11 parameters. We must then limit the number of parameters to be considered at the same time.

Figure 16 shows the percentage curves of first and second eigenvalues simultaneously greater than 1 followed by cyclone while simultaneously considering the three parameters which gives the first three largest percentages (maximum of the specific humidity on 850 hPa level, maximum of specific humidity on 700 hPa level and maximum wind level on 850 hPa). After 15 days, the percentage of the phenomenon followed by cyclone increases and reaches 80% but the number of phenomena has decreased considerably. It appears only 10 times during the study period and the phenomenon was followed by cyclone only every 3, 7, 8, 13, 14 and 15 days after its onset.

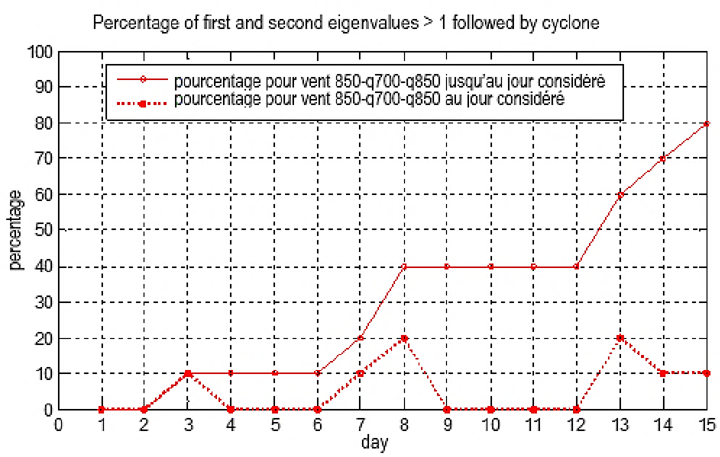

Figure 16 : percentage of first and second eigenvalues simultaneously greater than 1 followed by cyclone

All combinations of two parameters among the selected parameters were made. The maximum percentage was obtained for the torque (minimum OLR, maximum specific humidity on 850 hPa level) shown in **Figure 17**. After 15 days, the percentage of the phenomenon followed by cyclone increases to 86.05%. The phenomenon occurred 43 times over the study period. It was followed by a cyclone only from the third day at the earliest.

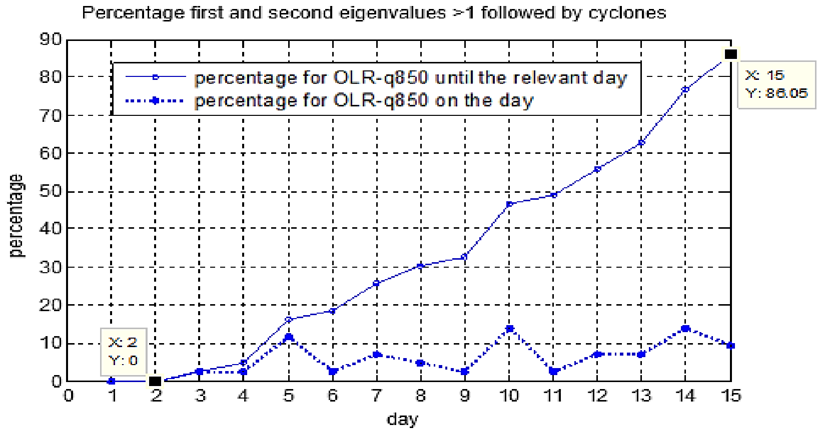

Figure 17 : percentage followed by cyclone for the couple (minimum of the OLR, maximum specific humidity at 850 hPa level).

All combinations of a selected parameter and an unselected parameter were also made. The torque (maximum wind at 200 hPa and the specific humidity at 700 hPa) gave a spectacular result of the phenomenon, shown in **Figure 18**. All first and second eigenvalues simultaneously greater than 1 of this pair were followed by a cyclone no later than 15 days after the onset of the phenomenon. This phenomenon occurred 52 times over the 21-year study period, an average of just over 2 times per year. Its trend curve has for equation $\mathbf{y = 0.0012x^6 - 0.0513x^5 + 0.8559x^4 - 6.8301x^3 + 26.639x^2 - 40.703x + 49.126}$ with a determination coefficient $\mathbf{R^2 = 0.9943}$.

A case of contrary phenomenon was also encountered during the investigation. When the phenomenon occurs for torque (minimum of mean sea surface pressure, maximum sea surface temperature), it was never followed by cyclone over this period of study as shown in **Figure 18**. This phenomenon is extremely rare, it has occurred only four times over the 21 years of the cyclone period.

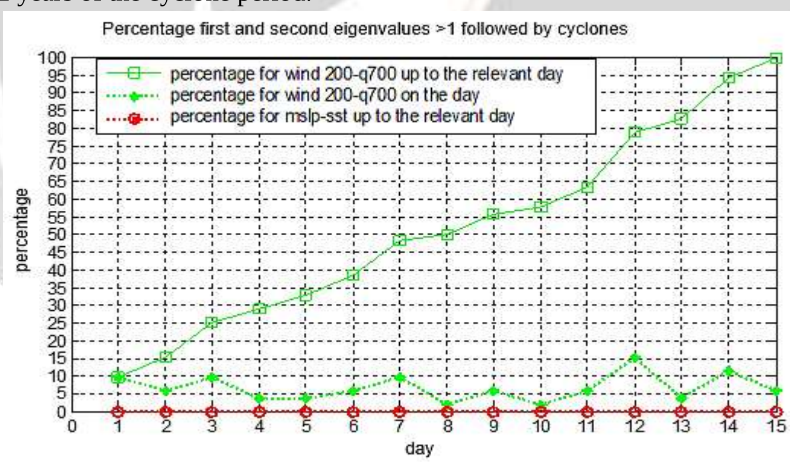

Figure 18 : pourcentage suivi de cyclone pour le couple (maximum de vent au niveau 200 hPa, maximum de l'humidité spécifique au niveau 700 hPa).

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. This weather phenomenon is a precursor to cyclogenesis.

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.

The normed principal component analysis shows that a structure of the field of these parameters where the first and second eigenvalues are simultaneously greater than 1, can be a precursor sign of cyclogenesis. However, the phenomenon does not occur on the same day for the 11 parameters in linear correlation with cyclogenesis.

- By considering the variables individually, we have :
  - more than 80% of cyclones that were preceded by the phenomenon considering the interval of 15 to 1 day before for the parameters wind on 700 hPa level and vertical wind shear between 200 and 850 hPa levels.
  - more than 69% of the first and second eigenvalues simultaneously greater than 1 that were followed by a cyclone, at the end of 15 days at the latest, for the parameters specific humidity on 850 hPa level, specific humidity on 700hPa level and wind on 850 hPa level.
- The combination of the three variables in linear correlation with cyclogenesis giving the largest percentage considered individually (maximum specific humidity on 850 hPa level, maximum specific humidity on 700 hPa level and maximum wind on 850 hPa level), improves the result up to 80% but considerably decreases its frequency.
- The combination of a linear correlation variable with cyclogenesis and a non-linearly correlated variable yielded two spectacular results :
- when the phenomenon occurs on the same day for the maximum wind on 200 hPa level and maximum specific humidity on 700 hPa level, it is followed by cyclone 100% cases in the interval of 15 days at the latest : it is a precursor sign of cyclogenesis ;
- when the phenomenon occurs on the same day for the minimum of the mean sea level pressure and the maximum of sea surface temperature, it has never been followed by a cyclone over the period of study . This case of the first and second eigenvalues simultaneously greater than 1 at the same day for these climatic variables is a rare phenomenon.

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