Cyclone climatology in the basin of the South West of the Indian Ocean.

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Abstract.

The cyclogenesis in the basin of the Indian Ocean spreads between latitudes 5°S and 15°S and between longitudes 60°E and 100°E. The data used in this work are those of the active cyclones from January 1945 to May 2002.

The PCA method (Principal Component Analysis) has been used to study the impact points of cyclones' trajectories on the coasts of Madagascar. Indeed, these points of impact on the Malagasy East coast oscillate between Vangaindrano and Antsiranana all twenty to twenty five years.

The FFT (Fast Fourier Transform) and the wavelet transform are used to study the yearly number, the life span, the yearly maximal intensity and the daily maximal intensity of cyclones.

The presence of 3 cyclones every month of January and the apparition of 3 cyclones every month of February have been foreseen by spectral analysis. These cyclones have respectively for period T=11,98 month and T=6,62 months. Sometimes these triplets of cyclones don't appear; the dates of their apparition appear on the result of the wavelet transform. The wavelet transform shows that the cyclones of periods 11,98 months decrease this last time, on the other hand the cyclones of periods 6,62 months increase.

The forecasting of the number of cyclones during the years 1998, 1999, 2000 and 2001 are treated by several methods: the simple exponential smoothing, the exponential smoothing of Holt, the ARIMA (2, 1, 2) and the ARIMA (1, 1, 1). It is the exponential smoothing of Holt and the simple exponential smoothing that give the best approximation with a relative uncertainty of about 7 to 8%. These curves of forecasting also show that the number of cyclones remained constant. This number turns around 13 cyclones per year in the basin of the West South of the Indian Ocean.

The life span of the cyclones is always lower than 35 days. The maximal life span Y is given by the equation: $Y= 0,0006\, X^2 – 0,2573X+34,594$, X is the number of the day of the active year from 1 to 366, X also designates the date of formation of the cyclone. Mostly, the life spans of the cyclones that repeat themselves are 5 days and 8-9 days.

The tropical depressions intensities represented by the scale 1 (15 kts ≤ speed of wind ≤ 33 kts) have increased since 1990. Those of the intense tropical cyclones (scale 5: 91 kts ≤ speed of wind ≤ 115 kts) and of the very intense tropical cyclones (scale 6: speed of wind > 115 kts) have increased mostly this last time.

1. Introduction.

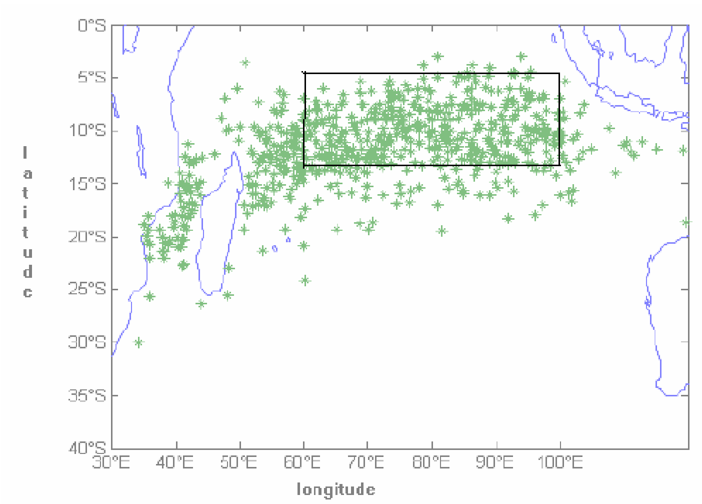


Figure 1: Position of the cyclogenesis in the Indian Ocean ($5°S \le$ latitude $\le 15°S$; $60°E \le$ longitude $\le 100°E$).

Madagascar is entirely in the tropical zone touched every year by disruptions to cyclonic character taking birth in the southern part of the zone at weak barometric gradient localized between [Fig.1].:

- in latitude, of 5 South and 15 South,
- in longitude, of 60 is and 100 East.

Every year, it forms itself, on average, a few more of 35 cyclones in the southern hemisphere [1] [2] and the number of those that touches Madagascar varies around 4 cyclones.

The goal of this work is to see the variations of different characteristics of cyclones during the period 1944 to 2002:

- Intensities,
- Life span and
- Cyclone number.

2. Methodology.

The Principal Component Analysis (PCA) has been proposed to determine the cyclogenesis zone and the direction of the cyclone trajectories that approach the coast of Madagascar; this direction is represented by the eigenvectors of the PCA.

The spectral analysis, the FFT (Fast Fourier Transform), has been opted to study the possibility of periodicity of number, intensity and life span of cyclones by the presence of remarkable peaks.

The wavelet analysis [4][5][6] permitted to determine when had place the phenomenon quasi cyclic correspondent to the remarkable peaks gotten by the spectral analysis.

3. Impact points of the cyclones on the East coast of Madagascar

In this part, we used the data of the cyclones dating from January 1945 to May 2002 that could reach Madagascar.

We regrouped the cyclones every five years during the period of 1944-2002. The figures 2 and 3 give us the spatial distributions of cyclones' trajectories in the periods of 1944-1948 and 1949-1953.

By the PCA method, we determined the two eigenvectors representing the scattering of the cyclone trajectories and we centered these scatterings in the center of these clouds of points (Fig. 2 and 3). The likely direction of the cyclones that arrives on the East coast of Madagascar will be represented by the resultant of these two eigenvectors.

We gather in the figure 4 the resultants of the eigenvectors gotten by PCA during the period 1944 - 2001.Theses resultants of these eigenvectors indicate us the likely cyclone trajectories that attack the Malagasy East coast.

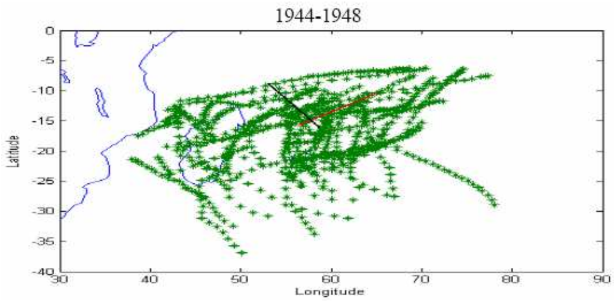
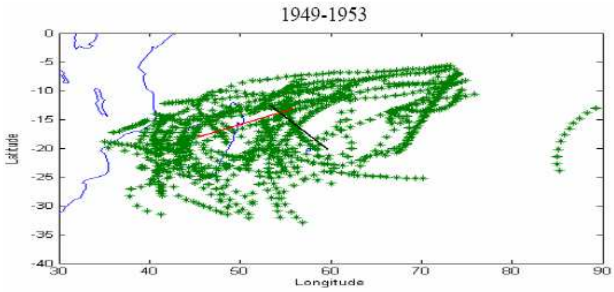


Figure 2: The cyclone trajectories between 1944 and 1948



Face 3: The cyclone trajectories between 1949 and 1953

According to this figure we note the cyclones' impact points on the Malagasy East coast oscillate almost periodically every twenty or twenty five years between Vangaindrano and Antsiranana:

- from 1944 to 1953 the impact points ascend from Maroantsetra to Sambava.

- from 1958 to 1968, the impact points of the cyclones come down from Sambava to Mananjary.

- from1969 to 1988, the impact points ascend again from Brickaville to Antsiranana.

- from 1989 to 2001, the impact points come down again from Antalaha to Vangaindrano.

Legend de figure 4 :

1: years 1944-1948	7: years 1974-1978
2: years 1949-1953	8: years 1979-1983
3: years 1954-1958	9: years 1984-1988
4: years 1959-1963	10: years 1989-1993
5: years 1964-1968	11: years 1994-2001
6: years 1969-1973	

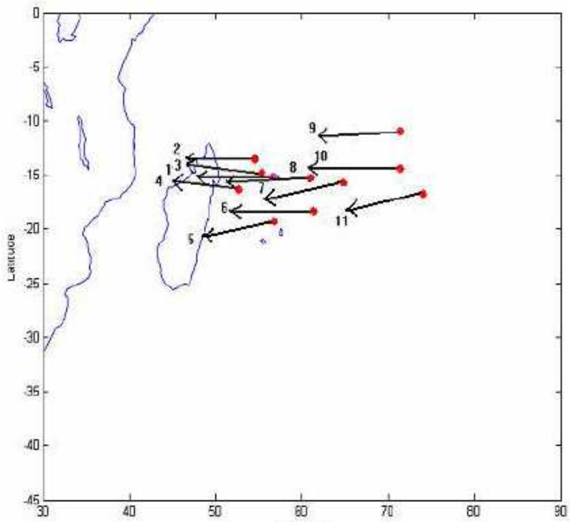


Figure 4: Resultants of the eigenvectors gotten by PCA

We could not determine precisely the period of oscillation of the cyclones' impact points on the Malagasy East coast because there are not enough data.

4. The cyclone number during the period of 1945-2002

4.a. Evolution of the cyclone number.

In this part, we choose to work always on the cyclones dating between 1945 and 2002 but we enlarged the domain of survey on nearly the South part of the Indian Ocean by prolonging the latitude until the latitude 30° south.

The yearly number of cyclones in the period 1945 - 2002 is represented on the figure 5. We noted that from 1959 to 1964, the cyclones number that is formed themselves increased considerably to reach the maximum of 25 cyclones per year. After this date this number decreases and seems to stabilize around 13 or 14 cyclones per year.

The figure 6 gives us the monthly number of cyclones in this same period. According to this figure, we could note that the cyclone number has seemed to decrease as the tendency of the straight line showed in the equation

$Y=-0.0004X +2.4408$, reduction hardly viewed.

Y is the monthly number of cyclones and X the month from January 1945 and to 2002.

Seen the lightness of the slope of the straight line regression, one cannot affirm the reduction of the number of cyclone this last time.

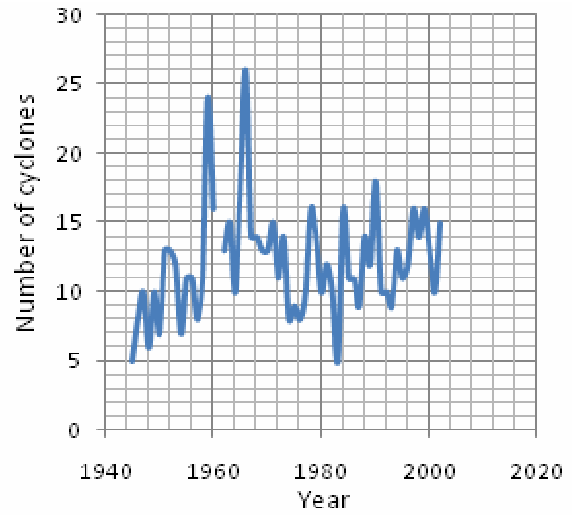


Figure 5: Yearly cyclone number in the period 1945 - 2002

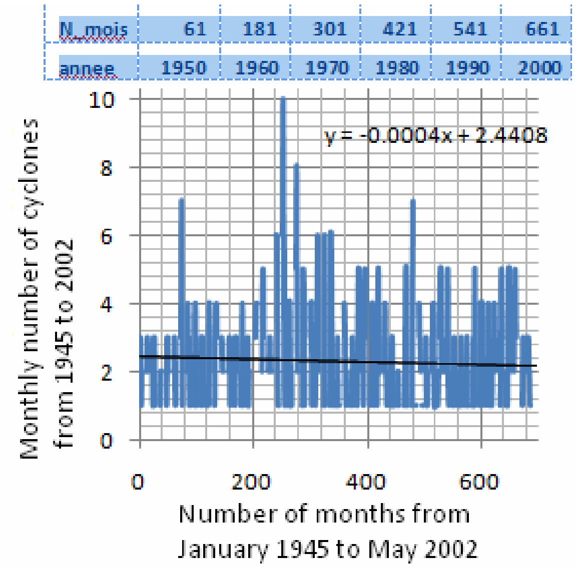


Figure 6: Monthly cyclone number in the period 1945 - 2002

4.b. Spectral study of the cyclone number.

The figure 7 shows us the fast Fourier specter (FFT) of the figure 6. On this spectral transformation, we notice 2 peaks: the first peak is of period 6,62 months and the second of period 11,98 months. The correspondence between month and period shows that:

- 11.98 months correspond to 3 cyclones in the month of February 1971. The dates of apparition of these 3 cyclones in the month of February or to the neighborhood of this month are pseudo periodic of period 11,98 months. The real dates of apparitions of these 3 cyclones are given by the figure 9, figure obtained with wavelet transform.

- 6.62 months correspond to 3 cyclones in the month of January 1991. Every 6.62 months, it should have 3 cyclones but the years and months of their apparition are represented on the figure 9.

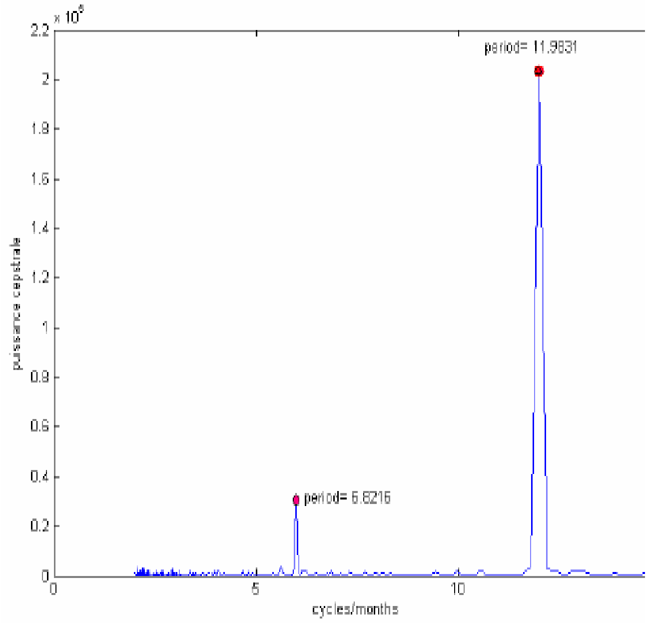


Figure 7: FFT specter of the numbers of yearly cyclones from 1945 to 2002

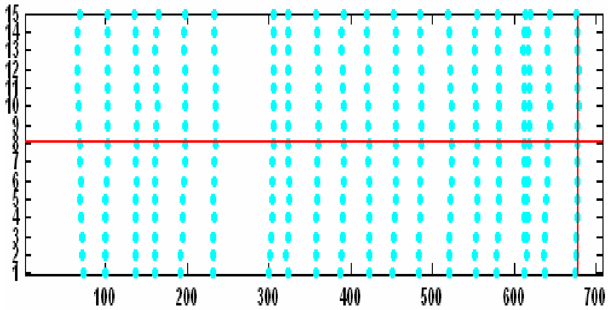


Figure 8: Localization of the peak of period 11.98 months.

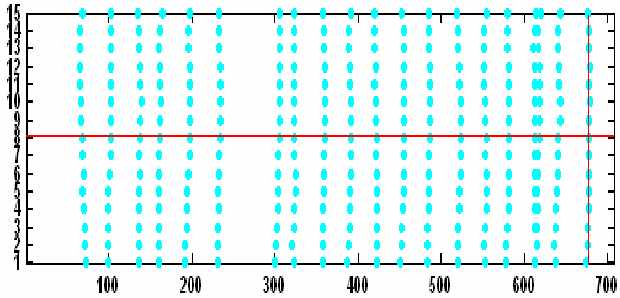


Figure 9: Localization of the peak of period 6.62 months.

According to the figure 8, between 100 and 200 months (from 1953 to 1961), there are 4 repetitions of these 3 cyclones of period 11.98 months. Between 200 and 300 months (from 1961 to 1971), there are only 2 repetitions. From 300 to 400 months (1971-1979), one arrives to 4 repetitions. From this date, there are 3 repetitions only every 10 years.

The figure 9 shows us that every 10 years; there are 2 or 3 repetitions of the 3 cyclones of period 6.62 months, except in the period 1995 - 2001 where one meets 5 repetitions.

In conclusion, the repetition of cyclones of period 11.98 months decrease during the time but the repetition of the cyclones of period 6.62 months increases.

4.c. Yearly forecasting of the cyclone number in 1998, 1999, 2000 and 2001.

From the cyclonic data of 1945 to 1997, we applied different methods to foresee the numbers of cyclones that could arrive respectively in 1998, 1999, 2000 and 2001.

The forecasting of the cyclone number during the years 1998, 1999, 2000 and 2001 is treated on the figure 10 by several methods: the simple exponential smoothing, the exponential smoothing of Holt, the ARIMA (2, 1, 2) and the ARIMA (1, 1, 1) [7] [8].

According to this figure, the exponential smoothing of Holt and the simple exponential smoothing give the best approximations with a relative uncertainty of about 7 to 8%.

This forecasting also shows that the yearly number of cyclones remained constant. It turns around 13 cyclones per year in the basin of the West South of the Indian Ocean.

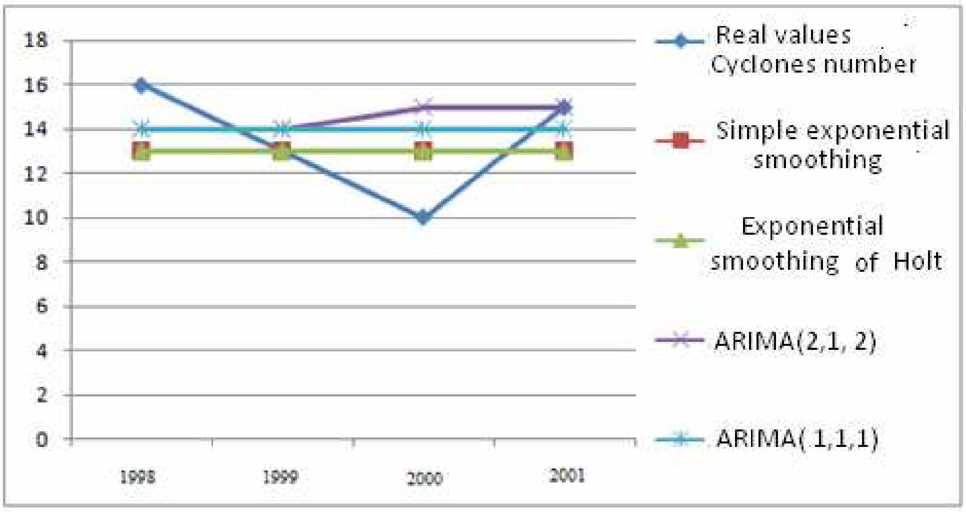


Figure 10: Forecasting of the cyclone number from 1999 to 2002 using the cyclonic data of the period 1945 - 1998.

5. Life span of the cyclones in the period January 1945 - May 2002

5.a. Evolution of the cyclones' life span.

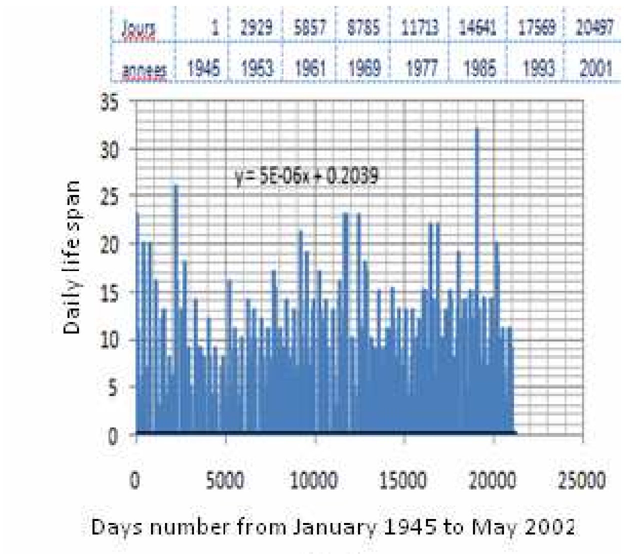
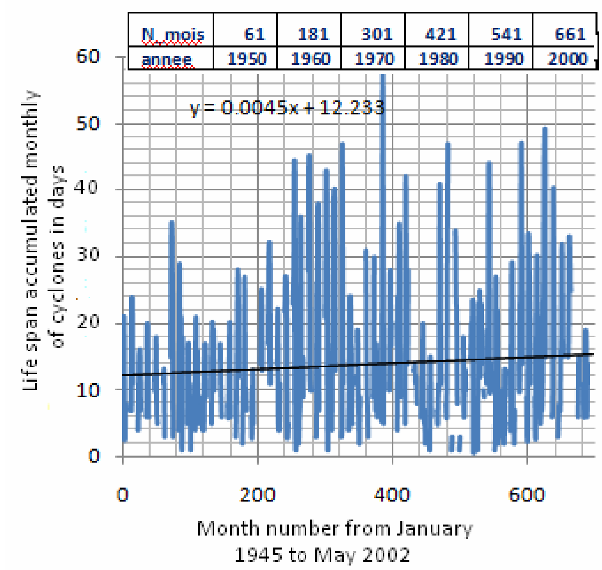


Figure 11: Daily life span of the cyclones during the period January 1945 - May 2002.



Face 12: Life span accumulated monthly from January 1945 to May 2008

The figures 11 and 12 represent respectively the daily life span and the life span monthly accumulated of the cyclones during the period from January 1945 to May 2002. Around 2000 days (year 1954), one notices that the life span increased from 10 to 23 days. After this date, the life span stabilizes around 10 days until the abscissa 6700 (year 1964). The extreme phenomenon of life span stands to the abscissa 18000 (year 1990) where it reaches 32 days.

The tendency of the straight lines on the figures 11 and 12 show us a light increase of the life span. But these figures are not sufficient to say that the life span of cyclones increases this last time because the slopes of these straight lines are very weak.

5.b. Maximal life span of the cyclones.

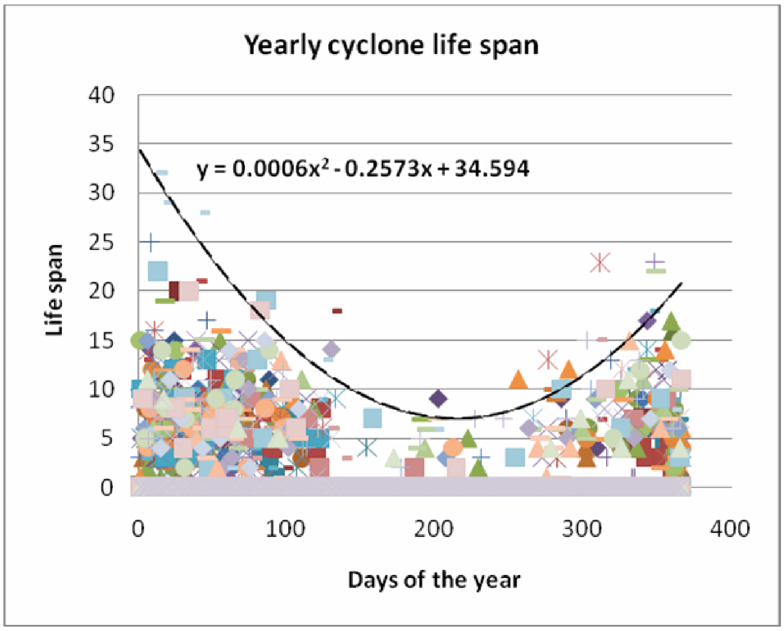


Figure 13: Superposition of yearly data of cyclones' life span.

We cut the data represented to the figure 11 annually and we have superimposed them annually from 0 to 366 days. The result of these operations is represented on the figure 13.

This figure shows that :

- The life span of the cyclones is maximal in the month of January,
- it decreases progressively from January to April,
- it ascend from October to December
- it is always lower than 35 days,
- the maximal life span is gotten fitting the life spans maximal; its equation is:

$Y= 0,0006\ X^2 – 0,2573X+34,594$

Y is the maximal life span,

X the day of the year of formation of the cyclone.

This knowledge of the maximal life span is very important; knowing the latitude, the longitude of formation of the cyclone (cyclogenesis) and the maximal life span, one can foresee how far can go the cyclone.

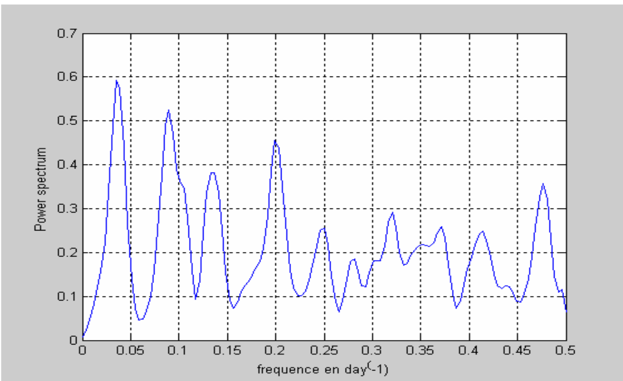


Figure 14 : FFT of span life in day^{-1}

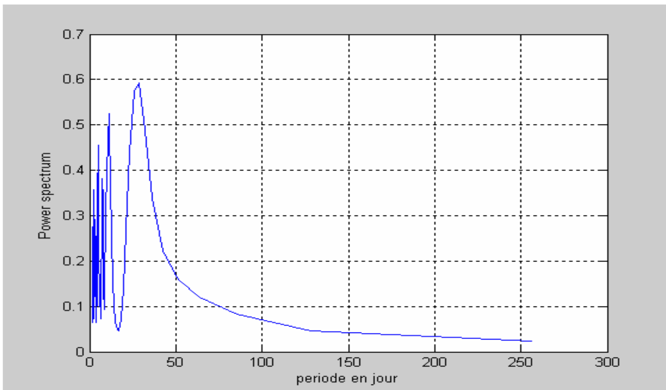


Figure 15 : FFT of span life in day

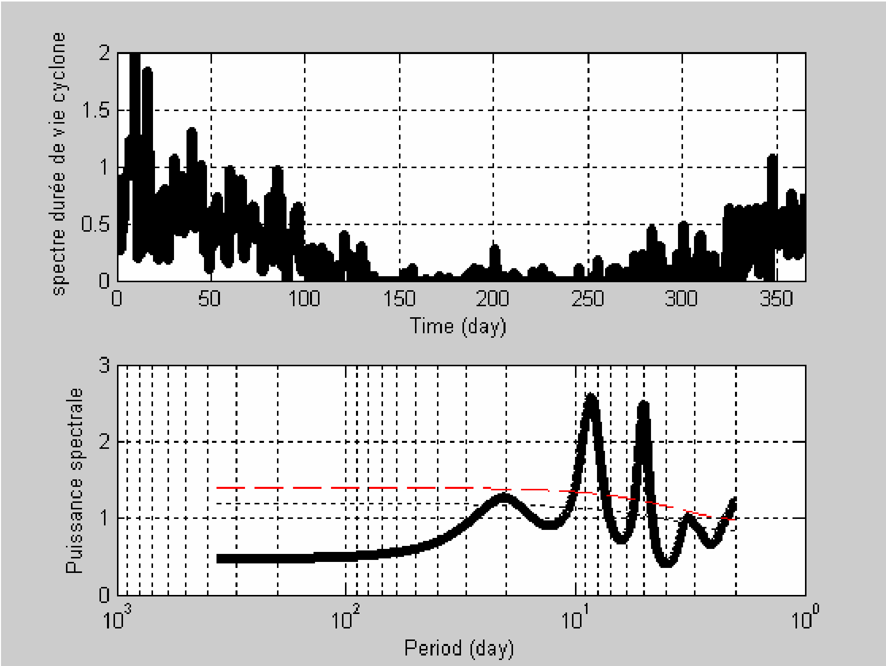


Figure 16: Spectral power filtered showing the periodicity of the life spans
(periods: 8 to 9 days and 5 days)

The spectral power of the data annually superimposed is represented on the figures 14, 15 and 16. The figure 14 gives the spectral power according to the frequency. The spectral power according to the period is on the figure 15. The figure 16 is the spectral power that shows 2 meaningful peaks over to the of the significance doorstep at 0.05%. The 2 peaks of this last figure show the repetition of the life spans of cyclones of 5 days and 8 - 9 days. The figure 13 shows these two life spans well.

6. Intensity of cyclones.

We are content with the cyclonic data after 1981 because there was not more data of the wind intensities before this date.

6.a. Maximal intensity of atmospheric disruptions according to the scale of Devorack.

The intensity of cyclones increases progressively after their birth toward a maximal value, and then it decreases gradually until their death. We raised these maximal intensities monthly and we classified them according to the scale of Devorack [9].

The figure 11 gives us the result of this census of the monthly intensities of cyclones in the Indian Ocean.

The tropical depressions represented by the scale 1 (15 kts $\leq$ speed of wind $\leq$ 33 kts) increased during these last years, since 19 90 (abscissa 80 on the figure 12).

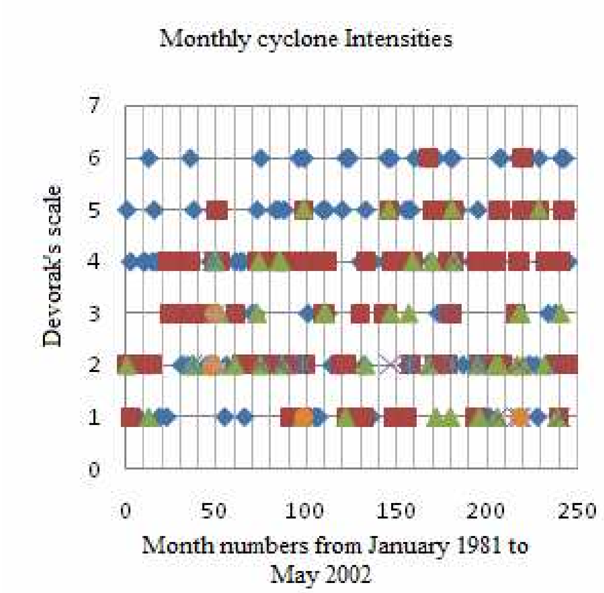
The storms or tropical depressions moderate (scale 2: 34 kts $\leq$ speed of wind $\leq$ 47 kts) are very dense from 60 to 100 and 150 to 250.

The strong storms or tropical depressions (scale 3: 48 kts ≤ speed of wind ≤ 63 kts) seem to be in regression from 190 to 250.

The number of tropical cyclones (scale 4: 64 kts ≤ speed of wind ≤ 90 kts) remains constant from 1981 to 2002.

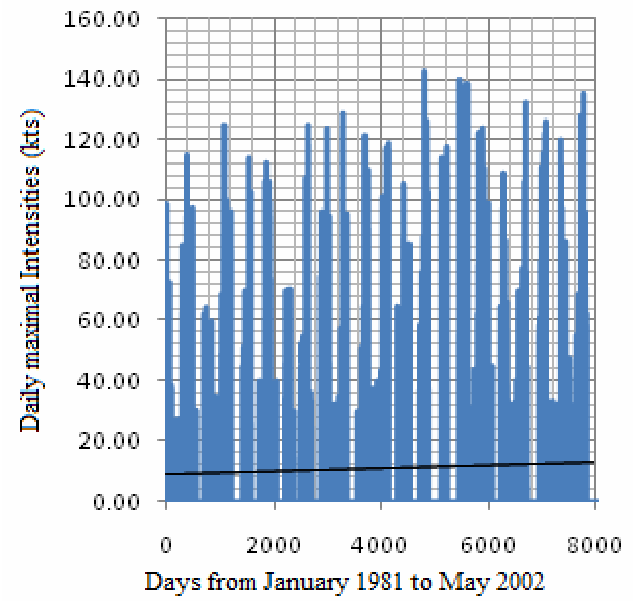
The intense tropical cyclones (scale 5: 91 kts ≤ speed of wind ≤ 115 kts) and the very intense tropical cyclones (scale 6: speed of wind > 115 kts) increased this last times a lot.

In conclusion the cyclones become more and more intense.



Years	1981	1990	1996	2002
Months	1	109	181	253

Figure 11 : Monthly accumulated intensities of cyclones counted in the period 1945-2002 according to Devorack's scale.



Days	1	1465	2929	4393	5857	7321	7687
Years	1981	1985	1989	1993	1997	2001	2002

Figure 19 : Daily maximal intensities of tropical cyclones from January 1981 to May 2002.

6. b. Daily maximal intensity of cyclones since 1981.

The raised daily of cyclonic data as the position (latitude and longitude) and the intensity makes themselves every 6 hours. For having the daily intensity of cyclones we have to take the average of these values. On the other hand, some times, there are two or three cyclones that evolve at the same time and we took the daily maximal value of these cyclones: from where the denomination" daily maximal intensity ".

The figure 19 gives us the daily maximal intensity of cyclones from January 1981 to May 2001. This figure shows us that apparently the daily maximal intensity of the cyclones increases slightly according to the straight line of equation tendency Y=0,0005X+ 8,4538. Between the abscissas 5000 and 6000 (years 1997- 2000) the daily maximal intensity increases strongly to reach the values of 140 kts.

In conclusion, the survey of the daily maximal intensity and the survey of the intensity accumulated monthly show a light increase of the intensity of the cyclones.

6. c. Spectral survey of cyclones' intensity.

The figure 20 that represents the spectral power of the daily maximal intensity, show us some remarkable peaks. This figure gives 2 particular peaks of period 365,95 days and 182,97 days.

According to the correspondence between periods and number of day from January 1981 to May 2002, these peaks correspond to intensities:

- the period 365,95 days correspond in the month of January 1985 to the course of which there is a cyclone of maximal intensity 57,50 kts.

- the period 182, 97 days correspond in the month of January 1983 of which a cyclone has for maximal intensity 63,75 kts.

In conclusion, one should meet every month of January the cyclones of intensity superior to I = 63,75 kts and to I = 57,50 kts.

Effectively these cyclones exist every year while referring to the cyclonic data of the period 1981 - 2001

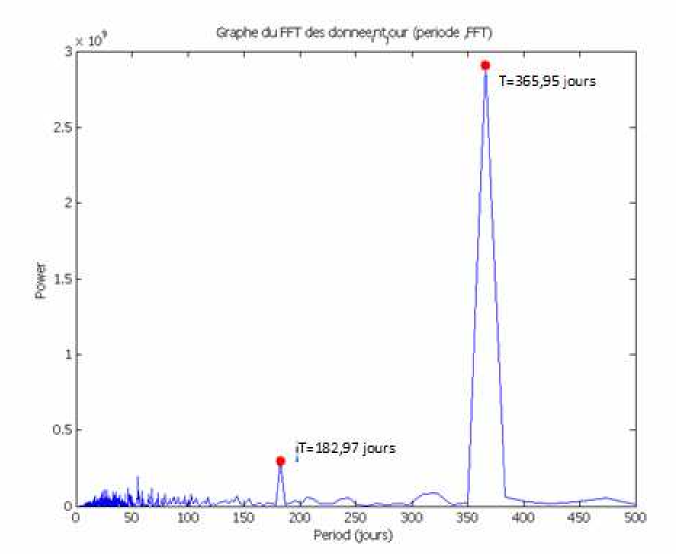


Figure20 : Spectral power of the daily maximal intensity

7. General conclusion.

The cyclones' impact points on the Malagasy East coast oscillate between Vangaindrano and Antsiranana all twenty to twenty five years.

Every month of February it should have 3 cyclones. It is in the same way the presence of 3 cyclones in the month of January. The repetition of cyclones which have a period of 11,98 months decrease during the time but the cyclones having a period of 6,62 months increase.

The forecasting of the number of cyclones during the years 1998, 1999, 2000 and 2001 are treated by several methods: the simple exponential smoothing, the exponential smoothing of Holt, the ARIMA (2, 1, 2) and the ARIMA (1, 1, 1). These are the exponential smoothing of Holt and the simple exponential smoothing that give the best approximation with a relative uncertainty of about 7 to 8%. This forecasting also shows that the number of yearly cyclone in the basin of the West South of the Indian Ocean remained constant and turns around 13.

The life span of the cyclones is always lower than 35 days. While designating by X the day of the year that is the date of formation of the cyclone, the maximal life span is given by the equation:

$Y = 0{,}0006\ X^2 - 0{,}2573X + 34{,}594$. Five days and eight nine days are the life spans that repeat themselves the most often.

The intensities of the tropical depressions represented by the scale 1 (15 kts speed of wind 33 kts) increased during these last years, since 1990. The intense tropical cyclones (scale 5: 91 kts speed of wind 115 kts) and the very intense tropical cyclones (scale 6: speed of wind 115 kts) increased this last time a lot.

These studies are coherent with those already made in the Atlantic. Indeed, two "studies" threw the quarrel, in Nature and Science (the main authors are Kerry Emanuel and Peter Webster appeared in 2005), and demonstrate that the number of cyclones remained steady but that their global power increases since a half century.

Indeed:

- The first survey, published August 4, 2005 in Nature, watch that the total energy dissipated by the cyclones of the Atlantic North and Pacific West has more than doubled since 1950. The author, Kerry Emanuel of the institute of technology of Massachusetts, essentially took the indication of energy dissipation as a basis (PDI for Power Dissipation Index). This indication, bound to the concerned surface and to the length of the cyclone, is gotten mainly by using the maximal speed noted for the winds of surface (to the conventional height of 10 m). Otherwise, this American meteorologist also compared the evolution of the power of the cyclones with the one of the temperature at the surface of oceans. Result: the curves evolve in a very similar way. Conclusion of Kerry Emanuel (Fig.21): "My results suggest that the future warming up can bring a tendency to the rise in the potential destructive of the cyclones and, while taking into account the increase of the inshore populations, to a substantial rise of the losses bound to the cyclones in the XXIe century ".

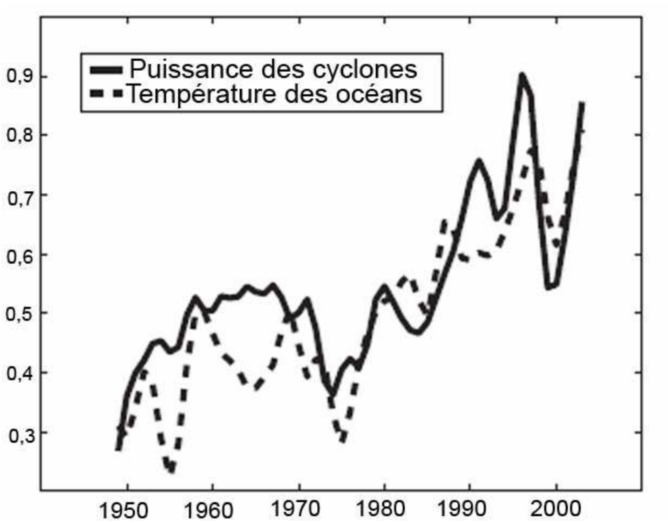


Figure 21 : Parallel evolution of the temperature of the oceans between 30°S & 30°N and of the PDI for the basins Atlantic & Pacific Northwest
Note: the unit of measure of the two variables results from a complex mathematical equation that facilitates their comparison © K. Emanuel, Nature 436, 686 (2005)

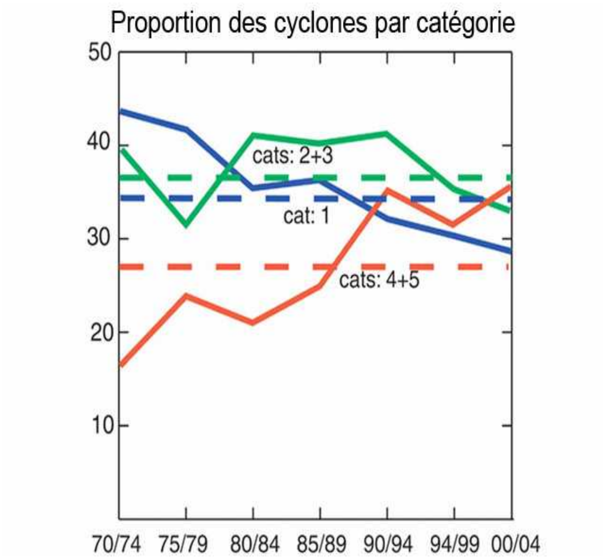


Figure 22 : The proportion of the category cyclones 4 and 5 doubled practically in thirty years
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- The second has been published in Science September 16, 2005. This time, the team of Peter Webster of the institute of technology of Georgia, calculated thanks to the archives available satellites since 1970 the number of storms (speed of winds <118 Km/h) and of cyclones (speed of winds> 118 Km/h), the length of these climatic events and their intensity. The results indicate that the total number of cyclones remained steady. On the other hand, the number of category cyclones 4 or 5 increased 57% enters 1970 and 2004 (Fig.22). In proportion, the cyclones by force major passed thus from 20% to 35% in 30 years. Only positive aspect: the maximal power of the cyclones is relatively steady since 35 years.

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