WINDS AND WAVES CHARACTERIZACION TO EVALUATE HAZARD IN EL SALVADOR COAST

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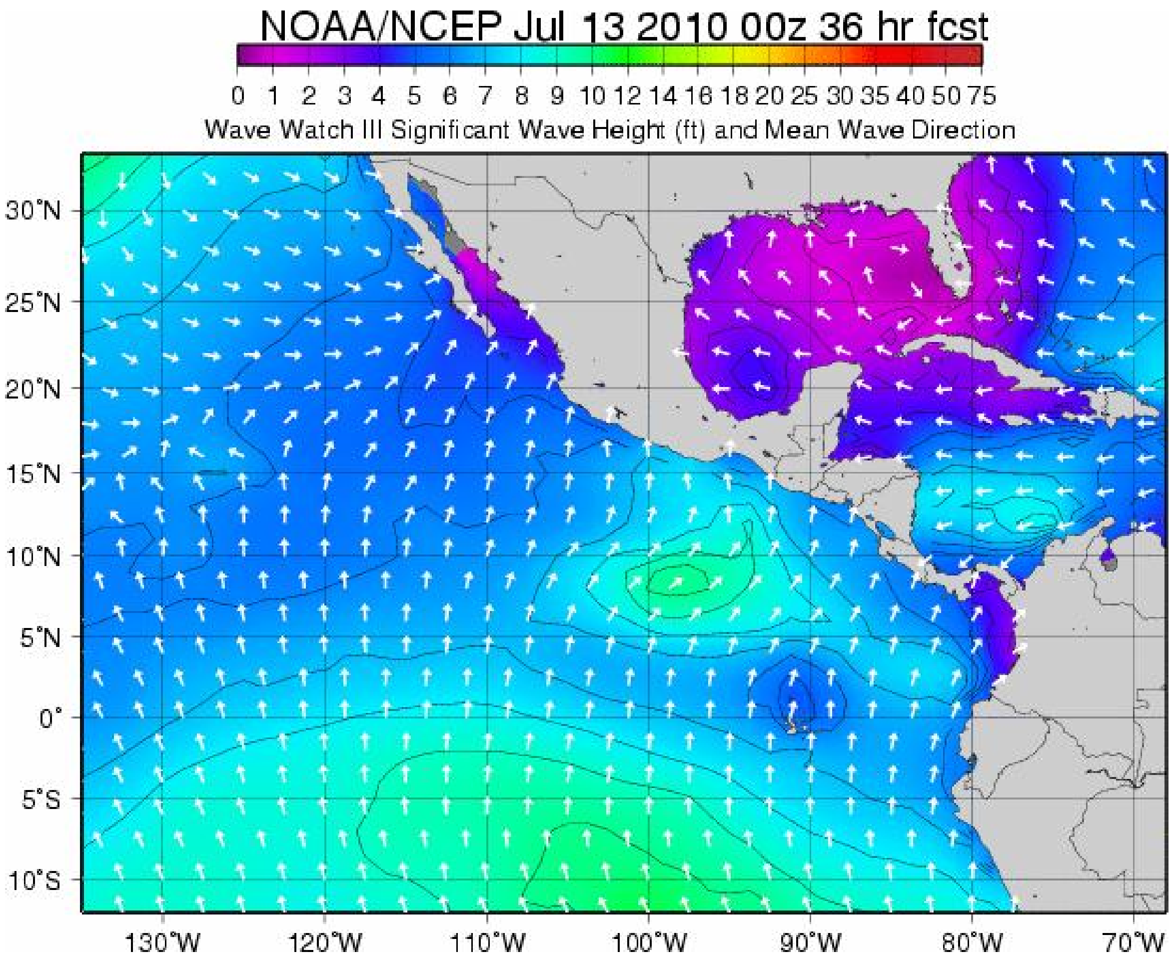
ABSTRACT

Few studies about the wind (energy) have been produced in El Salvador those studies were developed to investigate the potential for generating electric energy on a small scale, however due to undesirable results, the studies were discontinued. The studies were not extended to all possible points of exploitation.
Recently, after having considered an electric power company (CEI) alternative methods to produce electric energy; has installed one wave sensor on our shores as a pilot project, Also, it has been considered that the coastal areas of our country have few barriers to the movement of wind.
If we relate the sea breeze and the distant and local storms producing wind and waves it is logical to think that a model that produces data of both phenomena is useful to analyze both in coastal areas, which serves to extend previous studies of energy exploitation purposes, mainly to assess risk and vulnerability of the area.

INTRODUCTION

El Salvador is located Along the Pacific Ocean Cost in Central America in front of subduction zone of the Cocos and Caribbean plates. Local, regional and Distant tsunamis Have Been Reported Along their cost. Moreover the country is part of the intertropical convergence zone so it is influenced by waves of local and distant storms. Regarding to tsunamis the SNET seismology area warns of local earthquakes and PTWC on distant events. On the other hand, El Salvador has wave phenomena which have caused damage in populated coastal areas due to local and distant storm waves which there is no record or historical reference.
For this reason the area of oceanography at SNET developed a study of the characterization of wind and waves on our coast to differentiate and assess the risk of the effects of waves on them.
Currently there is no instrumentation to record the waves only two tide gages but soon SNET will install a coastal buoy in shallow water to record and transmit in real-time data allowing validating the models currently used for wave forecasting.

For planning purposes it is useful to have information on the rates prevailing characteristic of waves on a coast, its intensity, direction and period as well as wind data and the risks and potential effects that these represent.
This study focuses on these aspects and for this we used the data output of a numerical forecast wave model" Wave Watch III" which is a third generation model developed by NOAA.
This model serves to swell forecasts every 6 hours in the following figure shows a model output showing forecast for significant wave height and direction of wave to the coasts of Central America where our country El Salvador is located.



WAVE WATCH III PRODUCTS

METHOD

Due to the volume of data to process will be described in greater wind speed and wave height is the characterization that interests us, however for the conclusions and analysis are taken into account the five parameters and all the results of an annual series, monthly and seasonal.

For data processing a series of data in text files for a period of 11 years were used, so an algorithm was programmed and run in MAT LAB 2007 for getting graphics and statistical. The data correspond to virtual buoys used by the model located in our coast at node 13^0 Lat N, 90^0 long W, 60 km of the coast to deep water wave and node 13^0 Lat. N, 88^0,750'Long.W, 23 km for shallow water waves.
As a result in both nodes were obtained full time series (11 years), annual and seasonal (dry and wet) as signal of height, period, direction waves ,speed and direction wind.

DATA PROCESSING.

As previously mentioned we used the numerical model Wave Watch III (WW3) of NOAA. This model divides the earth into points, forming a mesh or as it is called in technical terms "GRID", forming small rectangles at the vertices that are nodes of analysis on which data is obtained, which are separated by 1 degree in latitude and 1.25 in longitude. In the present, the output data of two points from GRID is being used, which best corresponds in El Salvador for the analysis desired, and these points are : 13N 88.75W and 13N 90.00W, these were already mentioned in the introduction and can be seen in Figure 1.

FIGURE 1

The processed information is an output from the model , this output is in a text format,separated by comma and sorted as follows: Month, day, year, time, wave height (m), wave period (seconds) , swell direction (degrees), wind speed (m / s) and wind direction (degrees), as shown in Figure 2, which is the way how information was provided. The figure presents the complete information for a day where you can see the outputs of the program every three hours, thus comprising 8 data per day.

```
MONTH,DAY,YEAR,HOUR,WAVE HEIGHT(M),WAVE PERIOD,
WAVE DIRECTION,WIND SPEED(M/S),WIND DIRECTION
FEB,01,1997,00,0.3,3.55,40.79,0.960208,125.676
FEB,01,1997,03,0.26,3.55,41.25,2.30124,42.0056
FEB,01,1997,06,0.22,5.16,117.56,2.80016,334.625
FEB,01,1997,09,0.2,5.19,117.53,3.64088,35.6108
FEB,01,1997,12,0.18,5.19,117.23,4.36794,72.6849
FEB,01,1997,15,0.19,5.22,117.31,5.74674,63.2119
FEB,01,1997,18,0.16,5.65,158.1,3.4442,80.811
FEB,01,1997,21,0.14,6.07,195.98,0.87784,132.23
```

Figura 2. Data Format WW3 Model Output

This information will help to achieve a description of wind and waves characteristic for that period of time (11 years) and to describe the characteristic waves and wind for each year and monthly and / or seasonal.

The 11-year period provided by the study covers the years between 1997-2007.

Output parameters.

The wave model provides outputs of the following fields of meshes average wave parameters. Some of these parameters can also be found in the outlets for selected points.

- Average water depth (m).
- Current average speed (vector, m / s).
- Average wind speed (vector, m / s).
- The temperature difference air-ocean. (^{0}C)
- Friction velocity u * (scalar). The definition depends on the parameterization of the terms of the selected source (m / s).
- Significant wave height (m).
- Average wavelength (m).
- Average Wave Period (s).
- Direction average wave (degrees, meteorological convention)

- Average Directional Extension (degrees).

- Frequency of higher-energy waves (Hz).
- Direction of waves of higher energy (grade), defined as the average direction.

According to the output of the program in Figure 3.it can be seen that the directions of wind and waves are presented in numerical format in degrees (0-360 °). For this work, it is understood that the reference of zero degrees is located in the north of the land and subsequently is measured in degrees clockwise as shown in Figure 3. For instance you can see 90, 180 and 270 degrees This is the (E), South (S) and West (W). As shown in Figure 3., a wave with a direction from southwest (SW or 225 °) would be represented as shown in Fig.

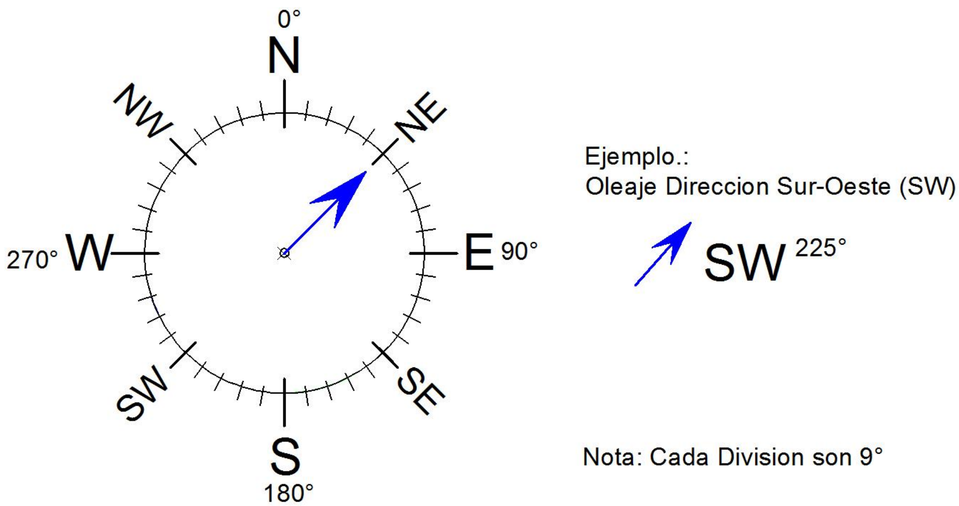


Figure 3.- Reference swell direction and wind speed

CHARACTERISTICS OF THE DATA.

Data to be analyzed have certain characteristics that are described below:

• The wind speed data is the speed at 10 meters above sea level because this is what affects the waves.
• The global model is for open sea and no obstacles for the wind and solve very well the swell in deep water.
• For wave height data the model works with significant wave height (height of the one third highest waves) known as H1 / 3. And is calculated by measuring the height of the wave at a record of few minutes, for example by taking the wave crests 120 values and record their heights, the model takes the 40 highest waves and the average value is calculated from all this .The calculated value of these waves is the H1 / 3 of the record.

• Data Values "9.999E + 20" means that values are undefined, this can be seen that at certain times and periods the ocean may become so calm that the model does not solve the period or directions, in a few words undefined values means a calm ocean.

• Hurricane winds and local sea may not be fully appreciated because the global models do not have the resolution needed to resolve tropical storm winds.

This is explained as follows: For the mesh of the model, 1 degree = 120 km which are the vertices of the mesh and local sea storms generates mostly smaller radius so are undetected . The model provide data in six hours.But if there were local storms within half an hour or an hour period of time the model donesn`t resolve it , only project the effects later.
There are regional models whose spatial resolution is 30 km with response times three Hours.

• The information can be validated and verified on the NOAA website http://polar.ncep.noaa.gov.

• The global model is used because it has the historical data of 11 years.

TOOLS USED FOR DATA PROCESSING.

For data processing a software program called Matrix Laboratory is used (its abbreviation in English MATLAB, version 2007 ª.) The strength of this computer software program is that can develop algorithms to automate tasks. The advantage is, it can formulate the information in the form of matrix and vectors, which is very convenient due to the amount of data, as the format data to be processed.

The algorithms to be developed must meet certain requirements, which are listed below:

• Be able to read matrix of data in columns, delimited by commas in text format.

• To calculate the average (mean value), Mode (more frequent value), standard deviation (dispersion value), Variance (arithmetic mean of squared differences), Maximum and Minimum values.

• Obtain visual outputs of data processed in bar graph form and signals for heights against time and wind speed against time for 11 years for each year and dry season and rainy season.

• To generate an output format consistent and easy to read.

STATISTICAL TOOLS USED

With the information ordered statistical tools are used to generate the parameters on which the respective analysis can be made for the description of the waves.

The statistical tools used are:

• Media: Describes the average value or arithmetic mean of a range of values.
• Mode: describes the most common or repetitive value in the range of values.
• Medium: the average value of a series of numbers or the central tendency which is half of a group of numbers in a statistical distribution.
• Standard deviation: average of the squares of the differences.
• Maximum: returns the maximum value of a range of values.
• Min: returns the minimum value of a range of values.
• Percentiles: a value that exceeds a certain percentage of the members of the population

ANALYSIS OF SIGNALS.

For the signal processing we used fast Fourier transform applying a Matlab toolbox called "TIME SERIES TOOLS" or tools of time series. This was done to make energy periodogram for the full time series, annual and seasonal.

The valid frequency range for a periodogram energy is according to Stewart scientific the wave record contains information about the waves in the frequency range shown in Equation 3.1, where T is the length of the series time and Δ is the sampling interval between data and the other. 1/2Δ This value is called the Nyquist frequency. Thus the length of the entire time series is T = N Δ, where N is the number of data.

(Eq. 3.1) $$\frac{1}{T} < f < \frac{1}{2\Delta}$$

In our case for both stations, has a sampling interval of 3 hours which is equivalent to Δ = 10.800 seconds the amount of data was approximately N = 31.600.

ANALYSIS AND RESULTS

This section shows the results obtained from the processing of data using Matlab and it is presented below for each of the seasons.

RESULTS NODE 13N-88.75W.

RESULTS OF FULL-TIME SERIES (1997-2007).
The signals obtained for 13N-88.75N node are presented below for significant wave height (meters) in Figure 4.1, swell direction (degrees) in Figure 4.2, wave period (seconds) in Figure 4.3, wind speed (m / s) in Figure 4.4 and wind direction (degrees) Figure 4.5. The reference to wind speed and direction of waves is the same as explained in Figure 3

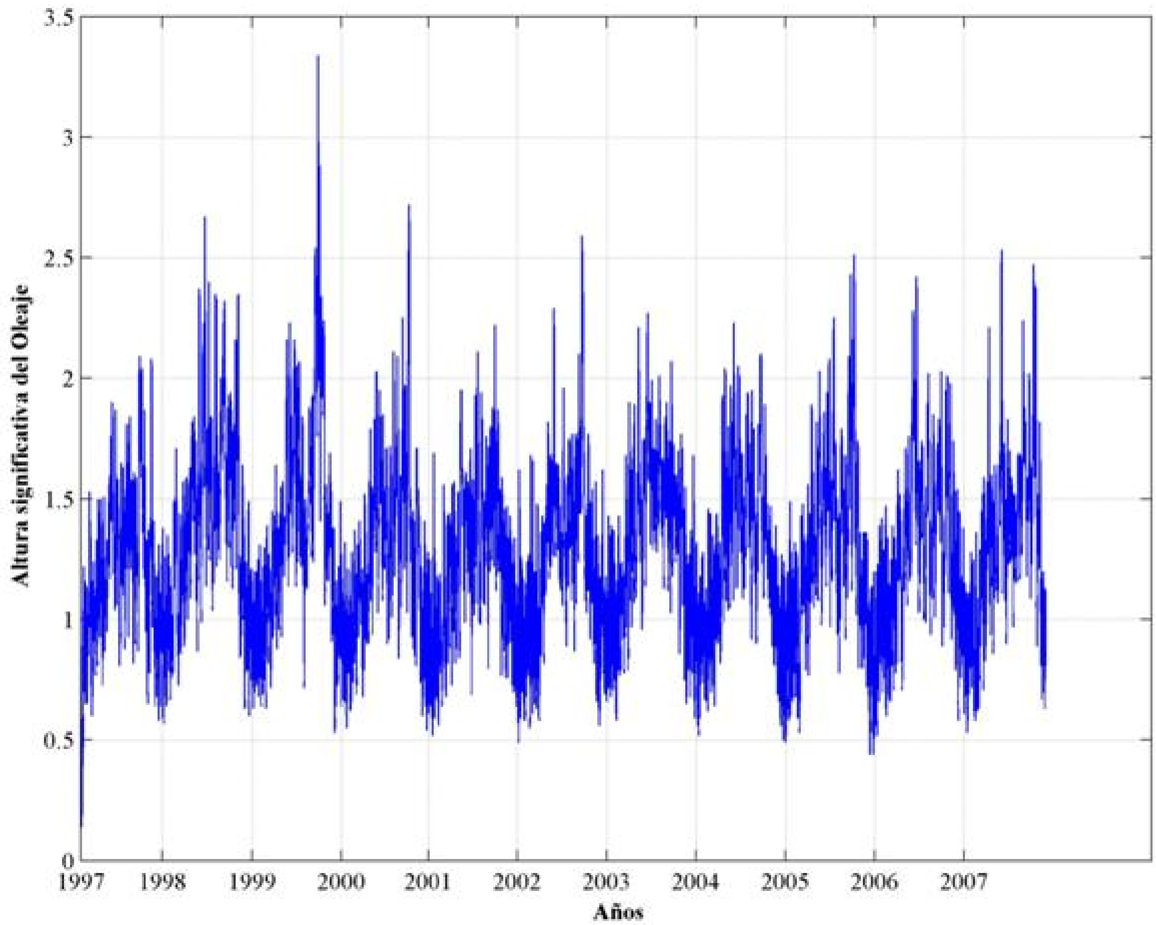


Figura 4.1 Signal significant wave height for period 1997-2007.

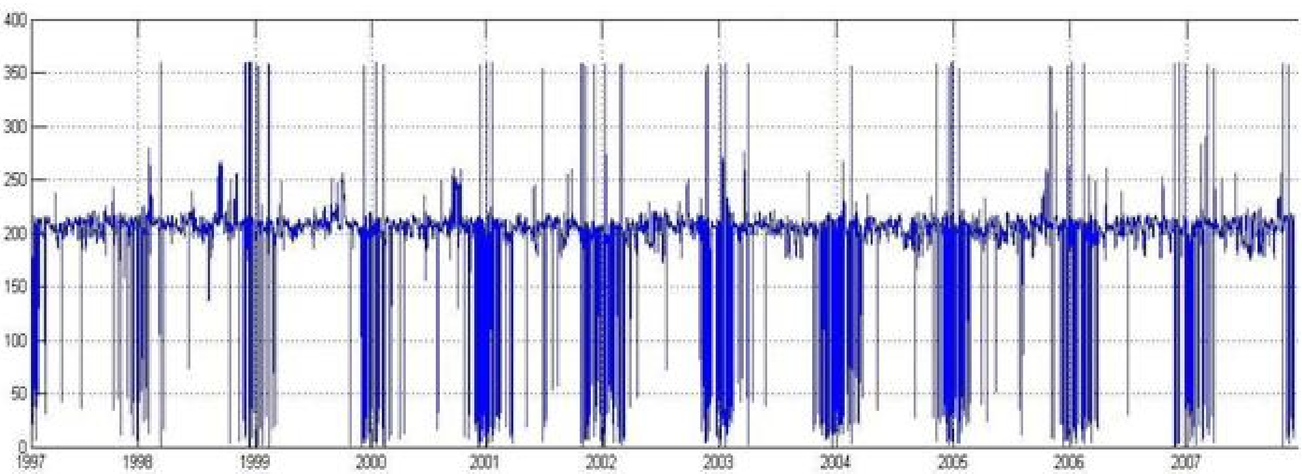


Figura 4.2 Signal to swell direction for 1997-2007

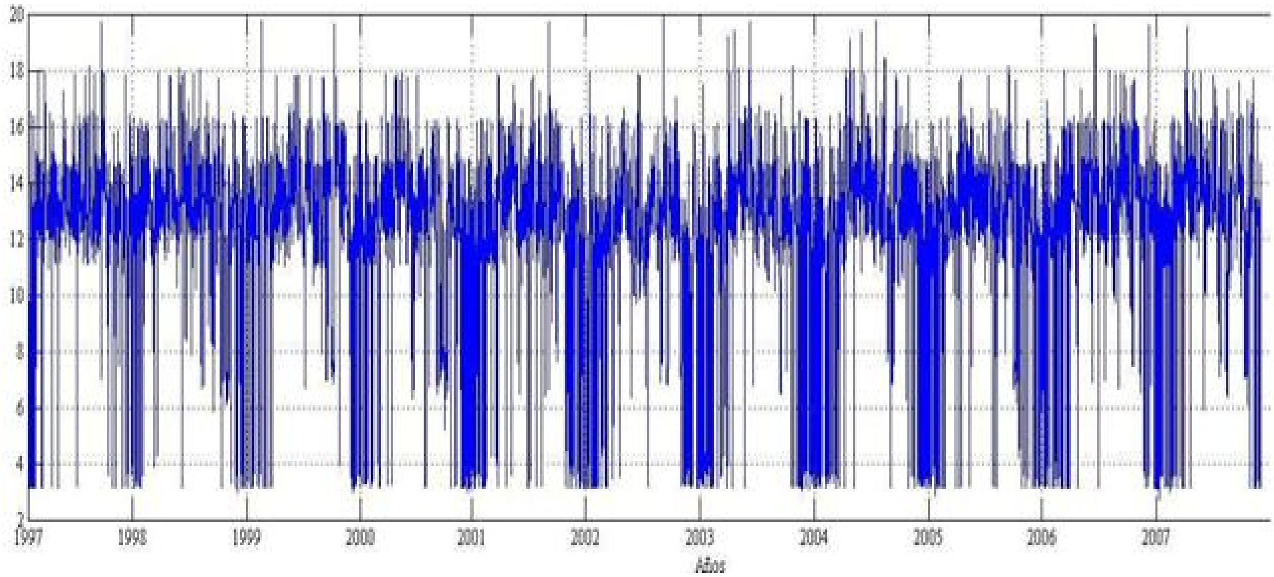


Figura 4.3 Signal of swell period 1997-2007.

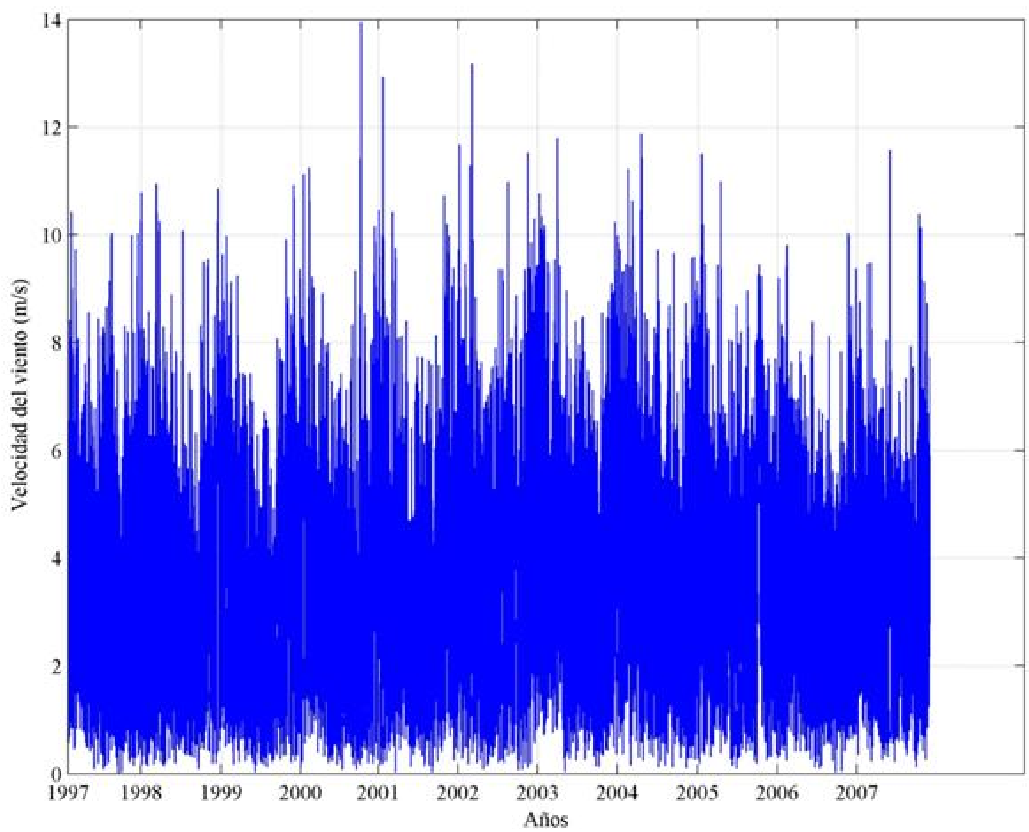


Figura 4.4 Sign of wind speed for period 1997-2007.

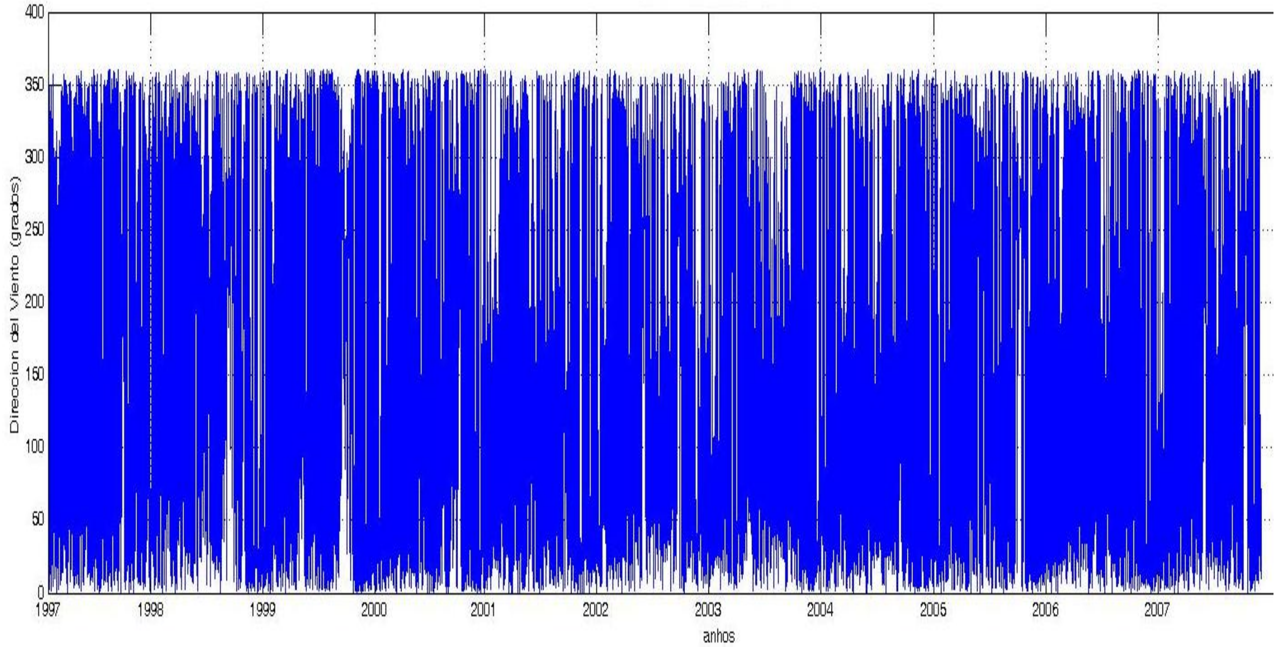


Figure 4.5 .- wind direction signal for 1997-2007

NODE RESULTS 13N-90.00W.

RESULTS OF FULL-TIME SERIES (1997-2007).

The signals obtained for node-90.00W 13N are presented below for significant wave height (meters) in Figure 4.6, swell direction (degrees) in Figure 4.7, wave period (seconds) in Figure 4.8, wind speed (m / s) in Figure 4.9 and wind direction (degrees) Figure 4.10

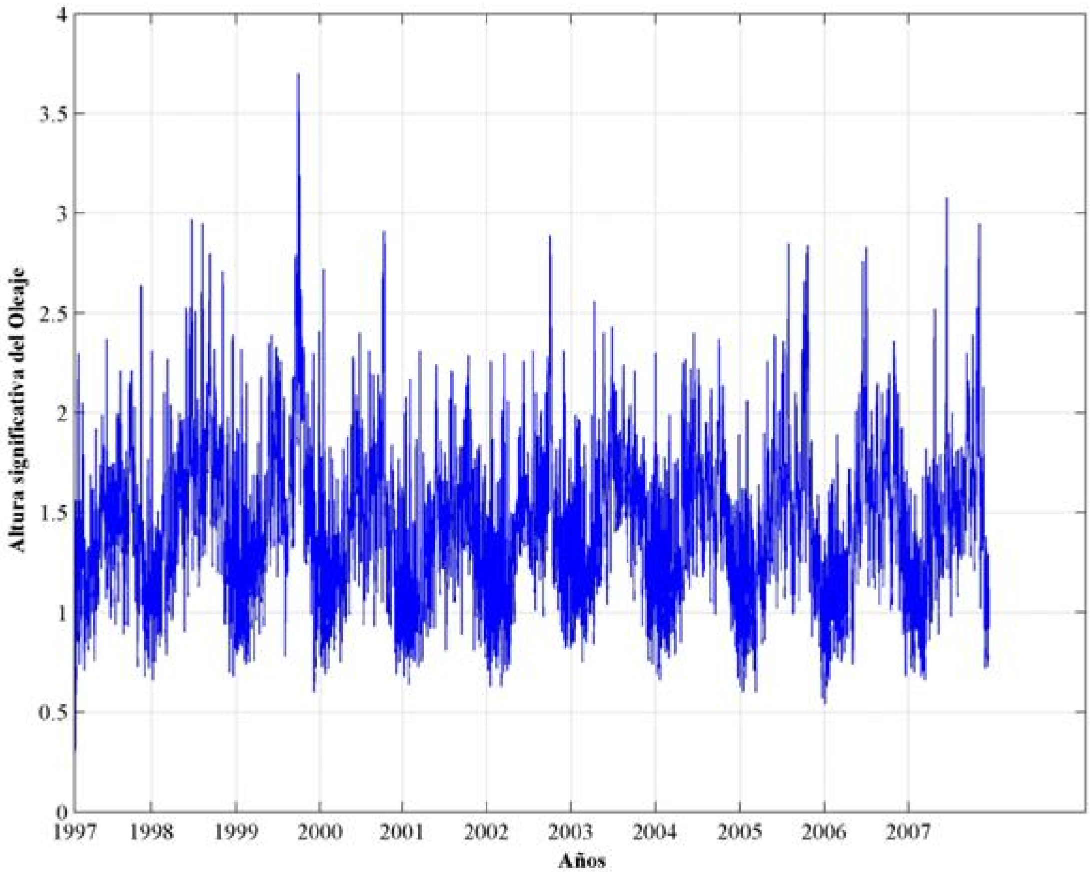


Figure 4.6 .- Signal significant wave height for period 1997-2007.

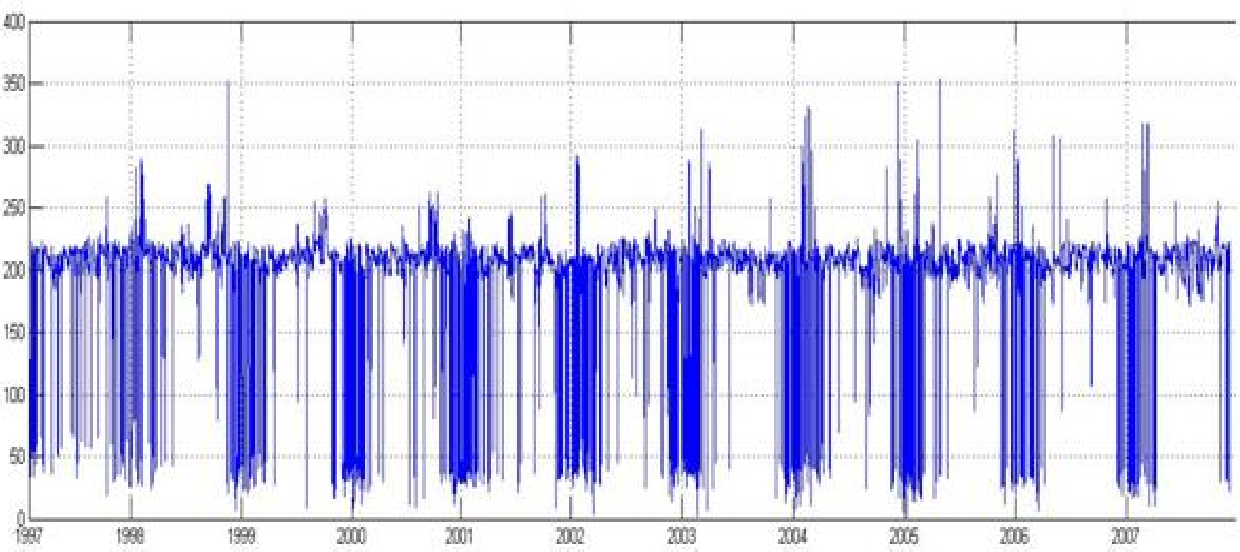


Figure 4.7 .- Signal to swell direction for 1997-2007.

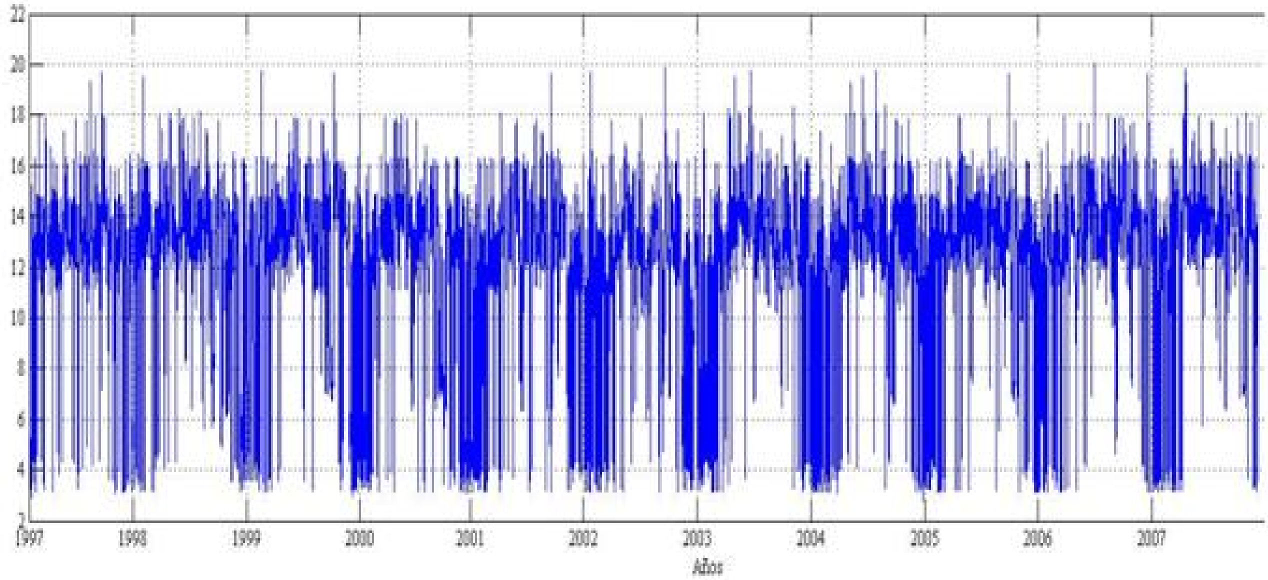


Figure 4.8 .- Signal wave period of 1997-2007.

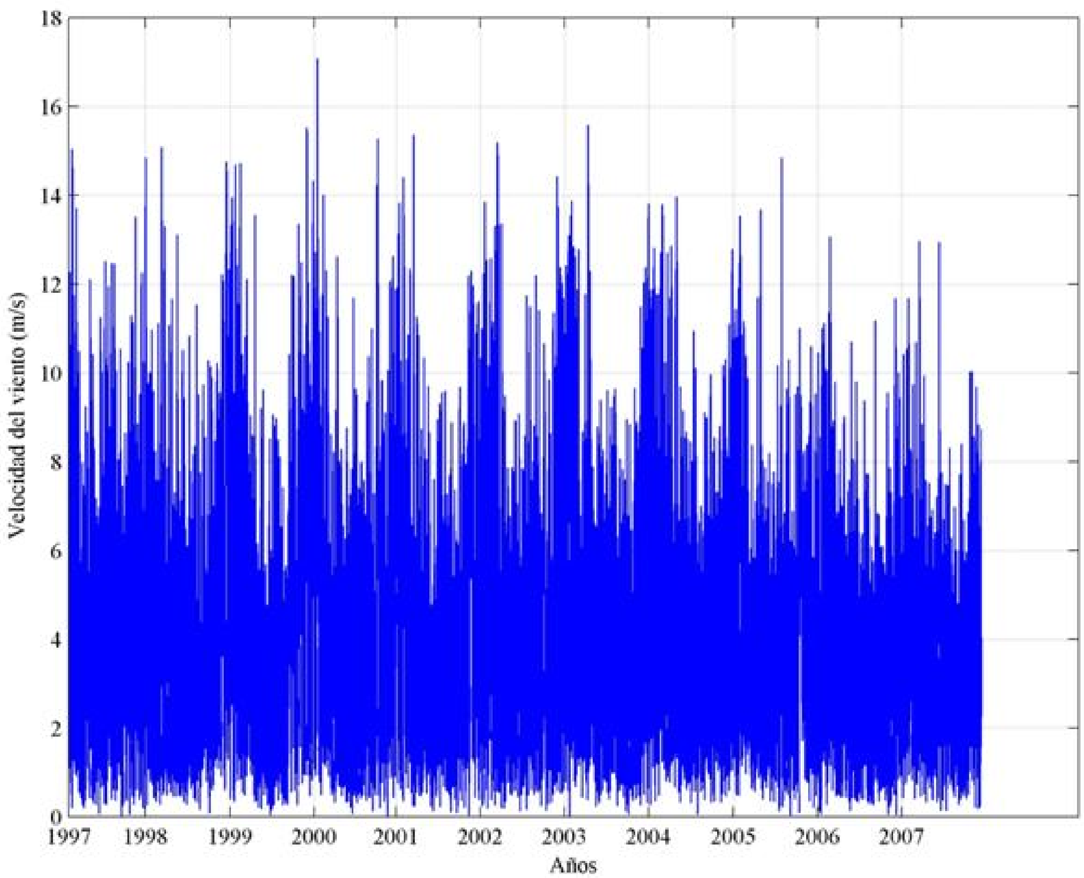
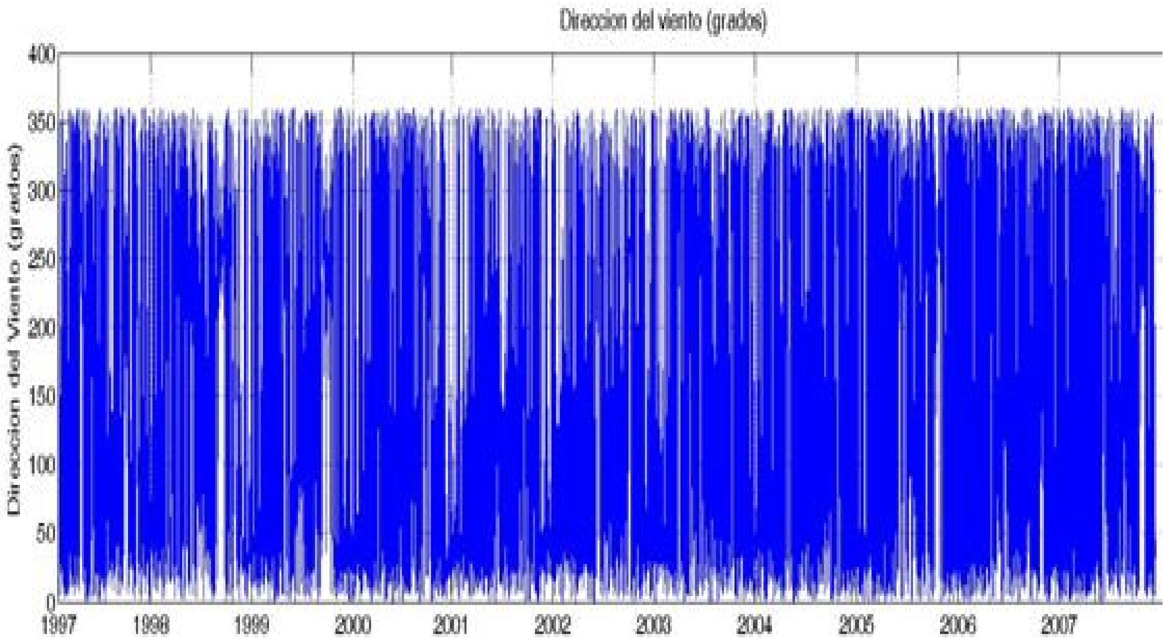


Figure 4.9 .- Signal to wind speed of 1997-



200

Figure 4.10 .- wind direction signal for 1997-2007

ANALYSIS OF RESULTS

For a clearer overlook of the waves and to interpret the statistical data analysis was performed of all time series, annual and monthly significant wave height, wind speed, swell direction, wind direction and wave period. Although we will discuss more about these variables, they have produced tables showing statistical values of these, which generalize the amount of data that is needed so you can have a better understanding. In conclusion this presents statistical values for the entire time series total in table 5.1 for node 13N-88.75W and Table 5.2, the node 13N-90.00W. Likewise for wave and wind direction using the same convention as detailed in Figure 3

Table 5.1 .- Statistical values of the entire time series for 13N - 88.75W

	average	maximum	minimum	moda	deviation
Significance of wave height (m)	1.2	3.3	0.1	1.2	0.4
Wind Speed (m/s)	3.9	13.9	0.0	2.8	2.0
Wave Direction (Degrees)	197	360	0	207	44
Wind Direction (Degrees)	138	360	0	45	107
Wave Period (seconds)	12.5	20.0	2.7	13.4	2.9

Tabla 5.2 Statistical values of the entire time series for 13N - 90.00W

	average	maximum	minimum	moda	deviation
Significance of wave height (m)	1.4	3.7	0.3	1.3	0.4
Wind Speed (m/s)	4.6	17.1	0.0	4.2	2.6
Wave Direction (Degrees)	192	360	0	212	53
Wind Direction (Degrees)	142	360	0	90	107
Wave Period (seconds)	12.2	20.1	2.8	13.4	3.3

For the annual time series we show annual statistical values presented in Table 5.3 for the node 13N-88.75W and Table 5.4 for the node 13N-90.00W. This include the average annual standard deviation in all variables less for wind direction, this is because the standard deviation for this variable goes by 100 degrees, this can be corroborated in Table 5.1 and 5.2 for direction wind, so moda was used to describe this.

Table 5.3.- Annual statistical values for 13N-88.75W

	Wave Height (m)		Wave Direction (°)		Wave Period (seg)		Wind Speed (m/s)		Wind Direction (°)
Year	Aver.	Dev.	Aver.	Dev.	Aver.	Dev.	Aver.	Dev.	Moda
1997	1.2	0.3	199.8	34.0	12.7	2.5	3.7	1.9	45.0
1998	1.3	0.4	205.6	35.3	12.6	2.7	3.6	2.0	135.0
1999	1.3	0.4	201.1	40.7	12.8	2.7	3.6	2.0	360.0
2000	1.2	0.4	198.9	46.1	12.1	3.0	3.7	2.0	14.0
2001	1.2	0.3	193.8	48.2	12.4	2.9	3.9	2.1	15.5
2002	1.2	0.4	192.0	50.3	11.8	3.1	4.1	2.1	135.0
2003	1.3	0.3	189.3	54.4	12.2	3.3	4.3	2.1	90.0
2004	1.2	0.3	193.4	47.3	12.5	3.0	4.2	2.1	49.4
2005	1.2	0.4	196.9	40.6	12.5	2.7	4.0	1.9	270.0
2006	1.2	0.3	198.2	41.0	12.9	2.7	3.7	1.7	45.0
2007	1.3	0.4	200.1	33.9	12.8	2.7	3.8	1.7	18.4

Table 5.4 Annual statistical values for 13N-90.00W

	Wave Height (m)		Wave Direction (°)		Wave Period (seg)		Wind Speed (m/s)		Wind Direction (°)
Year	Aver.	Dev.	Aver.	Dev.	Aver.	Dev.	Aver.	Dev.	Moda
1997	1.3	0.3	195.5	45.3	12.4	3.1	4.8	2.6	360.0
1998	1.5	0.4	200.3	49.1	12.4	3.1	4.5	2.7	270.0
1999	1.5	0.5	190.5	56.6	12.3	3.3	4.8	2.9	270.0
2000	1.4	0.4	188.8	59.9	11.7	3.5	4.6	2.7	90.0
2001	1.3	0.3	186.9	56.1	12	3.3	4.6	2.6	45.0
2002	1.4	0.3	184.1	59.2	11.4	3.5	4.8	2.7	90.0
2003	1.5	0.3	184.1	60.2	11.9	3.6	5.1	2.7	360.0
2004	1.4	0.3	189.0	55.5	12.1	3.5	4.8	2.4	38.7
2005	1.4	0.4	198.5	44.2	12.5	2.8	4.4	2.2	33.7
2006	1.4	0.4	196.6	45.0	12.8	2.9	4.1	2.1	26.6
2007	1.4	0.4	200.1	41.6	12.8	3.0	4.1	2.0	196.4

Table 5.5 and 5.6 are the statistics, which shows mean values for each month in each year of the entire time series.

Table 5.5 .- statistical values for each month of the entire series of time-13N 88.75W

AVERAGE VALUE PER MONTH FOR ALL TIME SERIES 1997-2007

	Jan	Feb	Mar	Apr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dec
A	0.9	0.9	1.0	1.2	1.4	1.5	1.4	1.4	1.6	1.5	1.1	0.8
Do	165.2	186.7	197.7	204.3	205.8	206.0	205.2	204.3	209.8	207.9	191.7	154.2
Pe	10.5	11.6	12.5	13.6	13.7	13.4	13.2	13.0	12.8	12.4	11.8	10.6
Vv	4.8	4.3	4.2	3.9	3.4	3.3	3.6	3.3	3.2	3.9	4.2	4.5
Dv	96.6	125.5	151.3	173.2	157.4	153.2	121.6	139.1	173.1	160.6	104.1	86.7

Table 5.6 .- statistical values for each month of the entire series of time-13N 90.00W

AVERAGE VALUE PER MONTH FOR ALL TIME SERIES 1997-2007

	Jan	Feb	Mar	Apr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dec
A	1.1	1.1	1.2	1.3	1.5	1.7	1.5	1.6	1.7	1.6	1.3	1.0
Do	148.6	175.7	191.5	203.9	207.6	208.3	206.4	205.5	212.7	208.5	180.8	134.2
Pe	9.7	10.9	12.2	13.5	13.7	13.4	13.1	12.9	12.7	12.4	11.4	9.9
Vv	6.0	5.3	4.6	4.3	3.8	3.8	4.1	3.8	3.9	4.6	5.3	5.8
Dv	101.3	129.7	146.7	169.8	151.5	158.2	127.3	138.7	190.0	161.4	109.7	90.3

Where: A = significant wave height in meters
C = wave direction in degrees
Pe = wave period in seconds
Vv = wind speed in meters / second
Dv = Wind direction in degrees.

SIGNIFICANT WAVE HEIGHT.

FULL TIME SERIES.

For the complete time series we can refer to Figures 4.1 and 4.6 which correspond to annual wave height signals for both nodes for analysis. At first glance you can identify a pattern in the signal of significant wave height and clearly we can see the 11 sub-annual signals that compose it. When referring to the statistical data we have in table 5.1 for node-13N 88.75W average significant wave height average of 1.2 meters, recorded a maximum of 3.3 meters and a standard deviation of 0.4 meters. In Table 5.2 for the node-90.00W 13N, we have an average significant wave height of 1.4 meters, a maximum of 3.7 meters and the standard deviation is 0.4 which is identical to the previous node. Recall that the wave height shown and discussed in this paper corresponds to the significant height is the average third largest height of a wave group.

Another feature of the signals is the month that usually given greater heights of waves are in September and is followed by June. Similarly observeving both signals it can be noted that in the rainy season, wave heights are higher than the average for the entire time series total and in the dry season are lower heights.

You can appreciate the significant height values in Table 5.2 for the node farthest from our shores (13N-90.00W) are higher than those in Table 5.1 for the node nearest to our shores (13N-88.75W) . This happens the same way when comparing the two signals of significant wave heights contained in Figure 4.1 and 4.6, which clearly can see that the farthest node of our coast register significantly higher levels than the nearby node .

This is because the node 13N-90.00W is located on the continental slope, which is the area where the sea has a depth greater than 200 meters, so the swell is not affected by friction with the bottom of the sea, which does not diminish the height of waves by bottom friction (potential energy). That's why this node represents the swell out of our coast.

At its counterpart node 13N-88.75W it is more representative for the waves in shallow waters (near the coast), because this is on the continental shelf where the ocean is at a depth less than 200 meters, so the waves it is affected by friction with the seabed reducing its potential energy with a dispersion relation for shallow waters and phase velocity values that depend only on the depth of the ocean.

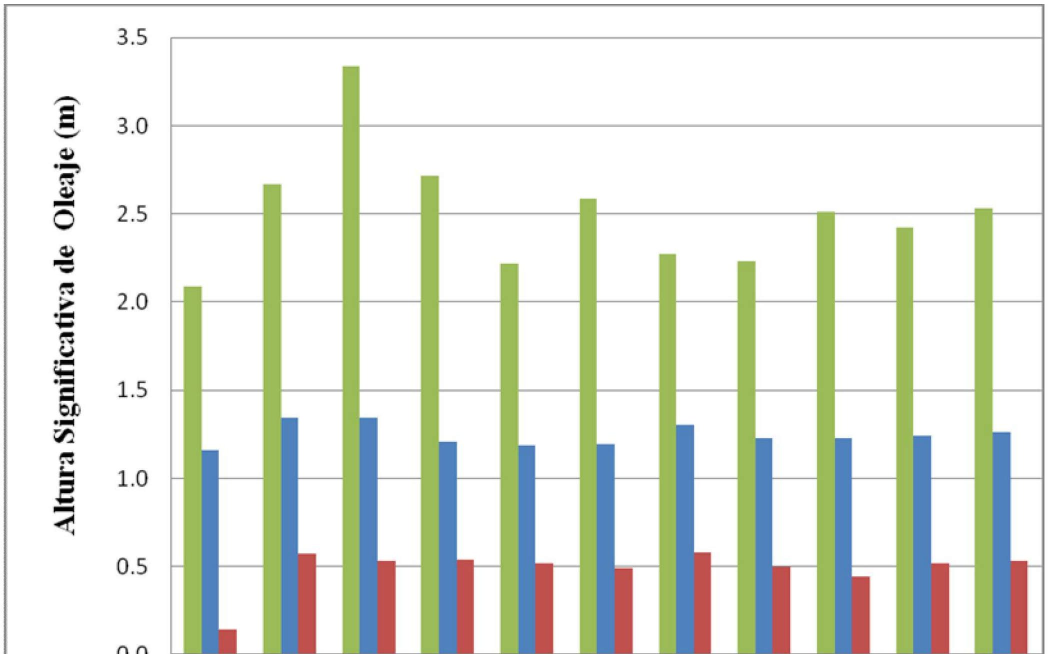
But unlike its counterpart node13 N-90.00W, in which the dispersion relation and phase velocity depends on the wavelength and wave frequency, which are not affected by the depth of the ocean.

ANNUAL ANALYSIS

Although the tables 5.3 and 5.4 are presented values of the mean and standard deviation for each year on both nodes, is presented in Table 5.7 and 5.8 more statistical values of significant wave height for 13N-13N-88.75W and 90.00W nodes.

From Table 5.7 and 5.8 they are achieve ng certain characteristics, one is that the value of moda is the most common value in a series almost always coincides with the average significant wave height for all years and for both nodes. The statistical values for node-90.00W 13N are higher than node 13N-88.75W. For both nodes the value of the standard deviation is in a range of 0.3 to 0.4 meters.

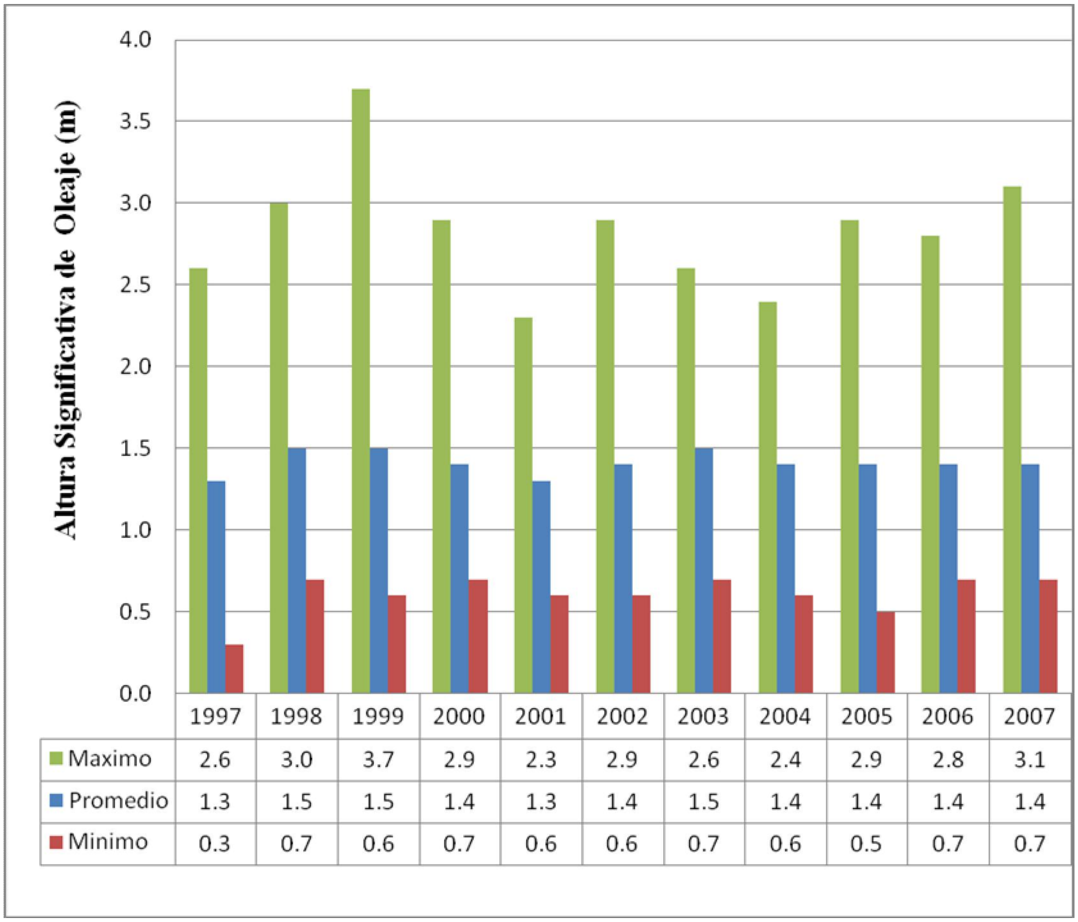
To ease the interpretation of the data histograms were generated for nodes 13N and 13N-88.75W-90.00W in Figure 5.1 and Figure 5.2 respectively.



	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Maximo	2.1	2.7	3.3	2.7	2.2	2.6	2.3	2.2	2.5	2.4	2.5
Promedio	1.2	1.3	1.3	1.2	1.2	1.2	1.3	1.2	1.2	1.2	1.3
Minimo	0.1	0.6	0.5	0.5	0.5	0.5	0.6	0.5	0.4	0.5	0.5

Figure 5.1 Histogram of statistical significant wave height per year for 13N-88.75W

Based on the histograms in Figure 5.1 and 5.2 we can noticed at first glance a maximum annual variation with a gap of three years, this can be seen in 1999, 2002 and 2005 where there are maximum values, then in the years subsequent to 2007 are maintained almost constant significant heights. In the year 1999 we had the highest maximum value that said that is 3.3 meters and 3.7 nearest node to the node farthest from our shores



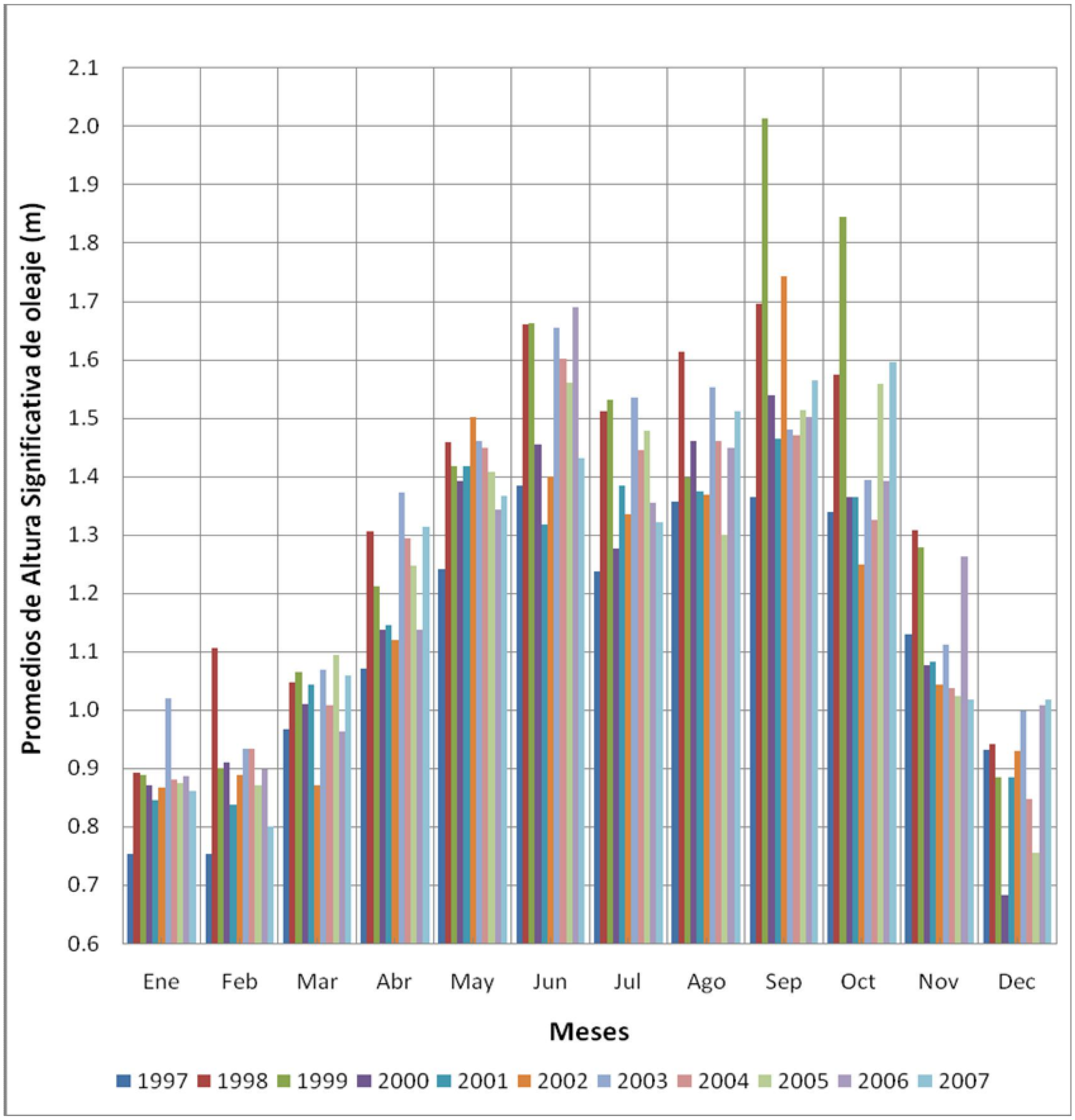
	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Maximo	2.6	3.0	3.7	2.9	2.3	2.9	2.6	2.4	2.9	2.8	3.1
Promedio	1.3	1.5	1.5	1.4	1.3	1.4	1.5	1.4	1.4	1.4	1.4
Minimo	0.3	0.7	0.6	0.7	0.6	0.6	0.7	0.6	0.5	0.7	0.7

Figure 5.2 .- Histogram statistical significant wave height per year for 13N-90.00W

MONTHLY ANALYSIS

For the monthly analysis has generated two bar charts containing the average significant wave height for each month of 1997 to 2007, 13N-88.75W node corresponds to Figure 5.4 and for node-13N 90.00 Figure 5.5 .

Using these figures mentioned above and the statistics of the monthly average of significant height shown in Table 5.5 and 5.6 we can corroborate several previous hypotheses. Among these, for both nodes we have in the rainy season (mid-May to mid October) the monthly mean height of each month are significantly greater than the average for the total time series is 1.2 meters for the node 13N-88.75W and 1.4 meters for the node 13N-90.00W. The same holds true for annual averages these months the average height is almost always significantly higher than the average annual significant wave height. As for the dry season (mid-October to mid May), the monthly averages are lower than the average significant height of the entire series or annual total. Similarly in September is when given the significant greater heights every month, then follows the month of June.



5.4 .-Average significant wave height monthly 13N-88.75W

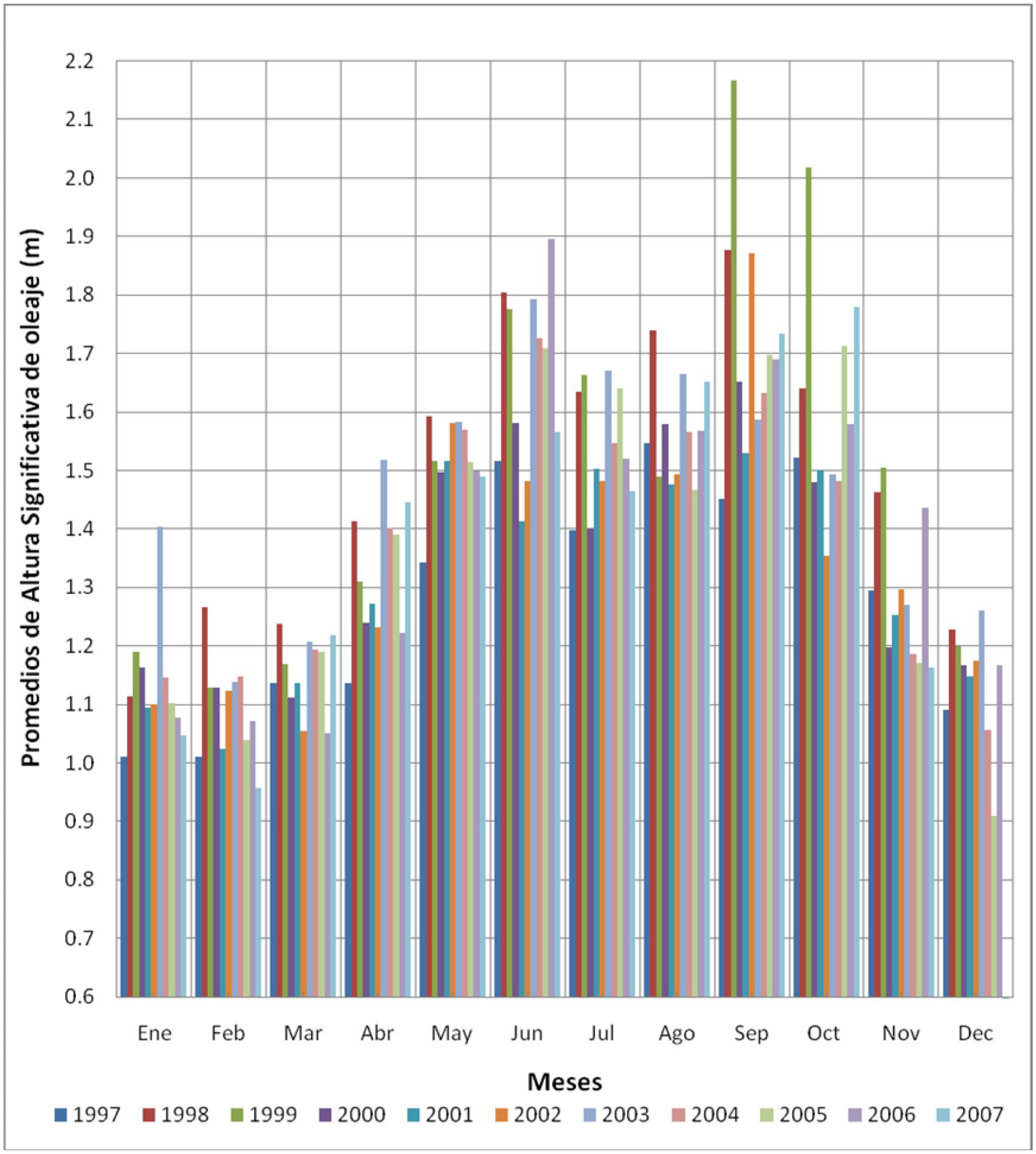


Figure 5.5 .- Average significant wave height monthly 13N-90.00W

Another feature of the monthly time series is that the month that has less significant wave heights is December. For the node farthest from the average of significant height are constant wave of December to March, while in the nearby are January and February. For the dry season in April is the height significantly higher values for both nodes have followed the month of November.

Table 5.9 and 5.10 are presented statistics of the dry season and rainy for the nodes 13N and 13N-88.75W-90.00W. These statistics shown in these tables were obtained from the separation of the months that make up the dry season during the total time series of the months that make up the rainy season the total serial of time.

Table 5.9. According to season statistical significant wave height for 13N-88.75W.

Season	Average	Maximum	Minimum	Mode	Standard Deviation
Dry	1.1	2.9	0.1	1.0	0.3
Rainy	1.4	3.3	0.7	1.3	0.3

Table 5.10.- According to season statistical significant wave height for 13N-90.00W

Season	Average	Maximum	Minimum	Mode	Standard Deviation
Dry	1.2	2.7	0.3	1.1	0.3
rainy	1.6	3.7	0.8	1.5	0.3

Table 5.9 and 5.10 shows that for both nodes the statistical values of significant wave heights are higher in the rainy season than the dry. The highest values recorded in both cases are recorded for the rainy season, likewise mode values for both nodes are greater than the average significant wave height of 1.2 and 1.4 meters respectively for both mode values 1.3 and 1.5 found in table 5.1 and 5.2 which correspond to node 13N-88.75W-and 13N-90.00W

WIND SPEED

Keep in mind that wind speed plays an important role in the analysis, since this is the potential energy gives the wave and as we know it affects up to this.

FULL TIME SERIES.

For the complete time series we rely on the statistical values of wind speed found in table 5.1 and 5.2, where it has to for node-13N 88.75W average wind speed is 3.9 m / s for 13N-90.00W node is 4.6 m / s, standard deviation data have values of 2 and 2.6 m / s, and mode of 2.8 and 4.2 m / s respectively. In general as the significant wave height the wind speed statistics for the remote node are greater than for the node close to our shores.

Similarly to observe the wind speed signals included in Figure 4.4 for the nearest node and Figure 4.9 for the node remote. From these one can observe a central tendency with a range of wind speeds with values from 2 to 5.6 m / s for the node near (13N-88.75W) and 2.5 to 6 m / s for the remote node (13N- 90.00W), which corresponds to the average value + / - standard deviation for both nodes.

ANNUAL ANALYSIS

For the annual analysis have created two tables which contain the annual statistical 13N-88.75W in Table 5.11 and Table 5.12 contains the node 13N-90.00W. From Table 5.11 and 5.12 can see certain characteristics, first at all the annual average values are lower n than node from node distance. The data of average wind speed between a node and the other has a different behavior, for example in Table 5.11 The average wind speed gradually increasing since 1998 with a value of 3.6 m / s up to the 2003 with an average maximum 4.3 m / s, while in Table 5.12 for node-13N 90.00W not given this same behavior, yet they agree that the year with higher average wind speed was 2003 with a value of 4.3 m / s for nearest node and 5.1 for distant node. Another feature is that the maximum values do not vary so dramatically with each other from one node to another.

Table 5.11.- Annual Statistical Wind Speed 13N-88.75W (m/s)

Year	Average	maximum	min	mode	deviation
1997	3.7	10.4	0	0.5	1.9
1998	3.6	11	0.1	0.8	2
1999	3.6	10.9	0	1	2
2000	3.7	13.9	0.1	0.2	2
2001	3.9	12.9	0	1.1	2.1
2002	4.1	13.2	0.1	2.2	2.1
2003	4.3	11.8	0	1.1	2.1
2004	4.2	11.9	0.1	1.6	2.1
2005	4	11.5	0.1	2.6	1.9
2006	3.7	10	0	1.5	1.7
2007	3.8	11.6	0.1	3.2	1.7

Tabla 5.12.- Annual Statistical Wind Speed 13N-90.00W (m/s)

Year	Average	maximum	min	mode	deviation
1997	4.8	15	0	2.4	2.6
1998	4.5	15.1	0.1	0.5	2.7
1999	4.8	15.5	0	3.1	2.9
2000	4.6	17.1	0	2.3	2.7
2001	4.6	15.4	0	1	2.6
2002	4.8	15.2	0.1	2.7	2.7
2003	5.1	15.6	0	1.3	2.7
2004	4.8	14	0.1	0.3	2.4
2005	4.4	14.8	0	0.6	2.2
2006	4.1	13.1	0	2.2	2.1
2007	4.1	13	0.1	2.5	2

ANÁLISIS MENSUAL

MONTHLY ANALYSIS

For the monthly analysis shows two histograms in Figure 5.6 and 5.7, these contain the monthly average values of wind speed for the entire time series for 13N-13N-88.75W and 90.00 respectively. From these figures one of them confirm that December and January is when it has the largest wind speeds, in this case the wind speed averages describing the monthly figures 5.6 and 5.7 reflect this well.

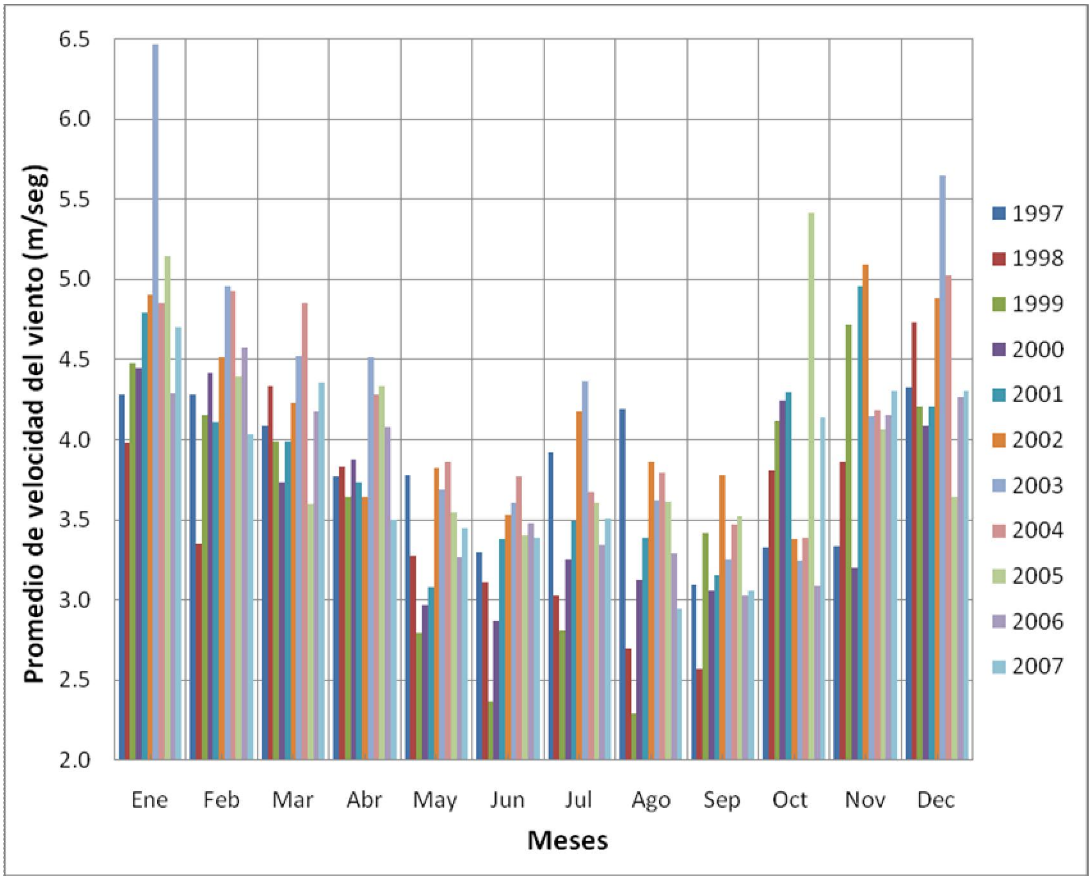


Figure 5-6 .- Statistical average wind speed for 13N-88.75W

As it shows for the months of November and March (months corresponding to the dry season) shows higher wind speeds. Which can be corroborated by observing the annual average wind speed of the node 13N-88.75 (3.9 m / s) shown in Table 5.1 and the monthly averages from November to March in Figure 5.6. Similarly in Table 5.13 presents the statistics for the dry season and rainy for the wind speed for the nearest node, which is striking in this table is what is suggested above is that in the dry season average wind speed is 4.3 m / s (above the annual average) while in the rainy season we have an average speed of 3.5 (below the annual average). The same is true for node-13N 90.00W by observing the histogram of Figure 5.7 with Table 5.2 of the average total time series and Table 5.14 that contains the statistical seasonal.

Table 5.13 Seasonal Statisticians as wind speed for 13N-88.75W (m / s)

Season	**Average**	**Maximum**	**Minimum**	**Mode**	**Standard Deviation**
Dry	4.3	13.9	0.1	2.0	2.1
Rainy	3.5	12.0	0.0	1.8	1.7

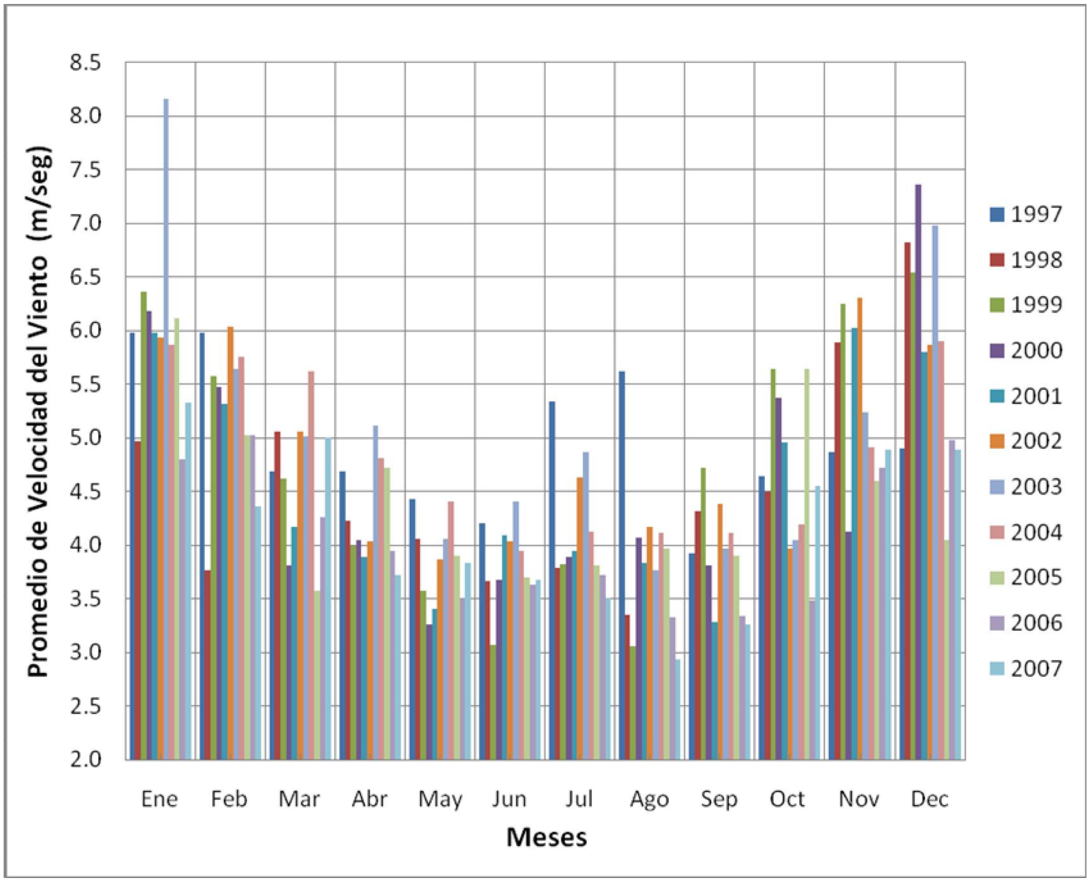


Figure 5-7 .- Statistical average wind speed for 13N-90.00W

Table 5.14 Season Statisticians wind speed for 13N-90.00W (m / s)

season	Average	Maximum	Mínimum	Mode	Stándar Deviation
Dry	5.2	17.1	0.1	2.4	2.8
Rainy	4.0	15.3	0.0	1.3	2.1

A curious feature that stands out is that enough to see the graphs in Figure 5.6 and 5.7 of the monthly average wind speed and then look at figure 5.4 and 5.5 that correspond to the graphs of average monthly wave height is can say that a is inversely proportional to the other so to speak.

This proves that definitel our dry season has higher wind speeds but significant less wave heights , while the rainy season has larger significant wave heights larger but lower wind speeds.

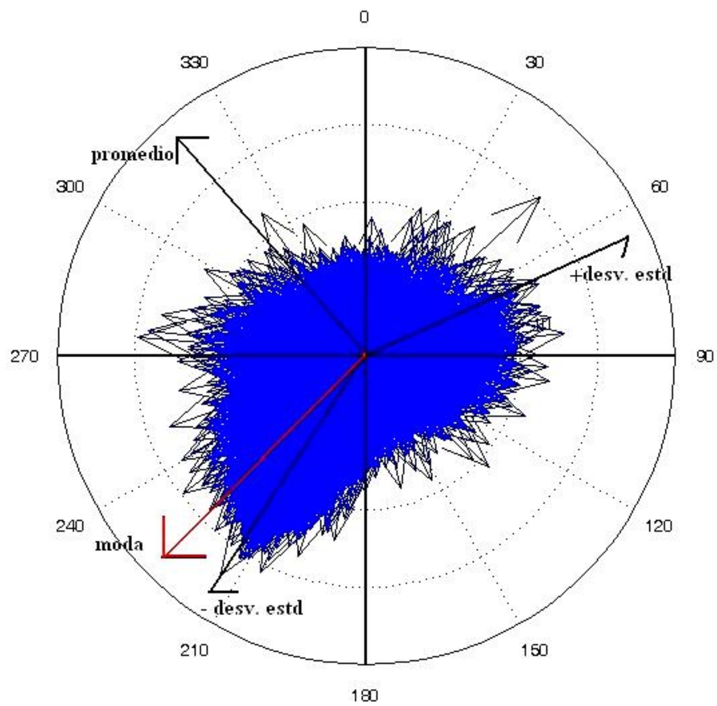
You can make several assumptions about this phenomenon and one is that if the wind blows in the direction of swell, this gives the wave kinetic energy which is combined with the potential energy that has, thus increasing the height waves and period, meaning this as an input of energy.

If in counterpart the wind blows in the opposite direction, which would make it function as a type of shock, defined as a type of decreas of energy, reducing wave height and period. However, this is just a general assumption since there are so many factors to be taken into account, this phenomenon has been observed that slows the fall of the wave and is favorable for the people who practice surfing.

WIND DIRECTION

Due to the variability in wind direction, we chose to represent the wind direction in the form of simplified wind rose for the entire time series which is in Figure 5.9 and 5.10 for node 13N 88.75W and 13N-90.00W. The directions of the arrows represent the direction of the wind. Similarly we can see that you have superimposed arrows representing the Mode, with the average reference + / - standard deviation (which indicates the range of values that is likely wind direction) . Clearly you can confirm that the average is not indicative value to characterize the wind direction.

Figure 5.9 .- Wind direction as a nautical rose for 13N-88.75W



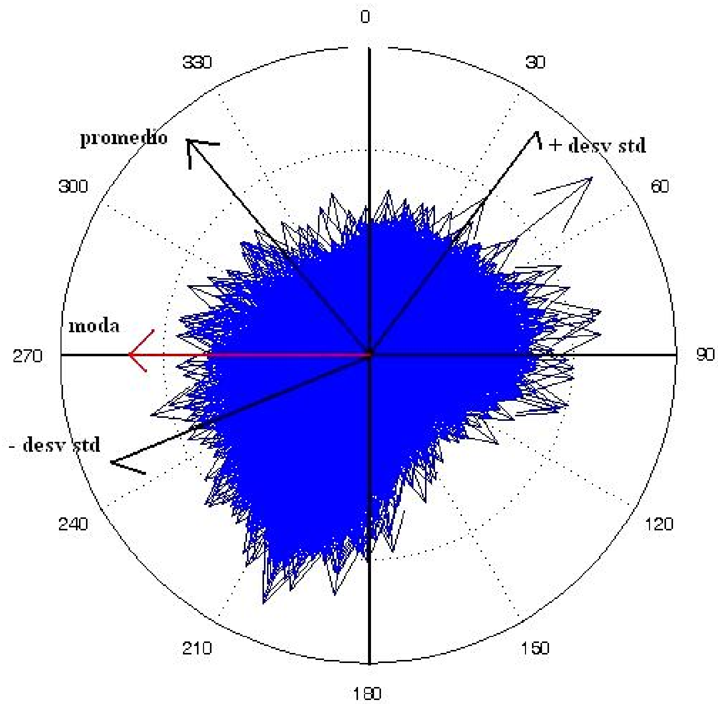


Figure 5.10.- Wind Direction as a náutical rose for 13N-90.00W

ANNUAL ANALYSIS
Table 5.15 and Table 5.16 shows annual statistics for the wind to both nodes, of which the value that best describes the behavior is the Mode. You can see consistency through the years in a directions range of winds coming mainly from North to East, This shows an annual prevalence of winds with directions from 180 ° to 270 °, which is consistent with analysis results for the total number of time.

Table 5.15 .- Statistical wind Direction for 13N-88.75W.

Year	Average	Maximum	Minimum	Mode	Estándar Deviation
1997	145	360	0	45	109
1998	161	360	0	135	104
1999	150	360	0	360	112
2000	131	360	0	14	108
2001	120	360	0	16	100
2002	121	360	1	135	95
2003	123	360	0	90	100
2004	127	360	0	27	106
2005	153	360	1	45	110
2006	135	360	0	45	109
2007	153	360	0	18	107

Table 5.16 .- Statistical Wind Direction to 13N-90.00W

Year	Average	Maximum	Minimum	Mode	Estándar Deviation
1997	134	360	0	360	99
1998	158	360	0	270	102
1999	141	360	1	270	107
2000	129	360	0	90	105
2001	119	360	0	45	98
2002	123	360	0	90	96
2003	141	360	0	360	109
2004	146	360	0	39	113
2005	167	360	0	34	112
2006	152	360	0	27	112
2007	157	360	1	196	108

When performing a seasonal analysis of the entire time series and separate the dry and rainy season, we can see that the wind direction (in terms of mode) in the dry season is different from the rainy season. This can be corroborated in tables 5.17 and 5.18, where are the statistical data for 13N-88.75W and 13N- 90.00W. Looking at both tables we can see that for both nodes are the same values of mode for dry and rainy season, so it can be described as for the dry season mode is 45 °, which indicates a wind coming from Northeast (NE) and the rainy season's Mode direction is 90 degrees, which indicates a wind from the east (E).

Table 5.17 .- Statistical Season to 88.75W 13N for the entire time series total

Season	Average	Maximum	Minimum	Mode	Estándar Deviation
Dry	122	360	0	45	108
Rainy	153	360	0	90	102

Table 5.18 .- Statistical Season to 90.00W 13N for the complete time series total

Season	Average	Maximum	Minimum	Mode	Estándar Deviation
Dry	127	360	0	45	107
Rainy	157	360	0	90	104

SWELL DIRECTION

ANNUAL ANALYSIS

For an annual review we have that the average and the mode of the swell direction remains almost constant throughout the years, this can be seen in Table 5.19, as a matter of fact, the standard deviation is less than wind direction at which the values of average direction can be taken as valid . Anyway, Mode is the most common value and the average hovering in the same direction, which is South-Southwest (SSW).

Table 5.19.- Swell Direction 13N-88.75W

Year	Average	Maximum	Minimum	Mode	Estándar Deviation
1997	200	242	7	207	34
1998	206	360	0	210	35
1999	201	358	0	205	41
2000	199	359	0	207	46
2001	194	359	0	205	48
2002	192	359	0	207	50
2003	189	359	1	209	54
2004	193	360	2	209	47
2005	197	356	0	206	41
2006	198	360	0	203	41
2007	200	359	0	205	34

Due to the similarity of data between two nodes for the annual review does not include a table for node 13N-90.00W

WAVE PERIOD

ANNUAL ANALYSIS

According to Table 5.22 and 5.23 it shows the statistical wave periods for node-13N-13N 88.75W and 90.00W. This can be seen clearly that for each year the average period corresponds to a sea of cam which are consistent with periods average total time series, that is supported with the values shown in fashion where most most repeated values correspond to periods of storm surges.

Table 5.22 .- Statistical annual periods 13N-88.75W (seconds)

Year	Average	maximum	min	mode	deviation
1997	12.7	19.7	3.1	13.3	2.5
1998	12.6	18.1	3	13.4	2.7
1999	12.8	19.8	3	13.3	2.7
2000	12.1	17.9	3	13.4	3
2001	12.4	19.7	3.1	13.3	2.9
2002	11.8	20	3.1	13.4	3.1
2003	12.2	19.7	3	13.3	3.3
2004	12.5	19.7	3.1	13.4	3
2005	12.5	18.1	2.9	13.4	2.7
2006	12.9	19.6	3.1	13.4	2.7
2007	12.8	19.5	2.7	14.7	2.7

Table 5.23 .- Statistical annual periods 13N-90.00W (seconds)

Year	Average	maximum	min	mode	deviation
1997	12.4	19.7	2.9	12.1	3.1
1998	12.4	19.5	3.1	13.4	3.1
1999	12.3	19.8	3	13.4	3.3
2000	11.7	18	3.1	13.4	3.5
2001	12	19.6	3.1	13.4	3.3
2002	11.4	19.9	3.1	12.2	3.5
2003	11.9	19.7	3.1	13.4	3.6
2004	12.1	19.8	2.8	13.6	3.5
2005	12.5	19.6	3.1	13.3	2.8
2006	12.8	20.1	3.1	13.6	2.9
2007	12.8	19.8	3.1	13.4	3.0

By linking all the previous analysis can be generalized with the period ,in the rainy season where there are longer periods, which means increased kinetic energy in the waves, possibly due to the magnitude of the swell at the time, because these periods as already was referring to a period is characteristic generated by distant storms or sea cam which produce higher waves, which is why in our rainy season, significant heights waves are bigger.

CONCLUSIONS.

We obtained sufficient information to characterize the wind and waves off the coast of El Salvador.

Factors that influence the vulnerability of a site are: its topography, strong winds, heavy rain, high tides and waves, overflowing of rivers (floods) these can be simultaneous as with the recent Tropical Storm Agatha, which was detected by model.

The model represents very well the surge (sea local, small period) is less with the wave height.

The swell has more speed and altitude than the local sea with small period and slow speed

Sometimes the model doesn´t detect local storm with wave from southeast of rapid development and sometimes very violent (gusts 45 km / h) They cause destruction in coastal areas.

When we have local storms with narrow radio and short term they generate strong winds but sometimes doesn´t affect too much the waves.

During the year our country is affected more frequently by South extra-tropical storms and seldom by northern extratropical storm

The local sea has the same direction of the storm, the swell is not in the same direction of the storm.

When we have storms or large systems over 120 kilometers and lasting several hours, for example the recent storm Aghata the model represents them.

The model is good to alert swell

The wave period is independent of height

The surface buoy located next the coast of Peru in 19 Degrees South and 85W is compare to validate the model on the values that arrive to our costs, because they are similar with ours with a difference of time.

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The waves on the coast of El Salvador for a period of 11 years can be characterized in two ways, waves near the coast and offshore. The waves next to our coasts, represented by the node13N-88.75W have a wave with an average significant wave height of 1.2 meters with an average direction of waves coming from the South-Southwest (197 °) and periods wave average of 12.5 seconds, a period that is representative for waves generated by storm surges or distant storms. As the wind direction have average wind speeds of 3.9 m / s and a direction represented by Mode from the north-east (45 °).

For the waves far from our shores, represented by the node13N-90.00W have a wave with an average significant wave height of 1.4 meters and an average direction of waves coming from the South-Southwest (192 °), the average wave period is 12.2 seconds which describes it as a swell waves. The average wind direction is 4.6 m / s in the direction represented by the Mode that comes from the East (90 °).

For the annual and monthly waves have certain characteristics and these are usually the months of April, May, June, July, August, September and October which is considered as our rainy season, significant wave heights are greater than average described above for 11 years. Particularly in the month of September is usually given when the largest wave heights, as this is the month where there were significant wave heights greater than 3 meters, which is considered as a wave end and high average values significant wave of 1.6 meters to surf off our coasts and 1.7 meters away from our shores. However, the wave period of waves in the month of September is the lowest when compared to other months of the rainy season. Apart from September, another month where wave heights are large compared to the other is in June, but with a difference with the month of September and in June the average wave periods are higher than September.

When comparing significant wave heights with the swell direction, one can clearly identify significant heights are greater when the wave comes from the South to West, than when it comes from the north to the east. For the months of April to October for both nodes the average direction is from the South-Southwest (SSW), while for the months of November to March the waves comes with a average direction of the South (S) or the Southeast (SE).

Relating the average wind speed with wind direction we have for the dry season the average wind speed is 4.3 m / s with a mode of direction of 45 °, which indicates a wind from the northeast (NE .) For the rainy season the average wind speed is 3.5 m / s with a mode of address 90, indicating that it is a wind from the East.

For the period, in the rainy season this one corresponds to period swells. For both nodes the average period is 13 seconds with deviations + / - 2 and + / - 2.4 for the node near and far, which we indicates which always corresponds to a swell. For the average period of the dry season we have a value of 11.6 + / - 3.8 seconds to the nearest node and 11.3 + / - 3.4 for remote node, this indicates that the average deviation less gives periods of less than 10 seconds for the local seas. Also when looking at monthly averages we have in December and January are most often swells with periods of less than 10 seconds.

According to the periodogram of energy made the 13N-90.00W node has higher values of power spectral density of wind speed that the node closest to our shores (13N-88.75W).

However, the spectral density of the node nearest to our shores is greater than that of 13N-90.00W. Another peculiarity is that wind speed has a ratio of power spectral density of 1:4 with respect to significant wave height / wind speed and a ratio of 1:10 with the node farthest from our shores.

You can check that the numerical model Wave Watch III can be useful as a tool for mitigating of extreme wave events and is applicable for our country, because it is a numerical model for predicting waves and fairly certain that when the model get high altitude wave, these usually coincide with events produced extreme tides and waves on the shores of our country.

Reviewing news of past events of destructive wave on our coastal , it was discovered that two of these dates coincide exactly with high waves in the model.Checking the accurate and important information of wind and waves obtained from the algorithm.