Wind waves variability in the Atlantic and Caribbean Sea.

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1. Introducción

Mexico has more than 11,000 km. of coastline, which are affected by extreme waves throughout the year. In the northern hemisphere winter, in the Gulf of Mexico and Caribbean Sea, there are observed wind waves associated with cold fronts, while in summer and autumn by easterly waves and hurricanes. Moreover, in the Mexican Pacific arrives swell associated with storms generated in the southern hemisphere. The nature of the origin of the waves reaching Mexico generates large variability, while in the Gulf of Mexico; the fetch caused by cold fronts does not change its direction significantly while crossing the Gulf of Mexico, but hurricanes does. On the other hand, given the persistence of the Caribbean low level jet (located at 925 mb), centered on 75 °W, 15 °N with winds greater than 15m/s in June and July, we expect a significant contribution to the variability of the wind waves (sea), with great impact on the Mexican Caribbean and Central American countries. The description of the variability (both in the ocean and atmosphere) observed in Mexican coast at different spatial and temporal scales will contribute to understand the origin of the sea and swell, evaluating and improvement the numerical simulations. In this paper we present the results of numerical simulations of 50 years (1960-2010). To analyze the seasonal, intraseasonal, and interannual variability in the Atlantic and Caribbean Sea, we performed 50 years of wind waves numerical simulations (1960-2010), using the WAM model with a resolution of 1 degree, it was forced dynamically with winds at 10m. from the NCEP Reanalysis data, its temporal resolution is 1 hr. The numerical model WAM (WAMDI, 1998) was used in version 4, integrating the transport equation, which describes the evolution of a two-dimensional spectrum of wave energy with respect to frequency and direction without any initial assumption about its spectral energy distribution.

2. Methods of analysis

2.1 Data

The winds used to force the model are from the NCEP Reanalysis database, available at: http://www.esrl.noaa.gov/psd/data/ncep_reanalysis. The zonal and meridional wind components at 10 m above the sea surface were used, with temporal resolution of 6 hours during the period 1960-2010. The bathymetry was extracted from the database *ETOPO 2*, with a resolution of 2 minutes.

2.2 Numerical simulations

We performed numerical simulations from January 1st, 1960 to December 31th, 2010, with a spatial resolution of 1° and temporal of two hours, however were averaged to obtain daily temporal resolutions, in the simulations, winds were updated every six hours, in a mesh located on the Atlantic Ocean, Caribbean Sea and Gulf of Mexico (5 ° N-35 ° N, 0 ° - 262 ° E) (Fig. 1).

2.3 Bathymetry

Bathymetry used (ETOPO2) with a resolution of 2 ° shown in Figure 1

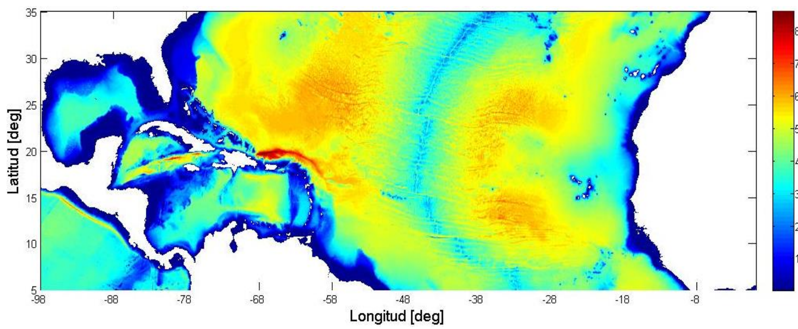

Figure. 1. Bathymetry (m) and mesh used.

2.4 Empirical Orthogonal Functions Analysis

Empirical orthogonal function analysis (EOF) was applied to calculate the main modes in the Atlantic, Caribbean and the Gulf of Mexico. The principal modes of variability was calculated to associate the wind waves spatial and temporal variability to the atmospheric local forcing, as the Caribbean low level jet, easterly waves, hurricanes and cold fronts, to do that, the two main modes was analyzed to explain the variability of the 50 years of simulations.

2.5 Wavelet analysis

Spectral analysis was used to identify the main frequencies and its atmospheric origin, wavelets are an extension of the spectral analysis, and the former includes oscillatory description in time scales, which helps to identify variances dates associated with maximum activity dates. The spectral decomposition of time series determines both the dominant modes of variability and the variation of these modes in time.

3. Results

In the Caribbean and Atlantic Ocean, the wind distribution in July were used to identified the Caribbean jet and the trade winds (Fig. 2), which are expected to generate impacts on wind waves.

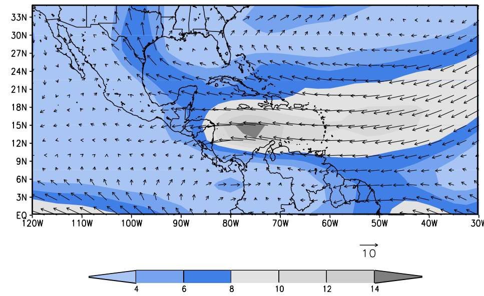

Figure 2. Mean wind (m.) at 925 mb (1960-2009).

As an example of the WAM model performance, we show the mean Hs in summer 1960-1964, which identifies events that generate clear wind patterns as the trade winds, without significant change direction. Maximum heights area is located in both the North Atlantic and in the Caribbean Sea, with mean values of 2.4 m (Fig. 3), its maximum match the location of the Caribbean low level jet (Fig. 2) and the trade winds (see Fig. 2), less intense but persistent. For the summer time, the greatest wave activity is observed in the Caribbean, with 2.4m values in regions where the jet reach 15m / s in July, on the other hand, in the trade winds region, the wind waves are lower, with 1.5m height, with large areas of influence (10 ° N - 15 ° N and 20 ° W - 60 ° W) (Fig. 3).

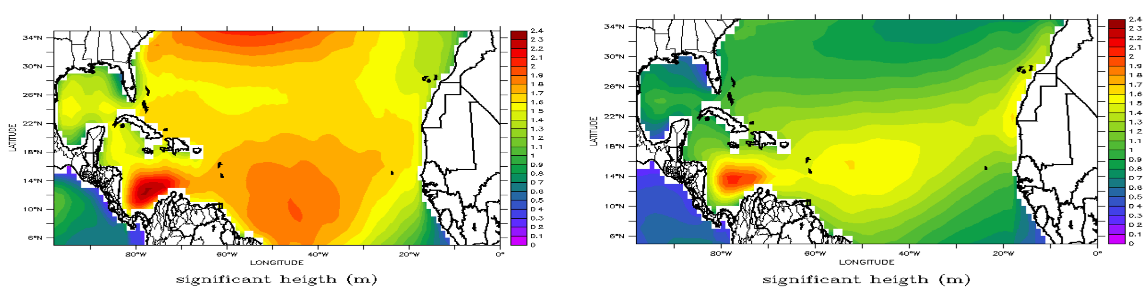

Figure 3. Wind waves simulated for winter and summer (1960-2009).

The 90th percentile for winter shows two relevant areas: the North Atlantic and the Caribbean Sea (Fig. 4), with heights between 3m and 3.4m. In the central Atlantic intermediate values are observed (2.5m). For the summer time, in the Caribbean Sea is observe the highest waves (Fig. 4), with more than 3.4m.

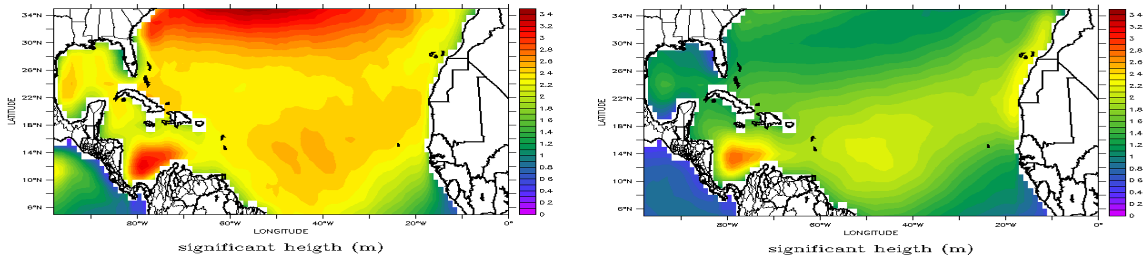

Figure 4. 90th percentile for winter and summer (1960-2009).

For the 10th percentile, in the Caribbean and Central Atlantic are located the maximum values in both summer and winter (Fig. 5) with highest amplitudes in winter.

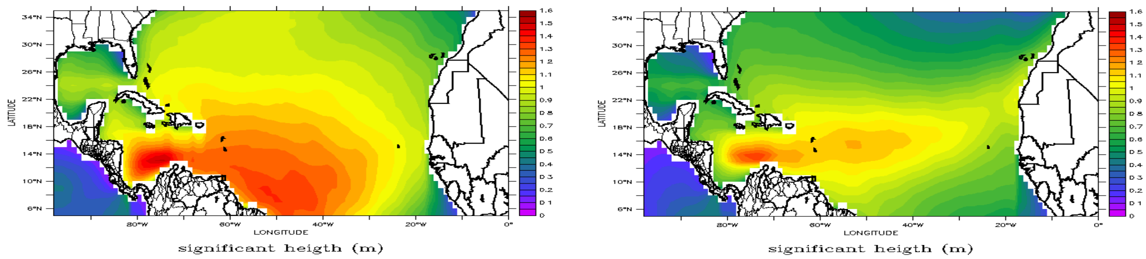

Figure 5. As in Fig. 4, but for 10th percentile.

For the daily data, the most important EOF, which explains 72% variability, was located in the North Atlantic (Fig. 6), the coefficients of the first EOF shows low time variability. There is a second region located in the Caribbean Sea, which has a jet- like structure (see Fig. 2).

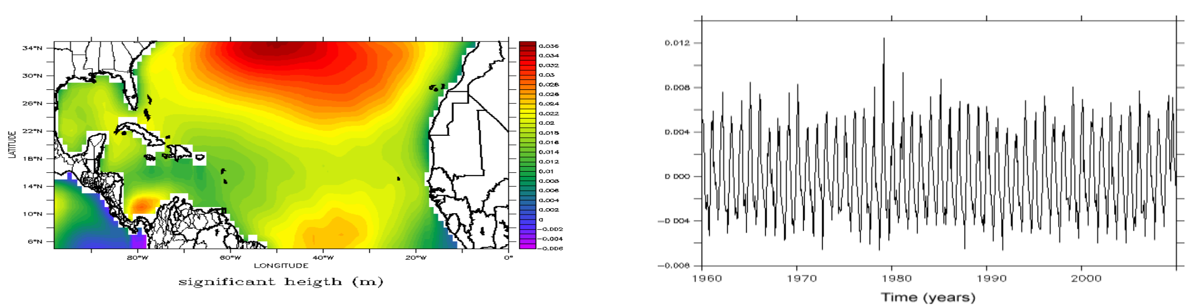

Figure 6. EOF1 (72%). 1960- 2009

For the second mode, (24%), the tropical area has more variability, showing trade winds and jet-like structures (Fig. 7), the persistence of both processes impact in the second mode, with low frequency variability (decadal) identified in the coefficients.

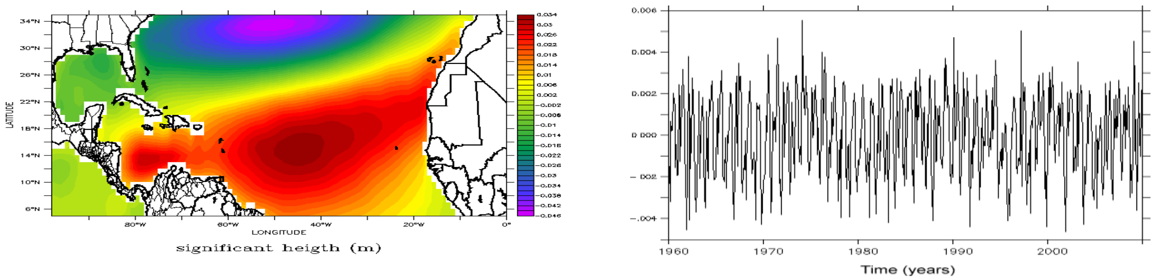

Figure 7. EOF2 (24%). 1960- 2009.

For the winter time, the greatest positive variability for the main mode (99.6%) is identified in the North Atlantic area, and the negative one in the tropical area (Fig. 8), where the activity is reduced in winter, easterly waves and cyclones are met only in summer and autumn.

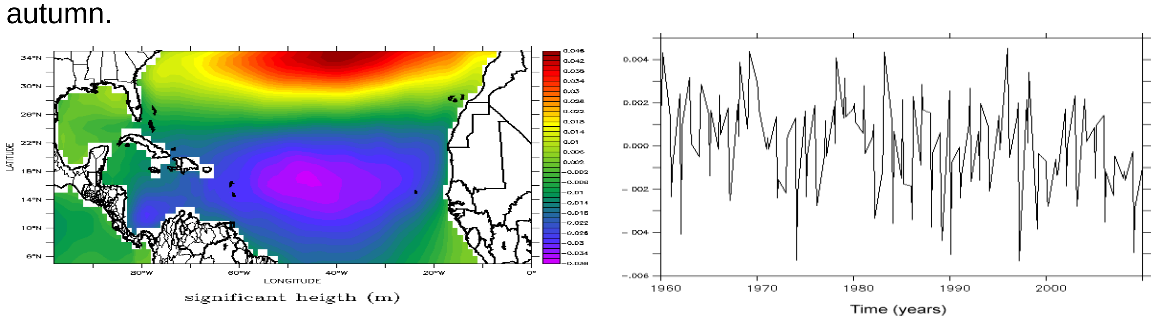

Figure 8. EOF1 winter (99.6%). 1960- 2009.

On the other hand, for the summer time, the first mode (62%), in the Atlantic is not related to the tropical processes (Fig. 9), but for the second mode the tropical activity is important (37.8%), from the equator to 20°N, including the Caribbean Sea, it is speculated that this activity is related to easterly waves, hurricanes and the Caribbean low level jet because of its position and seasonal activity.

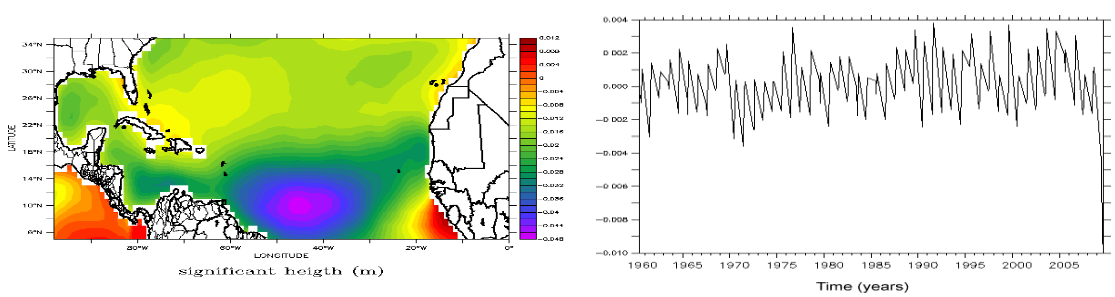

Figure 9. EOF1 summer (62%). 1960- 2009.

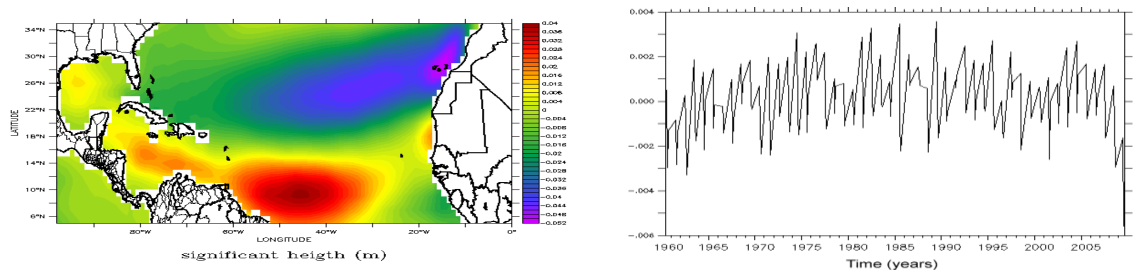

Figure 10. EOF2 summer (37.8%). 1960- 2009.

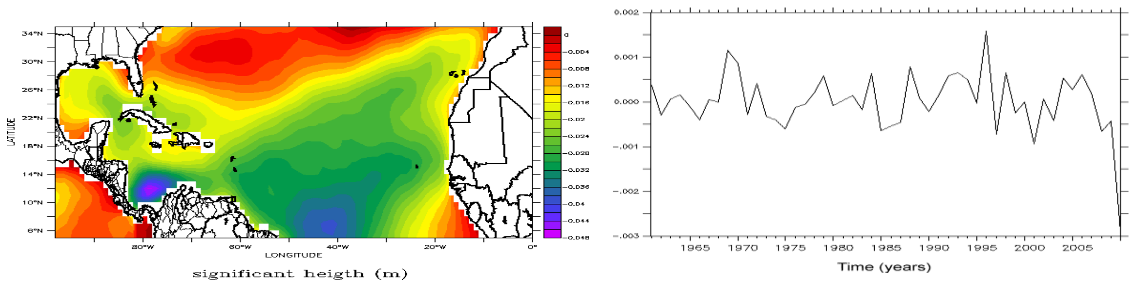

Figure 11. EOF1 annual (72%). 1960- 2009.

To identify the seasonal variability in active and in inactive years, we use two extremes coefficients showed in Fig. 11. For the first mode (1995: active year and 2009: inactive year), and for the second mode (Fig. 12) (1962: inactive year and 1976: active year). Within these years, a wavelet analysis was applied to analyze the main frequencies and the dates associated with this spectral distribution to compare the intra annual behavior in extremes years.

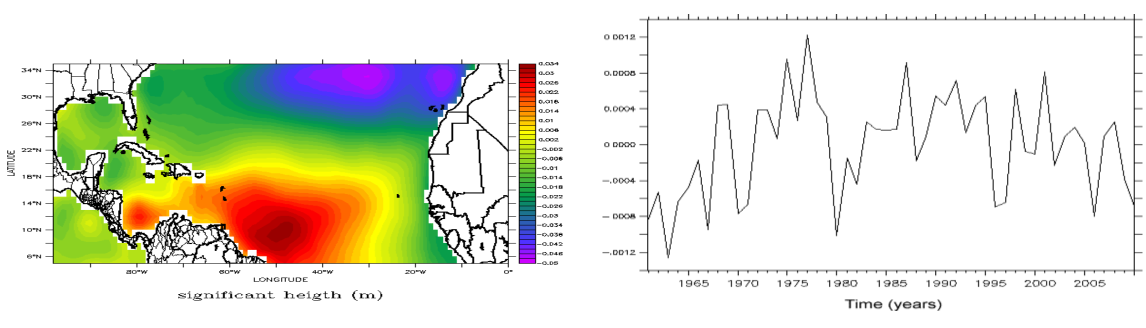

Figure 12. EOF2 annual (24%). 1960- 2009.

For the 50 years period (1960-2010), we selected three areas according with the EOF´s analysis: North Atlantic (25°N-35°N,20°W-70°W), the Caribbean Sea (9°N-18°N, 70°W-

82°W) and the Center Atlantic (9°N-18°N, 17°W-60°W).In each area we performed a wavelet analysis focusing in the high frequencies (1-15 days) to investigate the relationship in these years with the seasonal variability forcing (winds from the Caribbean jet, easterly waves and hurricanes) in the active and inactive years according to the first and the second mode (see Figures 11 and 12).

For the selected years (active and inactive using the first EOF criteria), we analyzed the contrast energy distribution, in the North Atlantic region, is clear the greatest activity from November to March, and the maximum scale are quite different in both years, the rest of the year becomes less active (Fig. 13 a)), in contrast, for the Caribbean Sea, with tropical activity, is greater in the selected active year (1976) than in the inactive year (1962), the summer and autumn influence is clear in the Caribbean and Central Atlantic (April to September, b) and c)), in both years the energy distribution is different and its maxima too.

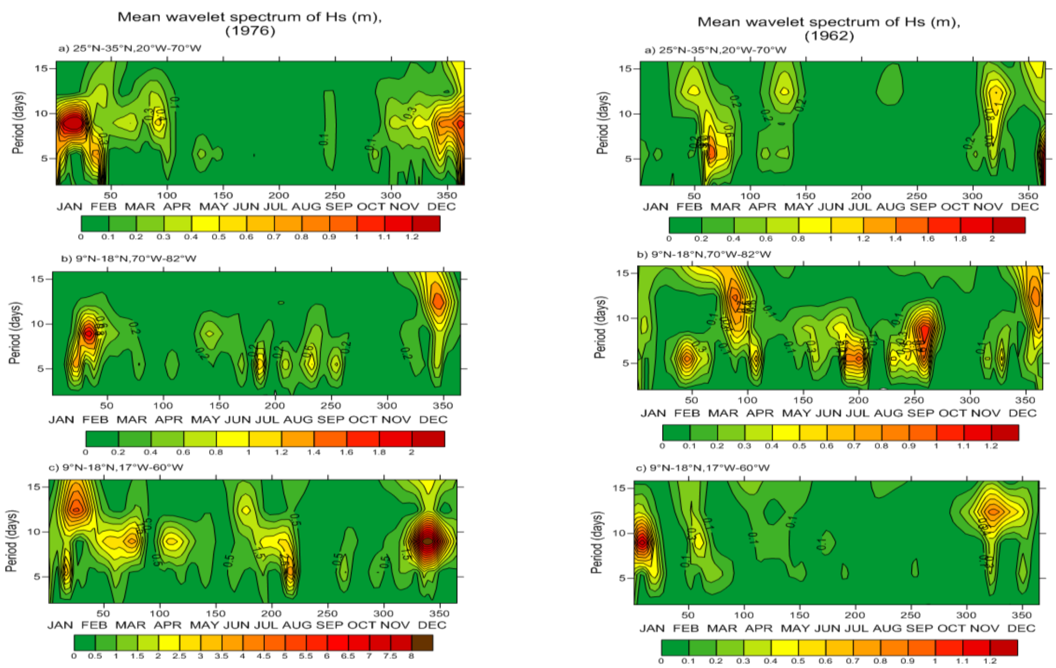

Figure 13. Mean wavelet spectrum for Hs: a) North Atlantic, b) Center Atlantic and c) Caribbean Sea. (1976 and 1962).

For the selected years identified as active and inactive (1995 and 2009 respectively) using the second EOF criteria, which affected the Caribbean Sea, the energy distribution contrast is clear in that region (Fig. 14 b)), in 1995 the frequency activity between 5 and 10 days (atmospheric easterly waves frequencies) is greater than for the rest of the frequencies, suggesting more energetic atmospheric waves in this year.

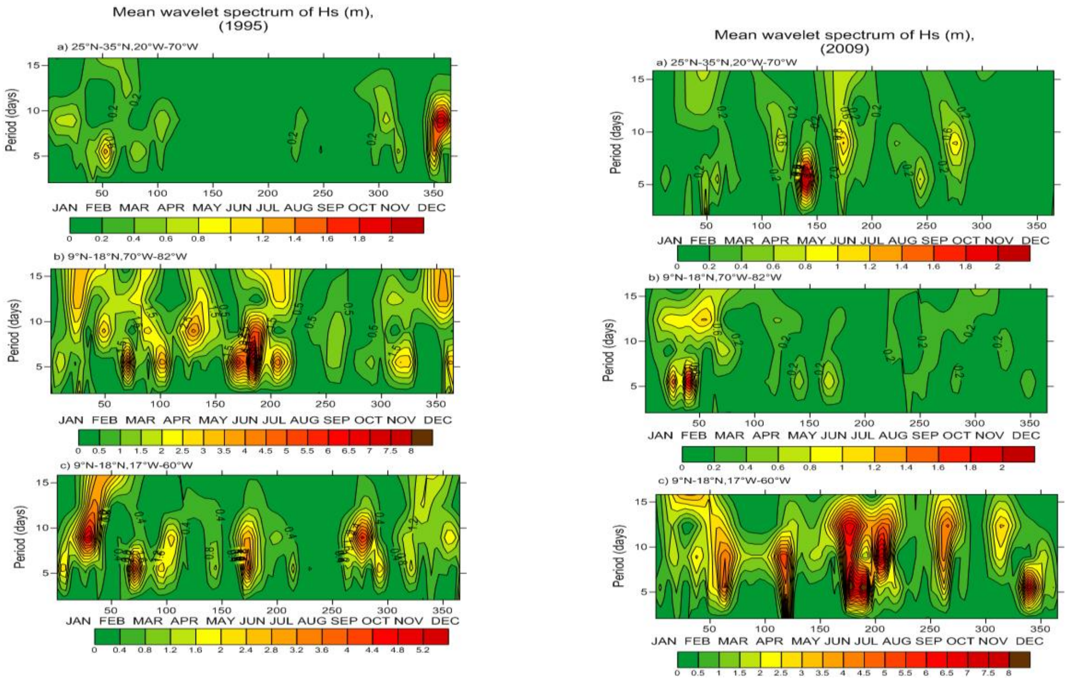

Figure 14. As in Figure 13, but for 1995 and 2009.

Conclusions.

The wind waves in the tropical Atlantic have different behavior as the extra-tropical area, for the former, three atmospheric processes was identified: trade winds, a low-level jet in the Caribbean Sea and easterly waves. In the mean significant height is clear the influence of the low frequencies (Caribbean jet and the wind trades) and in the wavelet analysis the impacts of the atmospheric perturbations was identified, as easterly waves.

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