CIENTIFIC Publishing Limited

Prevention and Treatment of Natural Disasters

http://ojs.ukscip.com/index.php/ptnd

RESEARCH ARTICLES

Dynamics of Hurricanes and Tropical Storms along the Pacific Coast of Mexico: A View from a Seismic Station

Vyacheslav M. Zobin*

Colima University, Colima, 28045, Mexico

Received: 28 June 2022; **Accepted:** 8 August 2022; **Published Online:** 25 August 2022

Abstract: This study presents the analysis of seismic signatures generated during passage of hurricanes *Newton* (September 2016) and *Willa* (October 2018), recorded on the daily helicorders of a short-period seismic station at the distances about 450 km from the tracks of events. This view from seismic station allowed to obtain the following results. Periods of passage of these tropical storms and hurricanes were identified. Analysis of the dynamics of sequences of these seismic signals allowed to separate the time intervals of increase and decrease in the development of atmospheric disturbances. The spectral analysis of the signals of tropical storm *Newton* and hurricane *Willa* showed that the spectral amplitudes of signals, recorded during the maximum stage of activity of the tropical storm, were larger than the same for the maximum stage of activity of the hurricane. This may be related to the presence of intensive hailstorms during tropical storm.

Keywords: Seismic signal, Tropical storm, Hurricane, Rainfall

1. Introduction

Hurricane is a tropical atmospheric closed circulation [1]. The term *hurricane* is used for Northern Hemisphere tropical cyclones east of the International Dateline to the Greenwich Meridian. As usual, the hurricane is developed from the *tropical storm*, representing a *tropical cyclone* in which the maximum sustained surface wind speed ranges from 63 km/h to 119 km/h (Glossary of NHC Terms, National Hurricane Center, https://www.nhc.noaa.gov/aboutgloss.shtml). When the wind speed exceeds 119 km/h, the cloud-free hurricane eye (Figure 1) typically forms because rapidly sinking air at the center dries and warms the area. The eye-wall, surrounding the eye, is composed of dense clouds that contain the highest winds in the storm [1]. The Saffir-Simpson Hurricane Wind Scale (SSHWS) defines hurricane strength by five categories. A category 1 storm is the weakest hurricane (winds 120 km/h ~ 150 km/h); a category 5 hurricane is the strongest (winds greater than 250 km/h) (Saffir-Simpson Hurricane Wind Scale, https://www.nhc.noaa.gov/

*Corresponding Author:
Vyacheslav M. Zobin,
Colima University, Colima, 28045, Mexico;
Email: vzobin@ucol.mx

DOI: https://doi.org/10.54963/ptnd.v1i2.71

aboutsshws.php).

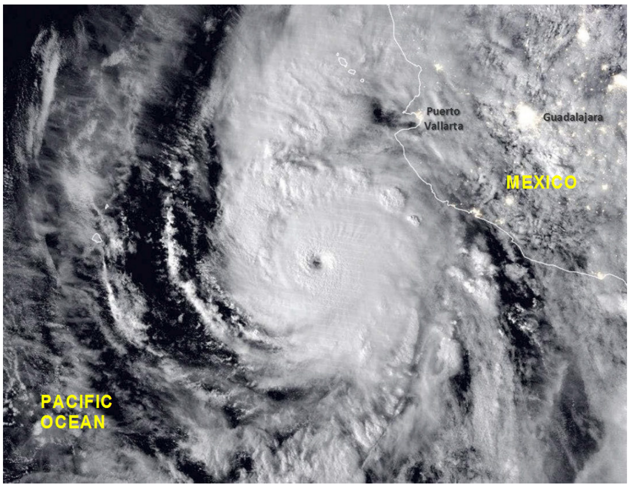

Figure 1. The satellite image, showing hurricane *Willa* approaching SW México. The NOAA-NASA Suomi NPP satellite image was taking on 22 October 2018 at 08:50 (UTC). Taken from Brennan [2].

The wind and rainfall, associated with the tropical storms and hurricanes, touching the ground may generate the seismic signals [3,4]. For a long time, the study of seismic signatures of atmospheric disturbances, cyclones, was based on analysis of the ambient seismic noise in the low-frequency range which allowed identification of cyclones and location of the storm position.

One of the first identification of hurricane was performed by Ebeling and Stein [5]. They showed that the August 1992 category 5 hurricane *Andrew* was detected using microseisms recorded at the Harvard, Massachusetts, analog seismic station. This sea storm was recorded at about 2000 km from the station. *Andrew* continued to generate microseisms for a long time before its final landfall located according to the position of the eye. Based on these results, a normalized microseism pseudo power amplitude in the 200 to 143 MHz passband was adopted to identify and characterize a seismically identified hurricane. Gualtieri et al. [6] showed the existence of persistent and frequency-dependent signatures of tropical cyclones in ambient seismic noise depending on characteristics of the storm and on the detailed location of the station relative to the storm.

The studies of excitation of seismic waves by atmospheric pressure changes during two tropical cyclones, tropical storm *Lee* (2011) and hurricane *Isaac* (2012), were performed basing on the low-frequency seismic signals in the range of 0.01 Hz and 0.02 Hz [7]. There were used the seismic and barometric data from the EarthScope network. The cyclones moved through this network after their landfalls. Seismic and surface pressure amplitudes showed a systematic decreasing trend with distance from the center of the hurricane. The decreasing rate was much higher for seismic waves than for pressure.

The surface-pressure solutions allowed to obtain some results about the behaviors of hurricane *Isaac* [8]. At the time of the landfall, the eye-wall existed at a distance of about 75 km from the hurricane center during approximately 10 hours after the landfall. In the following 24 hours, the eye-wall moved outward from the center of the hurricane to a distance of about 200 km ~ 300 km. At the end of this period (34 h after the landfall), the raw seismic data did not show any systematic, eye-wall-like signature.

The methodology of monitoring of the atmospheric events using the short-period seismic signals recorded by a sensor installed at a height of about 4 km above sea level at the summit of dormant volcano Nevado de Colima was proposed by Zobin [9]. This methodology included the indication of the seismic signatures of atmospheric disturbances on the daily helicorder displays of seismic signals with following analysis of waveforms, produced by the impact of rainfall drops and snowfalls with the ground surface, and their Fourier spectral characteristics. Then, the reconstruction of the passage of the atmospheric events, based on the power spectral densities of the one-hour seismic records, which was performed mutually with the satellite observations. The methodology was applied to study the passage of hurricane *Dora* and its preceding tropical storm (June 2017) and the cold front system number 25 (January 2018). Analysis of the spectral characteristics of these waveforms demonstrated that the rainfall drops, occurring during the tropical storm, hurricane, and the initial stage of the cold front passage, generated the seismic signals within the frequency range between 1.0 Hz ~ 1.8 Hz while the snow squall during the second stage of the cold front passage generated the seismic signals within the frequency range between 2.6 Hz and 3.7 Hz. The reconstruction of dynamics of the passage of the atmospheric events based on the power spectral densities of the one-hour seismic records allowed to see the comparable intensity of tropical storm and hurricane, and of two stages of the cold front.

In this article, a methodology of monitoring of atmospheric disturbances during tropical storms and hurricanes, proposed by Zobin [9], is applied for comparable study of hurricane *Willa* (HR) and a tropical storm (TS) that speeded up to hurricane *Newton*. For both events, the general description of development of atmospheric event, based on satellite observations, is presented. Then the processing of the seismic signatures of the passage of the atmospheric event and their Fourier spectral characteristics is applied. Finally, the reconstruction of dynamics of the passage of the atmospheric event, based on the power spectral densities of the one-hour seismic records, is realized. The data of observations, obtained during the passage of HR *Dora* [9,10], are used also for comparable characteristics of the events. The results are discussed from the point of view of specific generation of the seismic signals in the cases of tropical storms and hurricanes.

2. The System of Seismic Monitoring of Atmospheric Disturbances and Methodology of Analysis

The summit of dormant volcano Nevado de Colima (4,260 m), situated in Jalisco state, México at about 70 km from the Pacific Ocean coast (Figure 2A) and having low level of ambient seismic noise, was selected as a site for recording the drops of rain and snow, emitted during atmospheric disturbances. The tracks of hurricanes develop passing this volcano from the right side relative to the direction of their travelling. This side, as is noted in the NASA Hurricane Basics (http://hurricanes.noaa.gov), is characterized with the additive effect of the hurricane wind speed and speed of the larger atmospheric flow.

The seismic station EZV3, belonging to the seismic network of Colima University RESCO, was installed at the height of 3,957 m close to the summit of volcano (Figure 2B). The seismic signals were recorded by the short-period (T = 1.0 s) vertical-component analog sensor KINEMETRICS RANGER SS1 and then were digitized at 100 samples/s. The sensor was placed inside the booth located on the ground surface.

The arrival of atmospheric disturbances in a zone of sensitivity of a seismic station and their landfall activity were good seen on the daily helicorder displays of seismic records. In our study, one-hour seismograms (Figure 3A) were taken into analysis using interactive MATLAB software *Seismo_volcanalysis* of Lesage [11]. These one-hour records were used for study of the temporal development of atmospheric disturbances. For this purpose, the periodogram power spectral densities of each one-hour records, as is shown in Figure 3B, were calculated using a Hanning window. The selected good-written waveforms of seismic signals and their Fourier spectra were processed then with the program DEGTRA (https://degtra-a4-xp.updatestar.com/es).

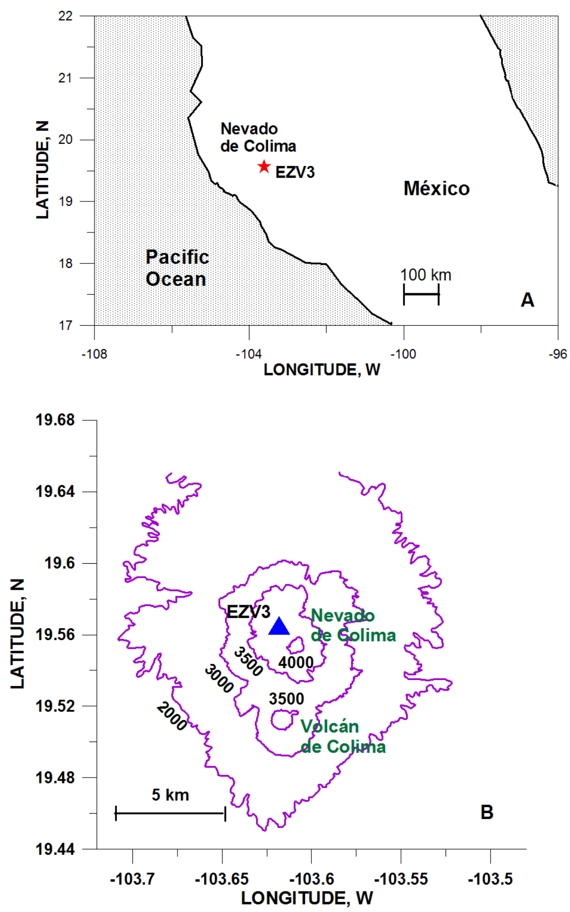

Figure 2. Position of the dormant volcano Nevado de Colima on the western coast of Mexico (A) and within the Colima Volcanic Complex together with the active Volcán de Colima (B). The seismic station EZV3 is shown as triangle. In B, the contour lines 2000 to 4000 m show the relief of the CVC.

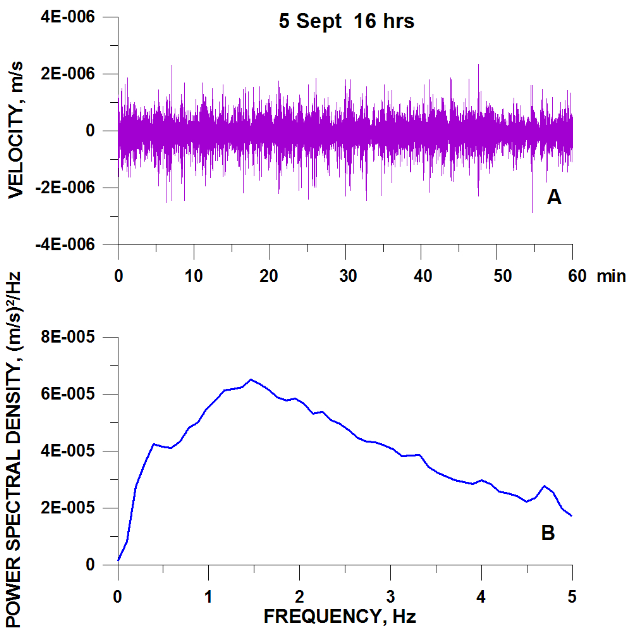

Figure 3. Example of the one-hour plot of seismic signals (short-period unfiltered seismic velocity waveforms) (A) during tropical storm *Newton* on 5 September 2016, at 18:00 hours, station EZV3 and their spectrum representing the periodogram power spectral densities vs frequency calculated using a Hanning window (B).

3. Descriptions of Atmospheric Events and Their Seismic Signatures during Two Hurricanes and Preceding Them Tropical Storms, Occurring along the Pacific Coast of Mexico in 2016-2018

Two hurricanes (*Newton*, September 2016; and *Willa*, October 2018) and their preceding tropical storms, occurring along the Pacific coast of Mexico in 2016-2018, are considered for this study. The information about them is presented in Table 1. Their tracks along the Mexican coast are shown in Figure 4.

As is seen in Figure 4, the tracks of TS-hours and the points of transition of TS into HR are different for them. They may be identified as passing near seismic station EZV3 at the stage of TS (*Newton*) and at the stage of HR (*Willa*). The strength of hurricanes varied from the SSHWS category 1 (*Newton,* maximum wind speed 148 km/hr) to category 5 (*Willa,* maximum wind speed 260 km/hr).

3.1 Hurricane *Newton*: 4 to 7 September 2016, TS Passed Near Seismic Station

3.1.1 Short History

The tropical depression, formed early on 4 September, strengthened into a tropical storm at 18:00 UTC 4 September while centered about 390 km south of Manzanillo, Mexico (Figure 4). The TS developed during 24 hours. It went through the period of rapid intensification and became a HR by 18:00 UTC 5 September at about 420 km west of the seismic station. The category 1 HR reached its peak intensity of 148 km/hr at 06:00 UTC 6 September when it was centered 670 km north-west of the seismic station. Then the intensity of HR weakened, and it became TS by 06:00 UTC 7 September [12].

3.1.2 Seismic Description of the TS and HR Development

Figure 5A demonstrates the helicorder displays of the seismic station for period from 4 to 6 September. As was noted above, the tropical storm was formed at 18:00 UTC of 4 September. This moment is marked on seismogram of this day with horizontal line. Seismic signals, produced by TS, began to appear at about 03:00 UTC of 5 September, 9 hours after the initial generation of TS, when the TS got closer to the seismic station, arriving at 350 km south-west from station. This arrival is marked as *1* on seismogram. Then they were changed with the signals of HR whose generation is indicated in the helicorder display of 5 October with horizontal line. This change occurred at 460 km from the seismic station (index *2* in Figure 5A). The signals of TS were recorded during about 20 hours (interval between *1* and *2* in Figure 5A). The time interval of recorded seismic signals of TS indicated that TS, preceding the HR *Newton*, passed about 445 km along the track, shown in Figure 4, with the mean speed about 22 km/h.

Table 1. General characteristics of hurricanes

Name of hurricane, dates	Stage of tropical storm	Stage of hurricane	Minimum pressure, mb	Maximum wind speed, km/hr	Category	References
Newton, 4-7 Sept 2016	4 Sept 18:00 – 5 Sept 18:00	5 Sept 18:00 – 7 Sept 06:00	977	148	1	Berg [12]
Dora, 24-28 June 2017	25 June 06:00 - 26 June 06:00	26 June 00:06 - 27 June 12:00	974	167	2	Berg [10]
Willa, 20-24 Oct 2018	20 Oct 12:00 - 21 Oct 06:00	21 Oct 06:00 – 24 Oct 00:00	925	260	5	Brennan [2]

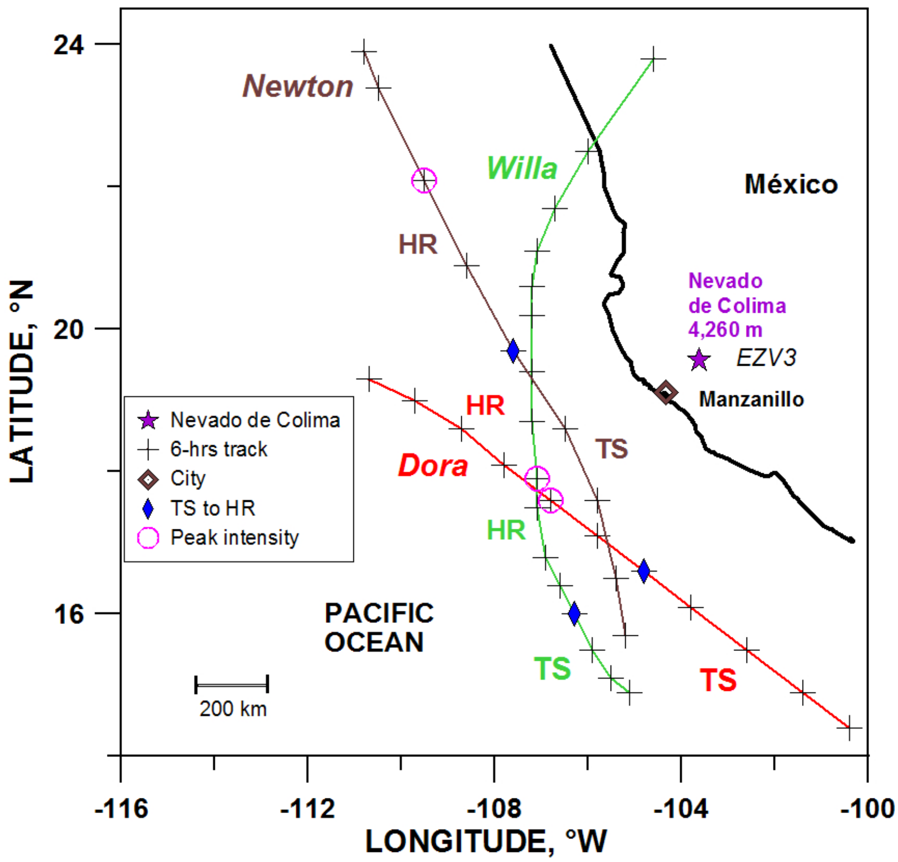

Figure 4. The tracks of hurricanes (HR) *Newton*, *Willa* and *Dora* and their associated tropical storms (TS) along the Western Pacific coast. Each of 6-hours duration parts of the tracks are marked with crosses. The moments of transformation of TS to HR are marked with rombos, the moments of peak intensity of the wind speed are shown with circles. The information about the tracks is taken from Berg [10,12] and Brennan [2].

A view of seismic signals, recorded during 5 September (Figure 5A), allows us to see that the tropical storm developed at least in three stages. The first stage of dense recording of signals continued from 03:00 to 07:00 UTC. Then the intensity of signals decreased and was of rather low level during next 4 hours. The last stage, from 11 to 22 hours, was the most long and intensive.

The seismic signals of HR began to appear in about 5 hours after the moment of the HR generation (index *2*). The signals of hurricane were recorded during the period between 22:00 of 5 September and 15:00 of 6 September (interval indicated in Figure 5A with *2* and *3*). Recorded at the distances greater than 460 km from the seismic station, they were significantly lower in their intensity than the signals of the first and third stages of TS. The signals disappeared from the helicorder display about 16:00 UTC of 6 September when the HR reached 960 km north-west from the seismic station.

Figure 5B demonstrates the variations in power spectral density (PSD) of seismic signals during the period between 4 and 6 of September together with variations of the wind speed and gives a quantitative view of the tropical storm and hurricane development. Vertical lines in Figure 5B indicate the moments of initial generation of TS and HR according to variations in the wind speed [12].

We can see that with the appearance of TS signals on seismogram, indicated with *1*, the values of PSD of recorded seismic signals increased from background level of $2.1e^{-5}$ to $6.1e^{-5}$ $(m/s)^2/Hz$ (Index *a* in Figure 5B). At the second stage of TS, the values of PSD decreased till $3.3e^{-5}$ units (Index *b* in Figure 5B). The third stage was the most intensive, gave two large peaks in PSD. This time the values of PSD increased up to $6.3e^{-5}$ units (Index *c* in Figure 5B). All these signals were recorded when the wind speed varied between 80 km/hr and 130 km/hr. At the same time, any direct dependence of the PSD amplitude of seismic signals, reflecting the intensity of TS landfall action, on the wind speed was not noted.

Hurricane was formed, as is seen in Figure 4, when the cyclone passed a long way from the seismic station, and the values of PSD, as is seen in Figure 5B, became too small for analysis of the hurricane development.

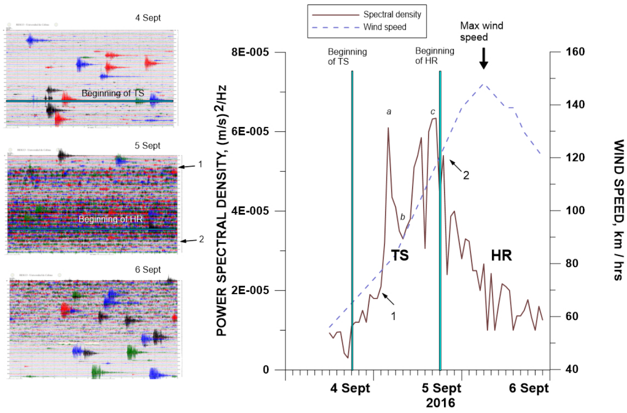

Figure 5. A view from seismic station on development of hurricane *Newton* and its preceding tropical storm. On the left (A), the daily helicorder displays of seismic signals (velocity, vertical component), recorded at short-period station EZV3, installed at the summit of the dormant volcano Nevado de Colima, are shown for 4, 5 and 6 September of 2016. There are indicated with horizontal lines the moments of beginning of the tropical storm (TS) and hurricane (HR). The moments of appearing and ending of seismic signals, generated by these events, are marked with arrows and numbers. The UTC time is shown in the right side of seismograms; the local time CDT is shown in the left side. In (B), the development of tropical storm and hurricane, expressed in the variations of amplitudes of power spectral density of one-hour seismic sequences, is shown together with variations in wind speed. Vertical lines indicate the moments of beginning of the tropical storm and hurricane. The moments of appearing and ending of seismic signals, generated by these events, are marked with arrows and numbers, the same as in A. Indexes *a*, *b* and *c* mark the stages in development of TS. The variations in wind speed are taken from [12]. The signals of earthquakes on seismograms are produced by explosive events of Volcán de Colima. They were not included in one-hour seismic sequences.

3.2. Hurricane *Willa*: 20 to 23 October 2018, HR Passed Near Seismic Station

3.2.1 Short History

The tropical storm, that speeded up to hurricane *Willa,* was formed by 12:00 UTC of 20 October at 520 km south-west from the seismic station and developed for 18 hours until 06:00 of 21 October, when the hurricane was born near the coast of NW México (Figure 4). The hurricane *Willa* developed for 66 hours and achieved of its peak intensity of 260 km/h, corresponding to the maximum category 5 of the Saffir-Simpson Hurricane Scale, by 06:00 UTC of 22 October at 410 km south-west from the seismic station [2].

3.2.2 Seismic Description of the TS and HR Development

Visual analysis of the helicorder display (Figure 6A) shows that the seismic signals, produced by TS, began to appear at about 20:00 UTC of 20 October, 8 hours after the generation of TS, when the TS arrived at 520 km south-west from the seismic station (Figure 4). The slight signals, associated with TS, were recorded for 15 hours (between indexes *1* and *2* on seismograms of Figure 6A), and then were changed with the signals of HR, which began to appear at about 13 hours of 21 October, 480 km south-west from the seismic station.

Seismic signals indicated two stages in development of HR. Initial stage, which continued for 18 hours from 13:00 of 21 October to about 07:00 of 22 October (between indexes 2 and 3 on seismograms of Figure 6A), was characterized by relatively slight seismic signals. The next stage (its beginning is marked with index 3 in Figure 6A) continued for 34 hours. It was represented with significantly denser signatures of the seismic signals. The seismic signals of HR disappeared from the helicorder display about 17:00 UTC 23 October when the HR reached 420 km north-west from the seismic station (index 4 in Figure 6A).

Totally, the signals of HR were recorded during about 54 hours (interval between *2* and *4* in Figure 6A). The time interval of recorded seismic signals of HR indicated that HR *Willa* passed about 545 km along the track, shown in Figure 4, with the mean speed about 10 km/h.

Figure 6B demonstrates the variations in power spectral density (PSD) of seismic signals during the described process. The variations in PSD show that TS developed as a single-stage process (marked between 1 and 2) for 12 hours and reached its maximum of PSD equal to $1.7e^{-5}$ $(m/s)^2/Hz$ between 22:00 UTC 20 October and 02:00 21 October.

Initial development of HR generally followed to the growth of wind speed. According to variations in PSD, the landfall of HR in the region of seismic station began at 13 hours of 21 October. During growth of the wind speed, there were observed three peaks in HR intensity. The first, with PSD equal to $2.6e^{-5}$ units, was recorded at 20:00 of 21 October. The second, with PSD equal to $3.1e^{-5}$ units, was recorded at 08:00 of 22 October, coinciding with the moment of maximum wind speed. The third, maximum, peak of PSD, equal to 3.6e^{-5} units, was recorded at 18:00 of 22 October, 12 hours after the wind reached its maximum speed. The second and the third peaks in PSD curve correspond to the second stage in development of HR noted in the above visual description of the seismic signals. Then the intensity of HR, represented in values of PSD, began to decrease, falling to 2.3e^{-5} units in the end of 23 October.

3.3 Comparable Characteristics of the Seismic Effects, Generated by Landfall of Products of the Tropical Storms and Hurricanes

The seismic signals, recorded during the tropical storms and hurricanes, are produced by the wind and rainfall drops when they are touching the ground. To study the relative effects of the wind and rainfall drops on generation of seismic signals, we compare the spectral properties of characteristic seismic pulses, generated during these atmospheric disturbances. For each event, same 12 pulses, recorded during maximum level of activity, were selected. Pulses recorded during maximum level of activity were selected. Their measurements are shown in Table 2. Figure 7 presents the characteristic triple pulses sequence, recorded during the peak stage *a* of tropical storm *Newton,* which was shown in Figure 5B. Figure 8 presents the same, recorded during the maximum peak stage of hurricane *Willa,* shown in Figure 6B.

The waveforms, shown in both figures, are similar in their durations and frequency content but their spectral amplitudes significantly differ. Figure 9A demonstrates these features of the signals. The spectral amplitudes of signals, recorded during the maximum stage of activity of the tropical storm, varied between 7.2e^{-7} m and 2.9e^{-6} m while the same for the maximum stage of activity of the hurricane are lower and varied between 2.6e^{-7} m and 9.5e^{-7} m.

Considering that the intensity of wind speed during HR *Willa* was undoubtedly higher than intensity of wind speed during TS *Newton*, and their tracks developed at the same distance from the seismic station (see Figure 4), this effect of higher amplitudes of seismic signals in the case of TS may be attributed to a difference in the nature of the rainfall during HR and TS. It is possible to propose that the rainfall drops during this TS were accompanied with intensive hail drops.

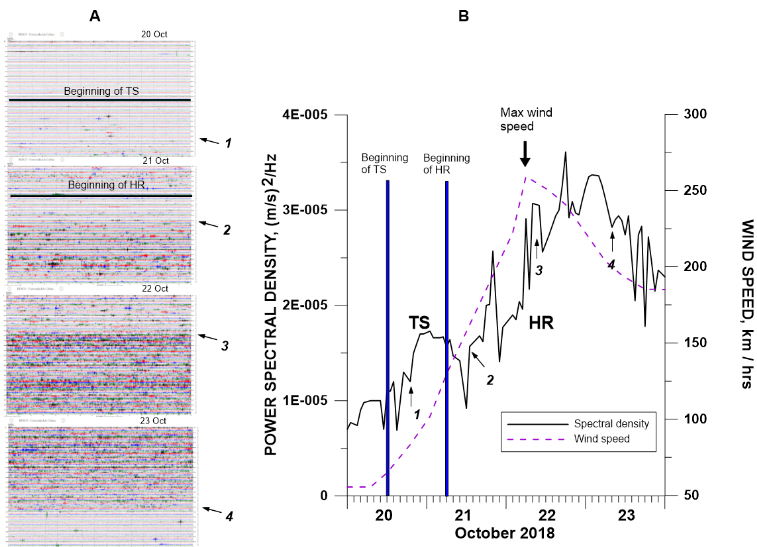

Figure 6. A view from seismic station on development of hurricane *Willa* and its preceding tropical storm. On the left (A), the daily helicorder displays of seismic signals (velocity, vertical component) recorded at short-period station EZV3, installed at the summit of the dormant volcano Nevado de Colima, are shown for 20 to 23 October 2018. There are indicated with horizontal lines the moments of beginning of the tropical storm (TS) and hurricane (HR). The moments of appearing and ending of seismic signals, generated by TS and different stages of HR, are marked with arrows and numbers. The UTC time is shown in the right side of seismograms; the local time CDT, in the left side. In (B), the development of tropical storm and hurricane, expressed in the variations of amplitudes of power spectral density of one-hour seismic sequences, is shown together with variations in wind speed. Vertical lines indicate the moments of beginning of the tropical storm and hurricane. The moments of appearing and ending of seismic signals, generated by TS and different stages of HR, are marked with arrows and numbers, the same as in A. The variations in wind speed are taken from [2].

Table 2. Spectral characteristics of impulses generated by raindrops

Date	Duration, s	Frequency, Hz	Amplitude, m
Hurrican *Newton*, tropical storm			
5 Sept 03:46	25	1.5	1.22E-06
	27	1.1	1.26E-06
	14	1.5	8.60E-07
5 Sept 11:52	8	2.7	1.00E-06
	8	1.8	1.00E-06
	9	1.3	2.90E-06
5 Sept 13:27	10	2.5	1.10E-06
	10	1.3	7.20E-07
	28	1.3	1.25E-06
5 Sept 17:56	28	2	1.80E-06
	19	2	1.00E-06
	15	2.2	1.00E-06
Hurricane *Willa*			
21 Oct 19:04	14	1.3	2.70E-07
	33	0.8	5.00E-07
	27	1.3	7.50E-07
21 Oct 19:14	14	1.3	2.60E-07
	18	0.9	4.80E-07
	31	1.6	5.20E-07
22 Oct 17:25	25	2.1	9.50E-07
	21	1.7	6.40E-07
	22	1.6	7.60E-07
22 Oct 17:47	50	1.2	8.60E-07
	28	1.2	5.00E-07
	17	1	9.00E-07

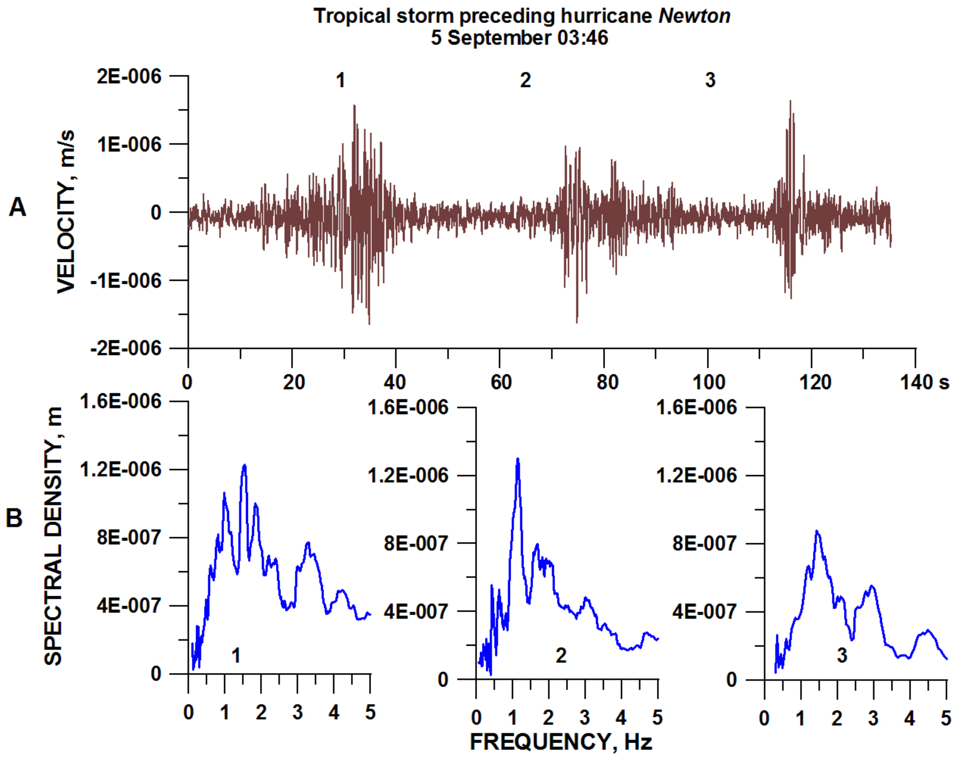

Figure 7. The short-period unfiltered seismic velocity waveforms, station EZV3 (A) and Fourier spectra of seismic signals (B) recorded during the action of the tropical storm preceding the hurricane *Newton* on 5 September 2016. 1, 2, and 3 indicate three seismic waveforms and their corresponding spectra.

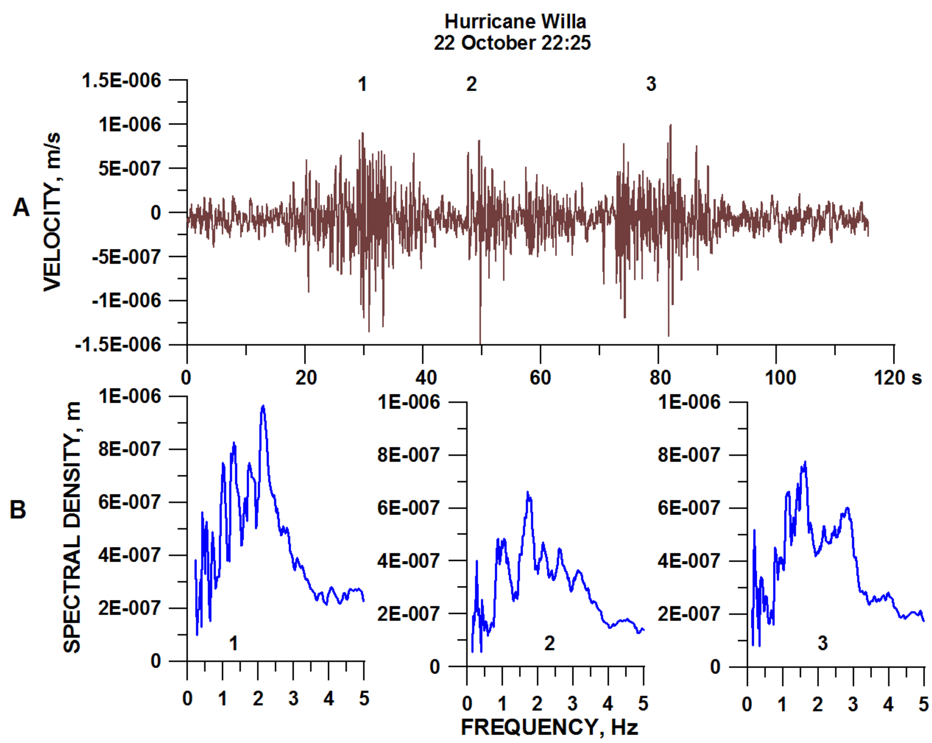

Figure 8. The short-period unfiltered seismic velocity waveforms, station EZV3 (A) and Fourier spectra of seismic signals (B) recorded during the action of the hurricane *Willa* on 22 October 2018. 1, 2, and 3 indicate three seismic waveforms and their corresponding spectra.

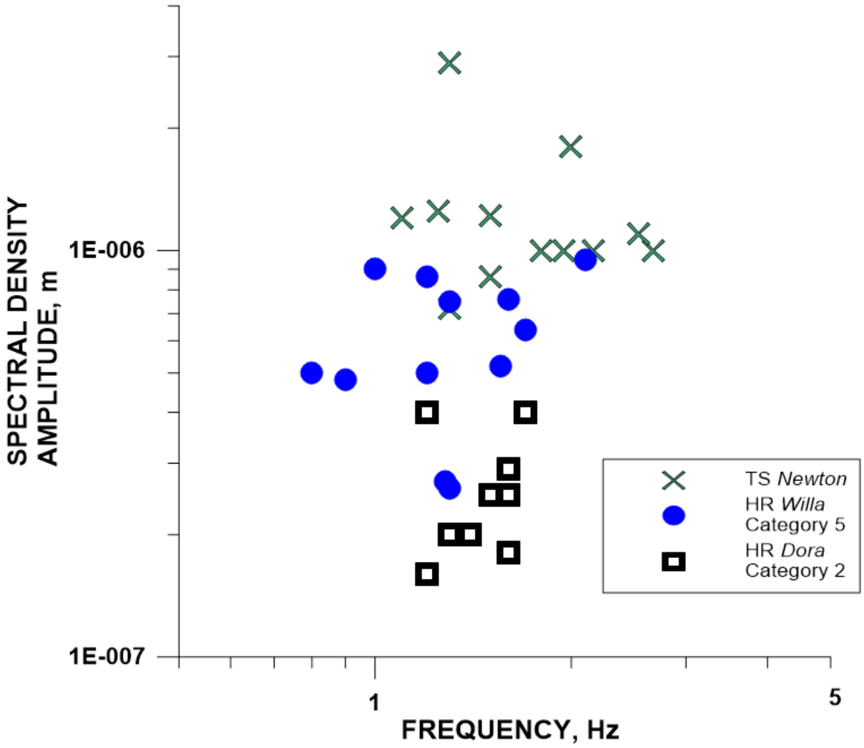

Figure 9. Plot of power spectral density vs frequency for characteristic waveforms recorded during tracks of the tropical storm preceding the hurricane *Newton* (crosses) and of the hurricane *Willa* (triangles) (A) and their comparison with the same characteristics of hurricane *Dora* and the pre-squall (open stars) and squall (stars) stages of the cold front 38 (B). Data about the hurricane *Dora* and the pre-squall (open stars) and squall (stars) stages of the cold front are taken from [9].

4. Results and Discussion

A view from near-situated short-period seismic station on the atmospheric disturbances during tropical storms and hurricanes of *Newton* and *Willy* demonstrated the level of informativity recoverable from the seismic signals.

1) The seismic records allowed us to identify the passage of tropical storms and hurricanes, appearing in radius of about 350 km ~ 450 km from the station.

Comparing with the methods, based on the signals of low-frequency seismic networks, which were mentioned in Introduction [5,8], this our view from a single short-period seismic station does not allow to locate the passage of atmospheric disturbances but gives the option to follow the development of these events. Analysis of the dynamics of sequences of these seismic signals allows to separate the moments of increase and decrease of intensity of atmospheric disturbances.

2) Analysis of the spectral amplitudes of seismic signals, recorded during the maximum stages of activity of the tropical storms and hurricanes, gives possibility to compare the intensities of these atmospheric disturbances.

To better see the effects of difference in the spectral amplitudes of hurricanes, we added in Figure 9 the data [9] for HR *Dora*. This HR (its track is shown in Figure 4 and it is close to the track of *Willa*) had reached category 2, lower than HR *Willa* of category 5. As is seen in Figure 9, the spectral amplitudes of signals, generated by *Dora*, are lower than those, obtained from seismic signals of *Willa*. It shows that the spectral amplitudes of seismic signals may serve for relative category classification of hours.

As was mentioned in the section 3.3, while the spectral frequencies of the seismic signals, generated by TS *Newton* and HR *Willa*, were within the same range, the amplitudes of signals of TS were significantly higher than the same of HR (Figure 9). This effect may be related to the presence of intensive hailstorms during TS *Newton*.

5. Conclusions

This study demonstrates the informativity of the seismic signatures of short-period station recorded during near passage of atmospheric disturbances. They may serve as a valuable addition to meteorological observations of these events.

Acknowledgements

The comments of anonymous reviewer helped us to improve the manuscript. I thank the personnel of seismic network RESCO of Colima University and their head

Rául Arámbula for providing me with the seismic records of the station EZV3. The processing of the digital seismic signals was realized using the program DEGTRA provided by Mario Ordaz, UNAM and the Interactive MATLAB software *Seismo_volcanalysis* for the analysis of seismic volcanic signals prepared by Philippe Lesage (Lesage, 2009) and adapted by Miguel Gonzalez.

Conflict of Interest

There is no conflict of interest.

References

[1] Hurricane basics, 1999. National Hurricane Center. http://www.nhc.noaa.gov.

[2] Brennan, M.J., 2019. Hurricane Willa, 20-24 October 2018. Tropical cyclone report. National Hurricane Center. pp. 29.

[3] Diaz, J., Ruiz, M., Crescentini, L., et al., 2014. Seismic noise generated by rainfall, snowmelt and floods on a Pyrenean mountain river. Abstracts, EGU General Assembly Conference.

[4] Dean, T., 2017. The seismic signature of rain. Geophysics. 82, 53-60.

[5] Ebeling, C.W., Stein, S., 2011. Seismological identification and characterization of a large hurricane. Bulletin of the Seismological Society of America. 101, 399-403. DOI: https://doi.org/10.1785/0120100175

[6] Gualtieri, L., Camargo, S.J., Pascale, S., et al., 2018. The persistent signature of tropical cyclones in ambient seismic noise. Earth and Planetary Science Letters. 484, 287-294.

[7] Tanimoto, T., Valovcin, A., 2016. Existence of the threshold pressure for seismic excitation by atmospheric disturbances. Geophysical Research Letters. 43(21), 202-208. DOI: https://doi.org/10.1002/2016GL070858

[8] Tanimoto, T., Lamontagne, A., 2014. Temporal and spatial evolution of an on-land hurricane observed by seismic data. Geophysical Research Letter. 41, 7532-7538. DOI: https://doi.org/10.1002/2014GL061934

[9] Zobin, V.M., 2021. Seismic signatures of atmospheric disturbances as a tool for reconstruction of their dynamics. Geofis. Inter. 60(4), 332-355. DOI: https://doi.org/10.22201/igeof.00167169

[10] Berg, R., 2017. Hurricane Dora, 24 – 28 June 2017. Tropical cyclone report. National Hurricane Center. pp. 12.

[11] Lesage, P., 2009. Interactive Matlab software for the analysis of seismic volcanic signal. Computers Geosciences. 35, 2137-2144.

[12] Berg, R., 2017. Hurricane Newton, 4 – 7 September 2016. Tropical cyclone report. National Hurricane Center. pp. 25.