

The Coastal Flood Regime around Cuba, the Thermohaline Structure Influence and Its Climate Tendencies

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Abstract An analysis of the coastal flood behavior on Cuban shore area, the influence of the thermohaline structure and its trends is presented, using data archive information from the Cuban Institute of Meteorology, the Institute of Physical Planning and other sources. Weather events that have generated these floods (hurricanes, cold front systems, southern winds and extratropical system combinations) are described, taking into account the influence of ENSO event and thermohaline structure changes at the end of the XX Century. The coastal flooding behavior shows an increase in frequency and intensity in the last 40 years, as a consequence of severe event intensity and frequency growth, in coincidence with higher sea surface temperature, mixed layer depth and salinity on the Cuban surrounding waters. Most of the maximum values of thermohaline parameters were located around the Cuban Western Region, in coincidence with the most favorable area for tropical cyclone development. ENSO acts as an important modulator of the coastal flood occurrence over the Cuban territory. When it is active, its behavior influences on the frequency and intensity increase of winter floods, but inhibits the hurricane activity over the Cuban coastal zone. Hence, in this case, the coastal flood occurrence by hurricanes decreases and the other way around.

Keywords Coastal Flooding, Thermohaline Structure, Climate Change, Cuban Shoreline

1. Introduction

The Cuban Archipelago is often affected by extreme meteorological events, such as hurricanes, frontal systems and extratropical system combinations, which produce severe coastal flooding; hence it is necessary to investigate the time and space behavior of coastal floods and events that

generate them, and their trends, with emphasis on sensitive areas affected by these phenomena. Of particular interest is the evolution of thermohaline structure, given its influence on the development of tropical cyclones.

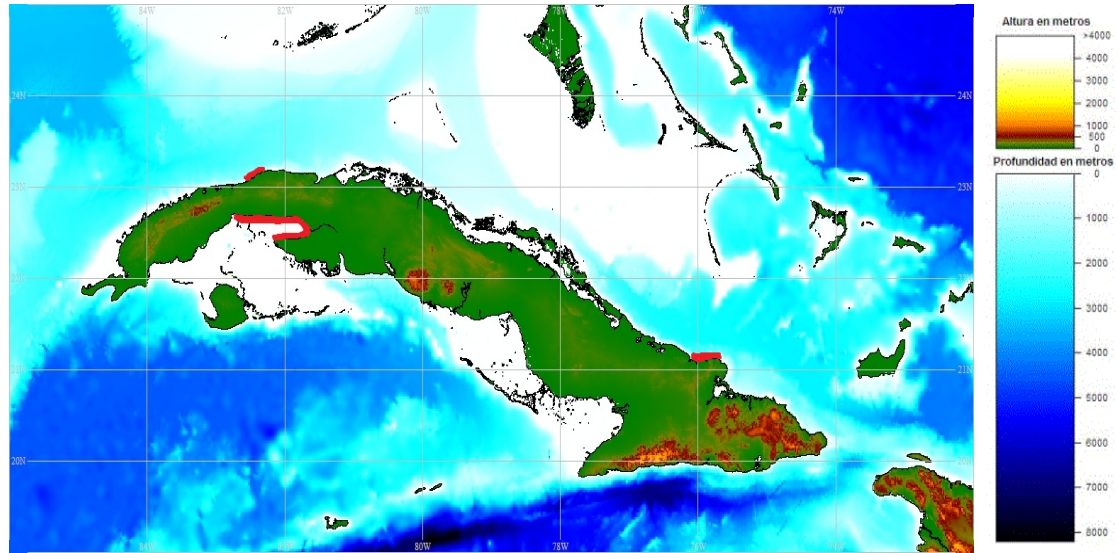
Cuba is one of the countries that would be seriously affected by sea level rise, under the influence of the expected climate change, given its island conditions, its geographical configuration and location, and the existence of many low-laying areas on its shore perimeter.

The country has over 5000 km of coastline. More than 10% of the population lives at a distance between 0 and 1000 m from the shoreline, located mainly in low-laying areas. Important cities with more than 20 000 inhabitants would also be affected by rising sea levels [1, 2].

Recent investigations demonstrated that sea level increase around Cuba during the last 40 years is between 0 y 0.214 cm year⁻¹ [3]. It is in correspondence with IPCC scenario of minimum sea level rise [4], but the possibility of occurrence of IPCC extreme scenario should not be ignored. Moreover, the extreme value of the sea level rise by the expected climate change (around 1 meter, according to the IPCC last report), could move the shore line inside some areas of the Cuban territory in one kilometer and more.

Considering the Cuban government concern about the possible future effects that could be brought about by the increase in coastal flood intensity and frequency, due the expected climate change, some scientific projects were executed to identify the most sensitive areas to this situation. The primary results are described by [1, 2, 5].

The main objective of this paper is to analyze some particularities of coastal flood behavior in some areas of Cuban territory and its trend, with emphasis on the occurrence of extreme weather situations. A brief description of thermohaline structure is also included. The obtained results are useful to make long-term contingency and integrated management action plans.



1) Havana Mole 2) Gulf of Batabano shoreline 3) Gibara-Guardalavaca shoreline

Figure 1. Bathymetry and topography of the Cuban Archipelago [6]. The study areas are marked in red.

2. Information Sources and Methods

Three coastal areas, among the most sensitive ones, are selected as study cases: Havana Mole, the Gulf of Batabano and Gibara-Guardalavaca (Figure 1). These areas are representative of all kinds of severe meteorological events that generate coastal flooding in Cuba.

Havana Mole area is extended from Havana Bay channel to Almendares River (Figure 2, taken from [7]). The coastline is rocky and abrupt in this zone, so it is very favorable to wave setup development. Mean tide value is around 30 cm, but some extreme values over 50 cm could be reported [8].

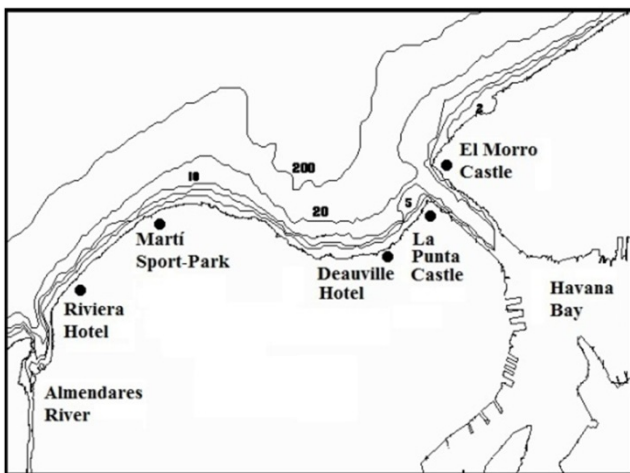


Figure 2. Havana Mole area (taken from [7]).

The Gulf of Batabano is a shallow and wide area with a very smooth topography, therefore it is favorable to sea level rise by wind setup and storm surge. The habitual astronomical tide values are around 20 cm, the smallest in Cuban shore areas, but some extreme ones, over 30 cm, have been reported [8].

The Gibara-Guardalavaca zone is significantly shallow, with a very smooth topography, although in some small

sections it is rocky and abrupt; hence it is generally favorable to sea level rise by wind setup and storm surge, but the wave setup effect can be significant in those small sections. This is the region of maximal astronomical tide values in Cuban territory; it is around 1 m in average [8].

Diverse information sources were used. The most important are the following:

- A. The coastal flood chronology, stored at the Center of Marine Meteorology (CMM) of Cuban Meteorological Institute (INSMET), for the period 1901-1914
- B. The meteorological synoptic maps, stored at the Archive of INSMET for the period 1919-1998.
- C. The datasets from oceanographic cruises, carried out in national waters by Cuban and foreign institutions (period 1966-2001), stored at INSMET.
- D. Other unconventional sources of historical evidences.

The meteorological event records were collected from INSMET and Institute of Physical Planning (IPF) archives, including old newspaper, personal testimonies, popular traditions and some traditional stories. INSMET map archive, ESRL reanalysis [9] and NHC archive [10] were consulted, to confirm the occurrence of meteorological events. Many cases from those data files were previously used by [1, 5, 7, 11-14], to obtain the return periods and other characteristics of coastal flood regime on the study zones.

Some cases had been discarded after analyzing all the testimonies, because the information is not reliable before 1975, the year of the CMM foundation at INSMET. Those cases of Havana Mole and Gibara-Guardalavaca records, that were classified at the CMM/INSMET archive and by [5] as moderate or strong, were included in the analysis; the main particularities of those cases was sea level rise over 1 m during the flooding process. The information from the Gulf of Batabano record was very incomplete, so only the very strong cases were included in the analysis. The record characteristics are shown in Table 1.

Table 1. Main characteristics of the study areas.

Study Area	Meteorological events that produce coastal floods	Principal components of sea level rise	Data File Period
Havana Mole	Hurricanes and frontal systems	Wave setup	1901-2014
Gulf of Batabano	Hurricanes and Southerly winds	Wind setup and storm surge	1901-2014
Gibara-Guardalavaca	Hurricane and extratropical system combinations.	Wind setup and storm surge, with smaller effect by wave setup	1960-2015

Table 2. ENSO index (IE) classification [15]

The ENOS index (IE) classification	
Weak	$IE < 48$
Moderate	$48 \leq IE \leq 360$
Strong	$361 \leq IE \leq 800$
Very strong	$IE > 800$

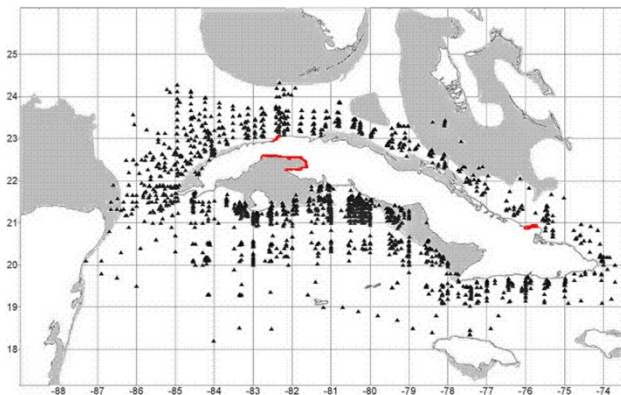


Figure 3. Distribution of the oceanographic stations, carried out in Cuban waters by 53 ship expeditions during the period 1966-2000

Images of synoptic re-analysis from [9] were used, as example of those atmospheric circulation patterns that produce floods on the Cuban shore area. Descriptions of those systems and hurricanes, presented as examples, were taken from INSMET and NHC archives [10].

ENSO (El Niño-Southern Oscillation) behavior influence was also analyzed, using the ENSO index deduced by Cardenas et al. [15] and the ENSO chronology from the

INSMET Climate Center archive, from 1980 to 2013, as it is recommended by Hernandez and Garcia [12]. The IE classification is shown in Table 2.

The oceanographic station points and an analysis of the measured methods are shown in Figure 3 and in Table 2, respectively.

The following parameters were used to characterize the thermohaline structure during the hurricane season:

- a) Sea water temperature
- b) Isothermal layer thickness
- c) 26 °C isotherm depth
- d) Isopicnal layer thickness
- e) Salinity maximum
- f) Salinity maximum depth
- g) Water mass vertical distribution

The Levitus criteria [16] were used, to determine the isothermal and the isopicnal layer thickness, (the difference between the surface level and the inferior boundary were 1°C and 0.125, respectively).

Water mass analysis was made, using the TS-curve methods and the water mass classification recommended by [17, 18].

The annual and seasonal average maps of the thermohaline structure parameters were made, using the free available software Ocean Data View, as it is described in [19], over the GEBCO maps [6]. There are two seasons over the Cuban territory: rainy, from May to November, and not very rainy, from December to April [20].The hurricane season is included in the rainy season, and for this reason, only rainy season maps were considered in the present work.

Table 3. Measurement methods, used to obtain sea water temperature and salinity in Cuban surrounding waters.

Expeditions and work periods	Sea temperature measurement	Precision in °C	Salinity measurement	Precision in psu
Cuba-URSS expeditions, before 1970	Reversible thermometer on Nansen bottles	± 0.02	Laboratory processing, using Nansen bottle samples	±10 ⁻³
Cuba-URSS expeditions after 1970	Automatic sonde-bathometer	± 0.01	Automatic sonde-bathometer	±10 ⁻³
Cuban research vessel "Ulises" 1987-1993	Reversible thermometer on Nansen bottles	± 0.02	Salinometer, using Nansen bottle samples	±10 ⁻³
Cuban research vessel "Ulises", from 1996 Mexican research vessel "Justo Sierra" 1989	Conductivity-Temperature-Depth (CTD) Instruments	± 0.01	Conductivity-Temperature-Depth (CTD) Instruments	±10 ⁻³

3. Results and Discussion

3.1. Characterization of Coastal Flooding in Cuba

Coastal floods in Cuba are usually caused by severe weather events. Although it is known the existence of an active seismic zone in the Eastern provinces of the country, there is no historical evidence of significant flooding by tsunamis. All cases of severe flooding have been generated under the influence of meteorological factors.

Over the Cuban territory, the habitual wind regime is basically under the influence of the trade wind circulation. The average speed is 2.8 m s^{-1} , while in the predominant direction is 3.8 m s^{-1} [20]. As a result, there are usually good weather conditions. This normal regime is often altered by tropical systems (hurricanes, storms, depressions and tropical waves) and continental systems (cold fronts and extra-tropical cyclones). Other causes have been identified as non-pre-frontal depressions; the combined high and low pressure systems, waterspouts and tornadoes.

The peculiar geographical configuration of the Cuban Archipelago with long and wide areas of insular shelf, promotes the sea level rise by the influence of the seabed.

The most significant coastal floods are caused by tropical cyclones, frontal systems and Southerly winds associated with extra-tropical low circulations; the most affected areas are Havana Mole zone and the Gulf of Batabano shoreline [1]. These phenomena generate the strongest winds in the region and major changes in sea level in the coastal area [2, 20]. Moreover, combined centers of high and low pressure occasionally generate winds of the first quadrant, causing floods on the north of the Eastern provinces, especially in the Gibara- Guardalavaca coastal stretch [5].

3.2. Significant Events That Generate Floods on the Cuban Territory over the Last 30 Years

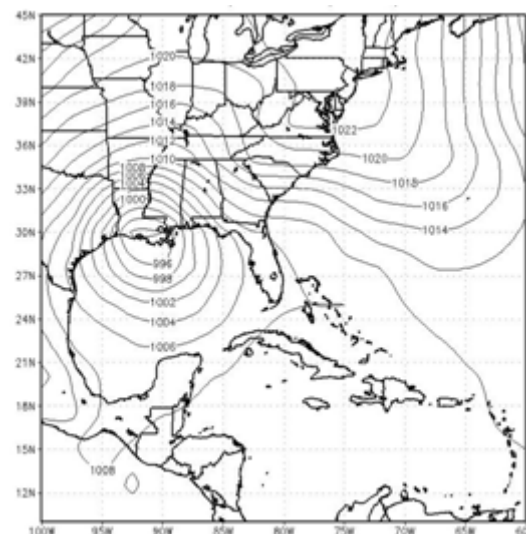
3.2.1. Hurricane "Juan" (1985)

It brought the lengthiest flood that has been reported in Havana city. It did not approach the Cuban coast, but its quasi-stationary position on the Southern coast of the United States, strong northwesterly winds with a long fetch and a persistence of 72 hours, led to the formation of heavy swells that hit the Havana coastline during three days. According to

[23], it originated in the central region of the Gulf of Mexico and reached hurricane strength of moderate intensity in the afternoon of October 27. On the 28th at 1200 z, its center was located very close to the State of Louisiana, making an erratic movement with a trace of two links in a long period of time, from early October 28 to the end of the next day (Figure 4 a).



a)



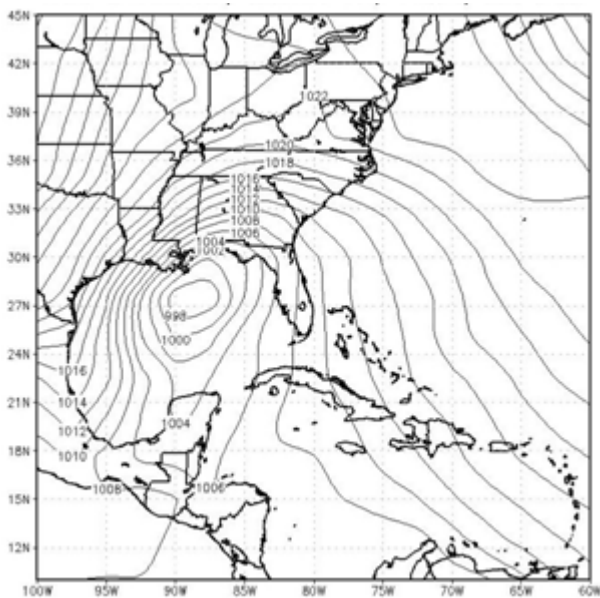
b)

Figure 4. a) Best track of Hurricane Juan, 1985 [23] b) Sea level pressure, October 30, 1985, 00 UTC [9]

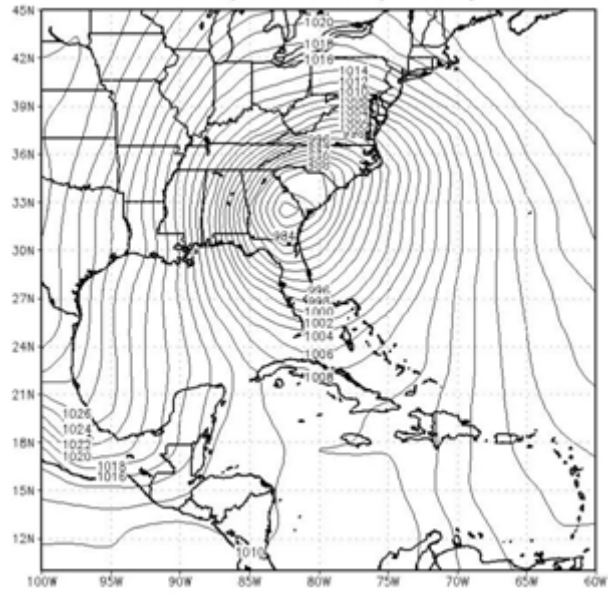
Its center remained in the vicinity of this area until October 30 at 00 UTC. This slow movement, coupled with an extensive sea level pressure field covering the area of the Gulf of Mexico almost entirely (Figure 4 b). The high wind wave generation areas persisted for a long time. Those waves affected the Cuban coast as swell with heights of 4- 6 m [21-23].

3.2.2. The Extratropical Storm of March 13, 1993, the Storm of the Century.

It was the strongest winter flood that occurred in Havana City during the 20th Century [21]. At the end of the morning of that day, severe coastal flooding were registered in the lower areas of the north-west zone, including Havana Mole, caused by an extratropical low pressure center, which was formed earlier. It developed abruptly in the northwest part of the Gulf of Mexico and began a rapid movement to the east and northeast, reaching the state of occlusion in less than 24 hours at the Northwest coast of Florida peninsula. It was a very unusual accelerated development for an extratropical cyclone. On the 12th, at 1800 UTC, the system had a minimum central pressure of 969 hPa. Some hours later, the circulation of the frontal area was propitious to the intensification of the Southern winds (Figure 5 a), whose speed over 12 m s⁻¹ generated severe flooding in the Gulf of Batabano shoreline by wind setup [2]. On the next day, at 6:00 UTC, the center position was around the 30° N and 83° W, near the northwest zone of Florida (Figure 5 b).



a)



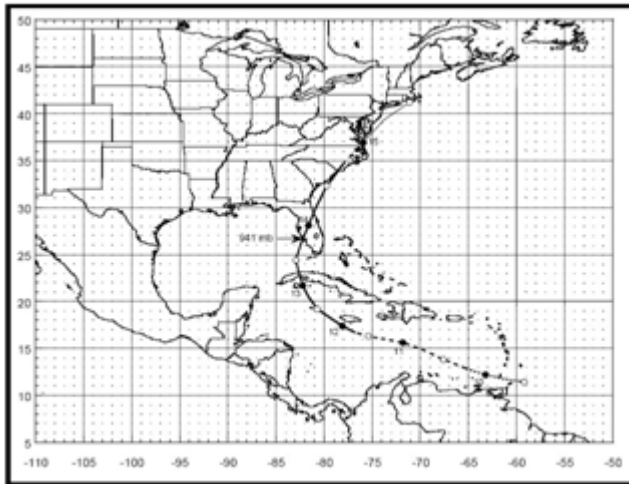
b)

Figure 5. a) Sea level pressure, March 12, 1993, 00 UTC [9] b) Sea level pressure, March 13, 1993, 06 UTC [9]

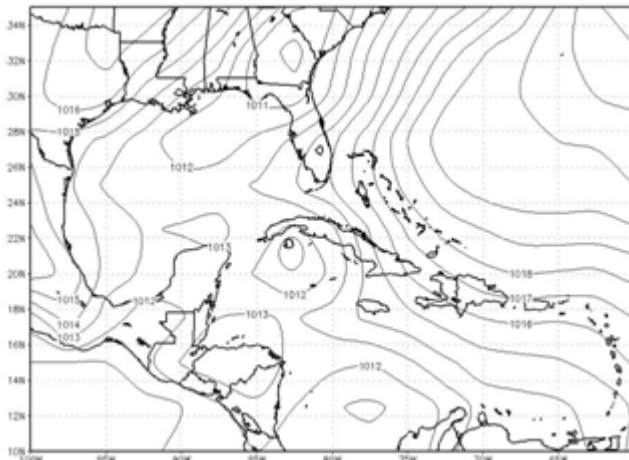
The northwest winds increased their speed to 25.2 m s⁻¹ and began to affect the eastern half of the Gulf of Mexico, where appeared a wind wave generation area between 25°-30° N W and 85°-90° W. The wind waves moved as swell, affecting the Cuban coast 12 hours later by wave setup. The low pressure center began to move to the northeast, causing an interaction between its extensive circulation field and that of the continental anticyclone, so the wind speed increased between 11.2 m s⁻¹ and 16.8 m s⁻¹ in this area. During this process, wind wave generation areas had also increased. The long fetch promoted the movement of the new wind wave trains and, when combined with the existing, caused the flooding persistence until the 14th. The waves in front of Havana Mole reached heights between 4 and 6 meters.

3.2.3. Hurricane Charley, 2004

This hurricane approached the Gulf of Batabano with north-northeast direction, entered Cuba through Playa Cajío at 4:30 UTC on August 13, 2004, and left the national territory from west of Havana City at 06 UTC, where intense winds with speed over 54 m s⁻¹, were reported (Figure 6 a, b). Charley remained on national territory only two and a half hours [24, 25]. The sea level rise by storm surge in Playa Cajío was over 2.5 m [13]; 630 houses were destroyed and only a doctor's office was left standing. The very low and nearly flat seabed favored the flood, with some contribution from the breaking surf and astronomical tide. Although the value of the astronomical tide in this area is less than 0.2 m in average [8], it reached over 0.3 m in that specific day [13].



a)

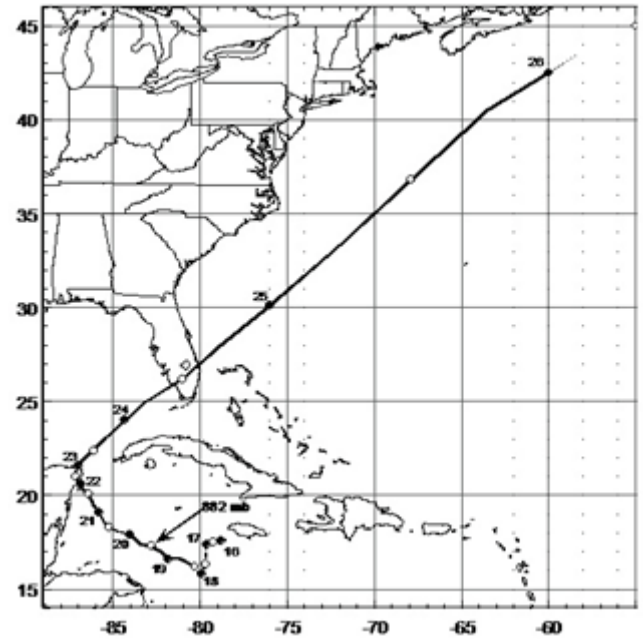


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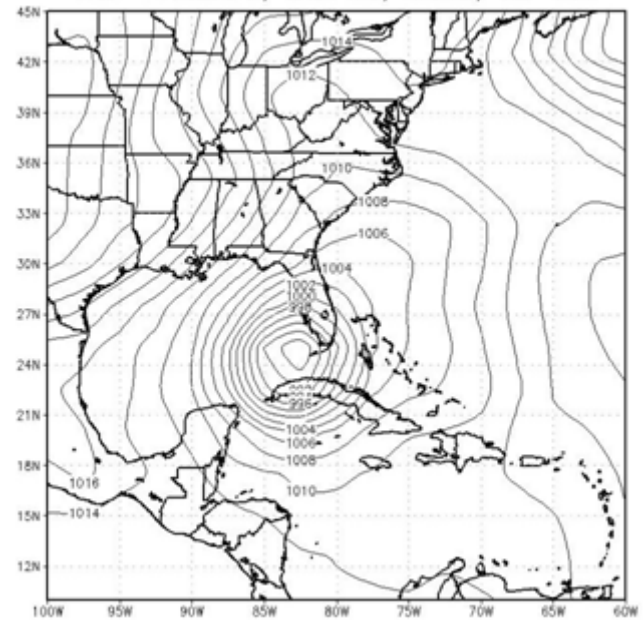
Figure 6. a) Best track of Hurricane Charley, 2004 [24] b) Sea level pressure, August 13, 2004, 00 UTC [9]

3.2.4. Hurricane "Wilma", 2005

This hurricane never touched Cuban land, as it is shown in its track (Figure 7 a). However, it generated a very destructive flood, which caused the highest economic losses in the history of Havana city, as reported in Granma newspaper in those days. Flooding at first occurred in low areas of the southern coast of Cuban territory, which were particularly notable on October 21, 2005 in the Gulf of Batabano shoreline [26, 27]. After his turn from the Peninsula of Yucatan to the Gulf of Mexico, it moved near the western Cuban coast and affected Havana on November 23 and 24. It caused a sea level rise over 2 m, by the combined effect of wave setup, storm surge and growing astronomical tide. In some points of the shoreline, the sea level rise reached more than 2.5 m. The flood lasted until the morning of October 25 and in some places, until the evening of that day. The circulation pattern that favored the flood is shown in Figure 7 b.



a)



b)

Figure 7. a) Best track of the Hurricane Wilma, 2005 [22] b) Sea level pressure, October 24, 2005, 06 UTC [9].

3.2.5. Combinations of extratropical systems

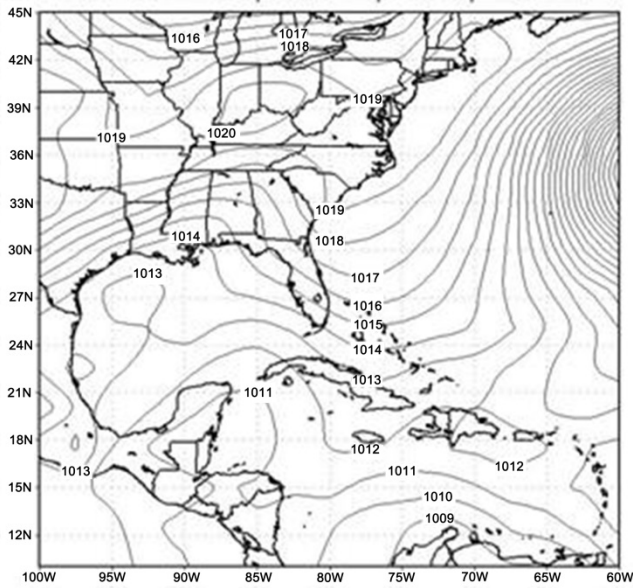
This kind of circulation sometimes generates very intense flooding on the north coastal areas of the eastern provinces (Figures 8 a, b, c). These combinations are the result of the interaction between a low pressure center, moving from the South of the United States or the North of the Gulf of Mexico to the Atlantic, and an anticyclone center from mean latitudes. As it was noted by [1, 5, 11], it is possible to identify the following synoptic patterns:

a) The high pressure center is located over the continent

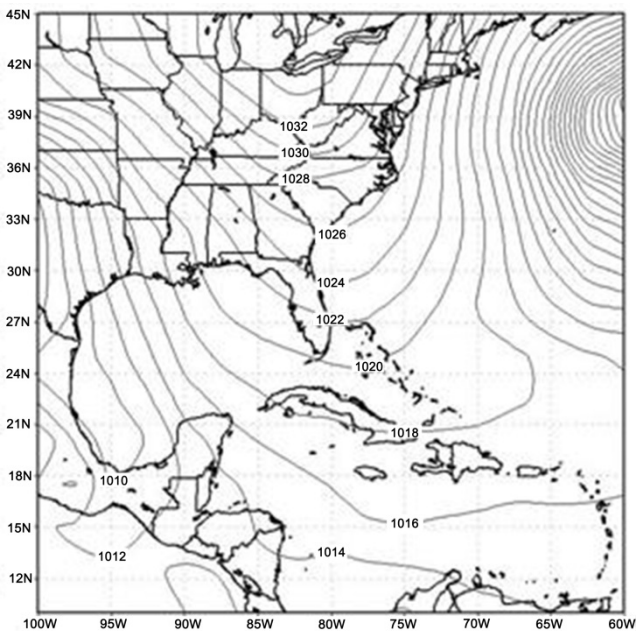
and the low pressure one, in the vicinity of the continental coasts, in mid-latitudes over the Atlantic. Flooding is generated by the winds of the periphery of the continental anticyclone (Figure 8 a).

b) The high pressure center is located on the ocean, near the West coast of the United States and a low pressure center in the Central Atlantic region, both between 30° and 40° N. The Cuban territory is under the influence of cyclonic circulation. Coastal flooding is generated by winds from the periphery of the anticyclone (Figure 8 b).

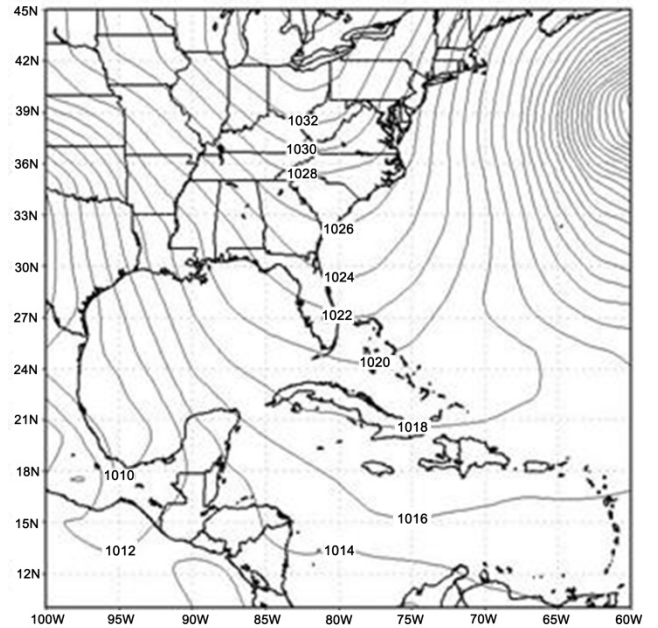
c) The high pressure center is located on land and the low pressure one, over the Atlantic; on the periphery of both centers the pressure gradient increases, which intensifies the wind. Coastal flooding is generated by northern winds associated with a cold front (Figure 8 c).



a)



b)



c)

a) Sea level pressure, October 12, 1982, 12UTC

b) Sea level pressure, March 22, 1998, 12 UTC

c) Sea level pressure, March 17, 2008, 06 UTC

Figure 8. Circulation patterns that generate coastal floods on the Cuban north-eastern provinces

3.3. The Coastal Flood Trends

The United Nations Development Program sponsored a project called "Development of Prediction Techniques Coastal Flood Prevention and Reduction of their Destructive Action", from 1994 to 1997 [1].

During the execution of this project, some researches were done to detect the settlements that could be affected by coastal flooding; at the end, a first version of the map of settlements that reported flooding was made. Subsequently, this map was updated in 1998, 2001 and 2007 by specialists from INSMET and IPF, during the execution of other two projects. Those versions were included in [1, 2, 12-14]. The latest update is shown in Figure 9. No new flooding points were reported until the present.

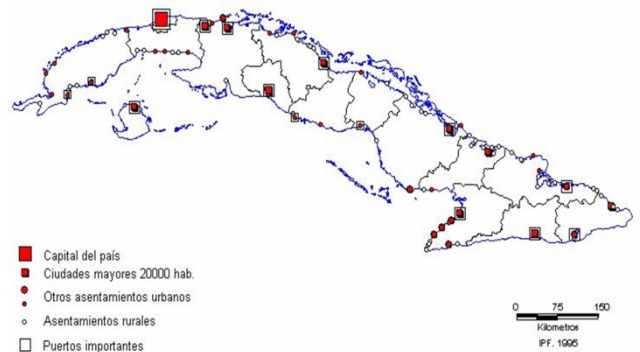


Figure 9. Settlements, where coastal floods cases were reported from 1901 to the current time

The behavior of the coastal flooding around Cuba shows an increase in frequency and intensity in the last 40 years. The best example is Havana Mole flood sequence, organized by decades from 1901 to 2014.

Gonzalez [28] shows a confirmation about an increase of cold front influence over the Cuban territory during the last decades, while in [29] it explains the existence of the same situation for the hurricane event sequence, but without statistical significance. Both this criteria are reflexed on the coastal flooding behavior, as it is shown on Figure 10 and 11. These graphical representations include the linear tendencies, which show a clear increase for both kinds of cases, with a frequency growth at the beginning of the 21th Century.

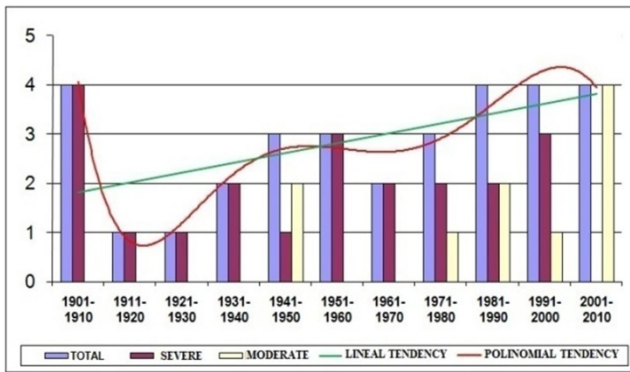


Figure 10. The winter coastal flooding tendencies in Havana Mole (1901-2013)

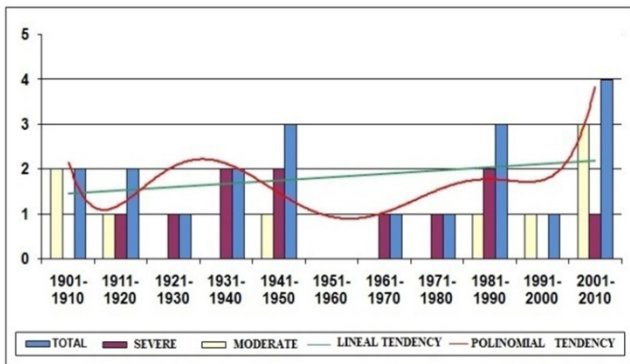


Figure 11. The coastal flooding tendencies in Havana Mole, generate by hurricanes (1901-2013)

The polynomial adjustment on Figure 10 and 11, shows a fluctuation, with periods of intense and moderate activity. A comparison between both graphical distributions shows that, in general, those polynomial lines are opposites and could be a consequence of ENSO influence.

During ENSO positive phase, the atmospheric circulation over the United State moves to low latitudes, so the extratropical system influence over the Cuban territory is stronger, but the hurricane season over the Atlantic area is weak and the tropical cyclone tracks rarely reach the Inter-American sea region. The inverse link is observed when the ENSO is in its neutral or negative phase [29, 30].

The link between the ENSO index and the coastal flooding occurrence is observed on Figure 12, were all the floods cases from 1980 to the current time were included (intense, moderate etc.)

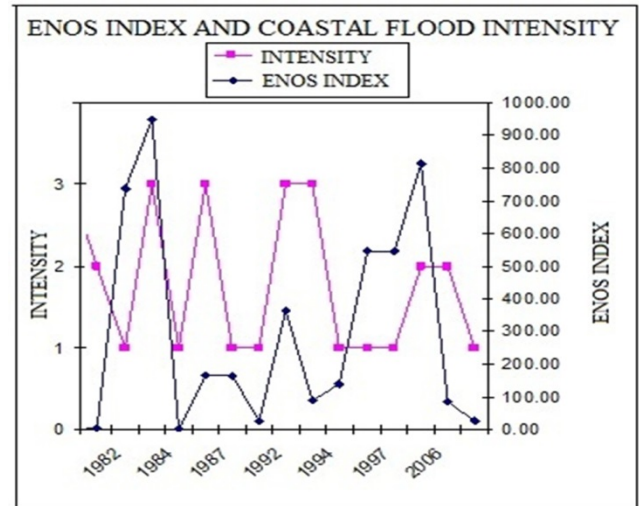


Figure 12. The ENSO index and the coastal flood occurrence (1980-2015).

- a) Blue line : ENSO index.
- b) Pink line: The coastal flood intensity, where the Intensity = 1 is for weak cases, Intensity = 2 for moderate cases and Intensity=3 for severe cases

The coastal flood behavior in the Gulf of Batabano and Gibara – Guardalavaca shorelines confirms the trends that were observed for the Havana Mole area (Figures 13 and 14).

In all the three series, a coincidence of low activity conditions is observed between 1951 and 1970. It is the same period, when global cooling and weakening of all systems in the global atmospheric and oceanic circulation were observed.

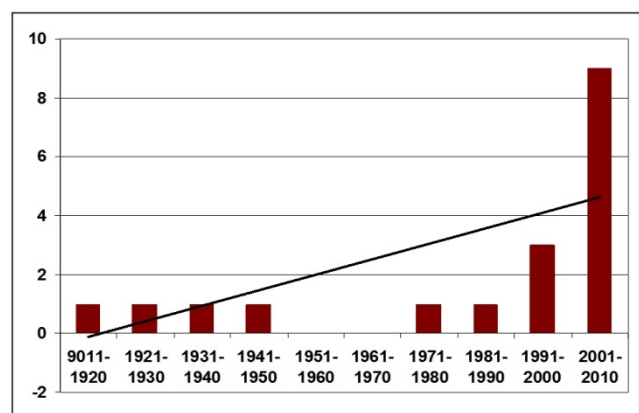


Figure 13. Tendency of the severe coastal flood occurrence (moderate and intense) in the Gibara-Guardalavaca shoreline from 1951 to the current time, by decades

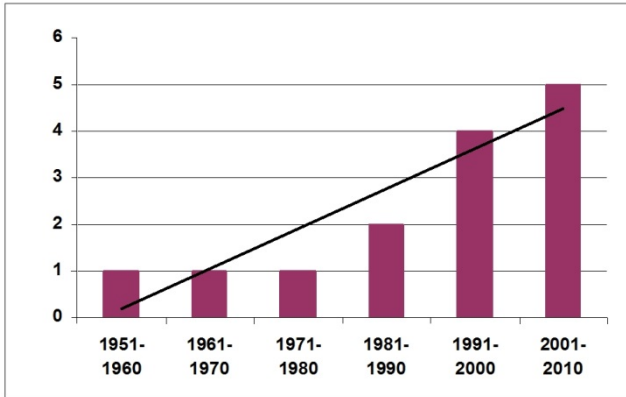


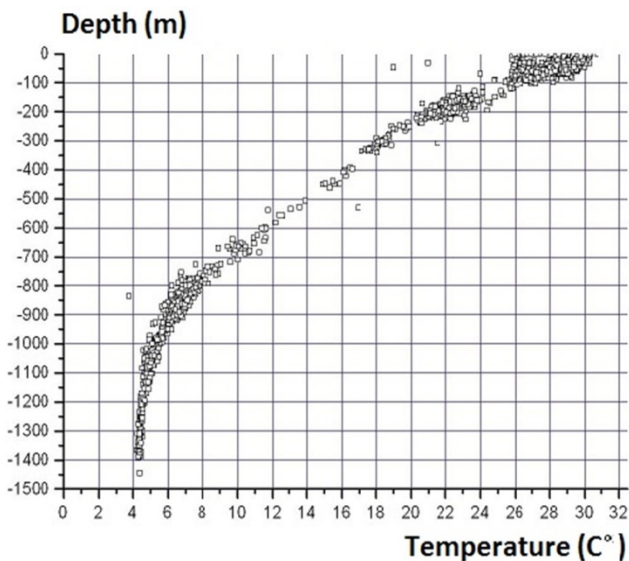
Figure 14. Tendency of the occurrence of very intense coastal floods in the Gulf of Batabano shoreline from 1951 to the current time, by decades

3.4. Changes on the Thermohaline Structure

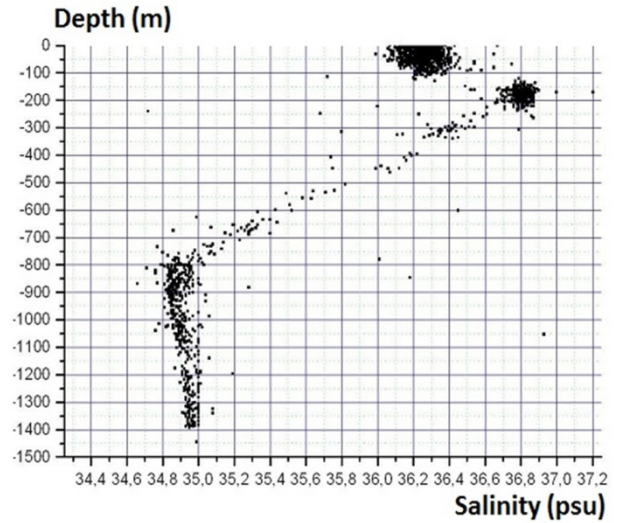
There has been an increase in global temperature in the last three decades, with a change point in 1980 [31]. Furthermore, some changes in the freshwater balance of the Atlantic Ocean were observed [32] and these circumstances had modified the hurricane seasons on this hemisphere [33].

Especially in Cuban waters, some changes on the thermohaline structure parameters were detected during the last 36 years of the XX Century, from the surface to 500 m depth. An increase in temperature and salinity [34] is appreciated, leading to the increase of the available energy for the development of tropical cyclones.

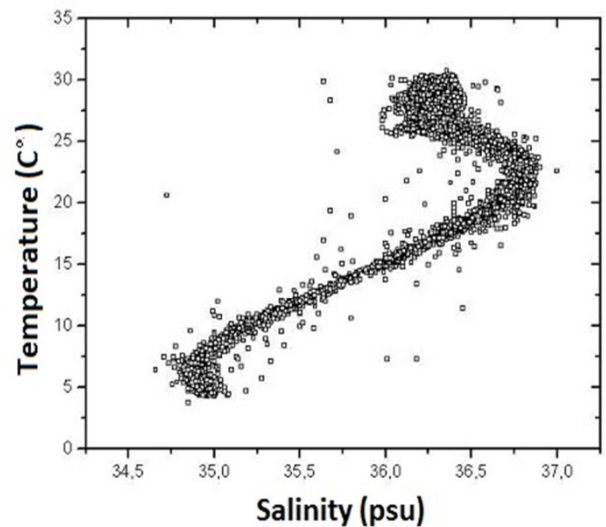
The vertical distribution of the temperature, salinity and water masses around Cuba is presented in Figure 15 and their identification, in Table 3.



a)



b)



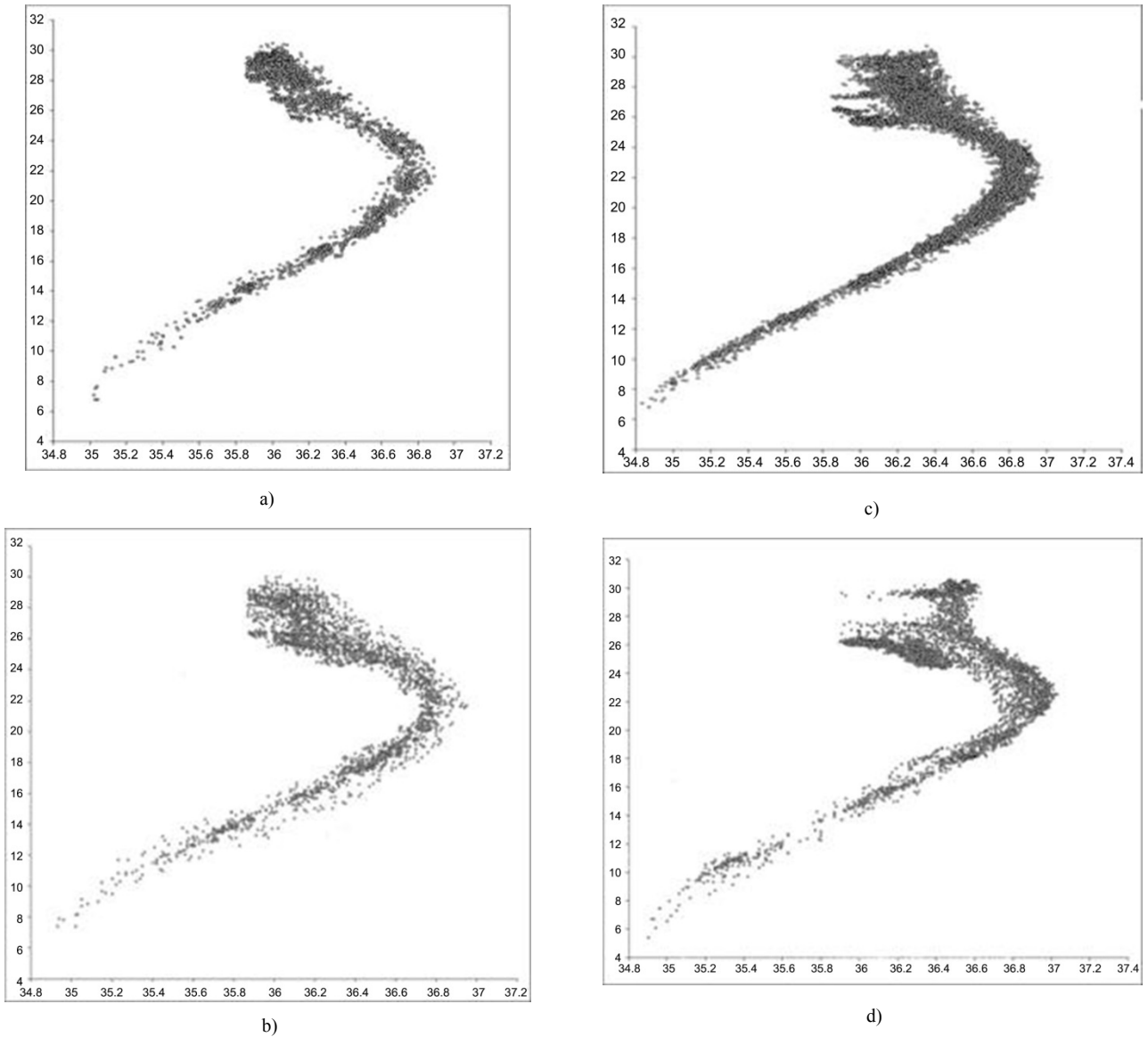
c)

Figure 15. Vertical distributions of the a) Sea temperature, b) Salinity and c) Water masses by TS-analysis, in Cuban waters

Table 4. The water masses distribution around the Cuban Archipelago.

Watermasses	Temperature [°C]	Salinity [psu]	Boundaries [meters]
Surface Local (SL)	31 - 25	36.0 - 36.5	Some tenths
North Atlantic Subtropical Tropospheric (NAST)	22 - 25	36.6 - 36.9	Until 250
Intermediate from the Atlantic North Central region (IANC)	22 - 8	36.6 - 35.0	Between 250-800
Sub-Antarctic Intermediate (SAnI)	8 - 4,5	34.8 - 35	Between 800-1200
Mediterranean Intermediate Transformed (MIT)	4 - 4.5	35	Between 1200-1400
North Atlantic Deep and Botton (NADB)	<4°C	<35	>1400

A graphical representation of the vertical TS-water mass evolution is showed in Figure16 and the numerical values of salinity and temperature intervals were plotted on Table 4.



a)1966-1979, b) 1980-1984, c) 1985-1989 d) 1990-2000

Figure 16. TS-water mass evolution from 1966 to 2000

Table 5. Evolution of the vertical thermohaline structure in Cuban waters at the end of the XX Century.

	1966-1979		1980-1984		1985-1989		1990-2000	
Water mass	T [°C]	S [psu]	T [°C]	S [psu]	Water mass	T [°C]	S [psu]	T [°C]
SI	29-24	35.9-36.5	30-25	35.8-36.6	SI	29-24	35.9-36.5	30-25
SNAST	24-20	36.8-36.6	25-21	36.7-36.8	SNAST	24-20	36.8-36.6	25-21
IANC	20-8	36.6-35.0	21-8	36.6-35.1	IANC	20-8	36.6-35.0	21-8

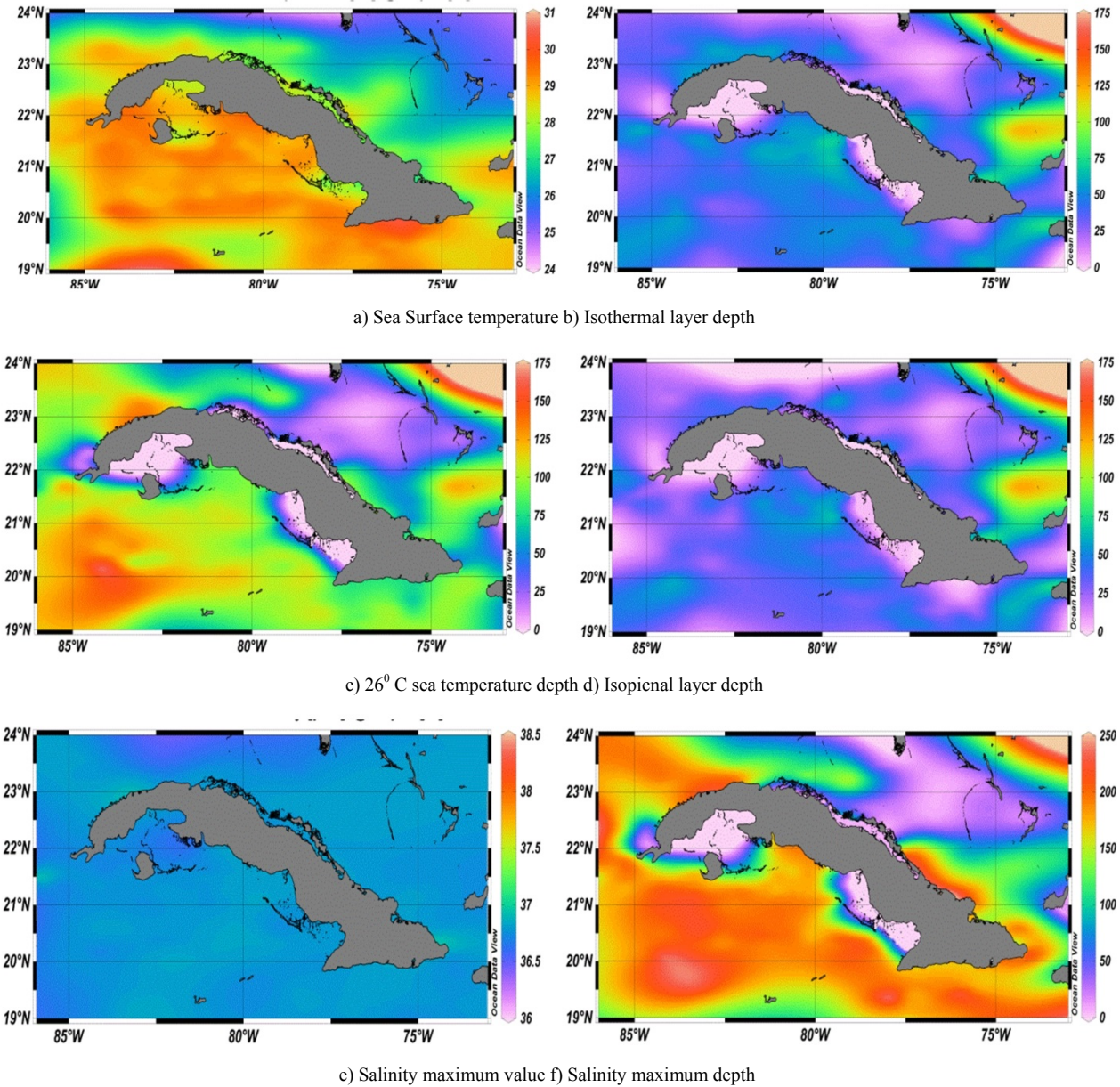


Figure 17. Spatial distributions of some thermohaline parameters during the rainy season (May-October)

The most important changes were the following: a) An increase of the sea surface temperature in 0.7 °C, b) An increase of the salinity maximum, located between 200 and 300 depth, in 0.1 psu, c) An increase in some tens on meters, of the mixed layer depth. The salinity maximum increase indicates a salinity rise in the surface and sub-surface water masses. It could attribute to the diminution of the rainfall volume over the study area in combination with the decrease of the Amazonas river contribution to the Central Atlantic and Caribbean stream systems [29, 34, 35].

The maximum values of almost all of the studied thermohaline parameters were located around the Cuban Western Region, in coincidence with the most favorable area to the tropical cyclone development. The sea surface temperature, the isothermal layer and the salinity maximum distribution during the rainy season (from May 01 to October 31) are showed in Figures 17 a, b, c, d, e, f).

The outputs of some numerical experiments, made with a regional climate model, have shown an increase of the hurricane tracks to the West and over the South region of the Gulf of Mexico [35]. These results confirm the characterization of the Cuban Western region as the most sensitive area to the coastal flooding influence.

4. Conclusions

The obtained results showed increasing coastal flooding tendencies on all the three studied areas, with an althernancy of 30-40 years of low and high activity. The ENOS event acts as a modulator of the flood occurrence; when it is active, the winter floods are more intensive and frequent, although the hurricane activity is weak, so the floods are lesser during the hurricane season. Of special interest is the situation around

the Cuban Western Region, where almost the thermohaline studied parameters are favorable to the future increase of the hurricane destructive power and, as a consequence, to the increase of coastal flooding intensity and frequency. Since the selected studied areas are usually affected by all kinds of severe events reaching the Cuban territory, it is possible to affirm that the detected coastal flooding tendencies are extensive to all the Cuban shore area.

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REFERENCES

- [1] Moreno A., I. Salas, R. Pérez Parrado, O. García, I. Mitrani, C. Rodríguez, A. L. Pérez, M. A. Portela. Desarrollo de la técnicas de predicción y las inundaciones costeras, prevención y reducción de su acción destructiva, Informe Técnico, PNUD/Defensa Civil, La Habana, Editora del Instituto de Planificación Física. 1998, 200 pp, 1998
- [2] Mitrani I., R. Pérez, O. García, I. Salas, Y. Juantorena, M. Ballester, P. Beauballet. The coastal floods in the Cuban territory, the most sensitive areas and the possible impact of the climate change. Proceeding of the Open Meeting of the Human Dimensions of Global Environmental Change Research Community, Río de Janeiro, Brasil, October 6-8, 2001. Online available from: <http://sedac.ciesin.columbia.edu/openmeeting/1mtg/01info.html>, 2001
- [3] Hernández M., O. Marzo, A. Acanda. Tendencia lineal del nivel medio del mar en algunas localidades del Archipiélago Cubano, Serie Meteorológica No. 7, IDO/CITMA, La Habana, Online available from: <http://www.ido.cu>, 2010
- [4] IPCC. The Physical Science Basis, *Climate Change*, Intergovernmental Panel on Climate Change WMO-UNEP, Online available from: <http://www.ipcc.ch/report/>, 2013
- [5] Hidalgo A. Características de las inundaciones costeras en el área Gibara- Playa Guardalavaca, Ciencias, Holguín, Revista Trimestral, año 15, 1:9, enero-marzo 2010
- [6] GEBCO. General Bathymetric Chart of the Ocean, "GEBCO" Digital Atlas, Centenary Edition of the IHO/IOC, Natural Environment Research Council/British Oceanographic Data Center, Updated november 2008-may 2009.
- [7] Juantorena Y., I. Mitrani, P. Beauballet. Las inundaciones por oleaje en el Malecón Habanero con el escenario actual y el previsto por posible cambio climático. Boletín SOMETCUBA, Vol. 6, No. 2., Online available from <http://www.met.inf.cu>, 2000
- [8] ICH, Derrotero de las costas de CUBA, Región Marítima del Norte y Sur. Tomos 1 y 2. Instituto Cubano de Hidrografía, La Habana. 432 pp, 1989;
- [9] ESRL, Earth System Research Laboratory, Physical Sciences Division, National Oceanographic and Atmospheric Administration. Online available from: <http://www.esrl.noaa.gov>, 2015
- [10] NHC. National Hurricane Center archive. Online available from <http://www.nhc.noaa.gov>, 2015
- [11] Hernández N., O. Alvarez, R. Casals, P. Beauballet. Cálculo de algunos parámetros el oleaje que ha afectado a Baracoa por ciclones tropicales" Memorias de la Conferencia Científica sobre Ciclones Tropicales "Rodríguez in Memoriam", WMO, SOMETCUBA, INSMET, La Habana, 185:191, 1998
- [12] Hernández I., E. García. Inundaciones en la Ciudad de La Habana por sistemas frontales y su relación con ENSO. Influencia sobre la costa, Memorias del V Congreso de Meteorología, SOMECUBA -2011, INSMET, La Habana, (in digital support), 13 pp, 201
- [13] Mitrani I., O.O. Díaz, A. Vichot, I. Hernández, A. Hidalgo, E. García, J. A. Rodríguez. Tendencias climáticas de las inundaciones costeras severas en áreas de Cuba, Revista Ciencias de la Tierra y el Espacio, Vol. XIII, No. 2. Online available from: <http://www.iga.cu/publicaciones/revista/index.html>, 2012
- [14] Mitrani I., O.O. Díaz, Y. Juantorena, O. E. Pérez, I. Salas, A. Morales, J. Pérez, J. Viamontes, C. Rodríguez, A. L. Pérez. Elaboración de la primera versión de un atlas oceanográfico de las aguas adyacentes al territorio Cubano. Memorias del VIII Congreso de Ciencias del Mar, MARCUBA-2009 (in digital support).
- [15] Cárdenas, P., L. Naranjo Un índice empírico de ocurrencia de ENSO, papel en la predictibilidad de eventos climáticos", *Boletín SOMETCUBA*, Sociedad Meteorológica de Cuba, Vol. 4, No. 1. Online available from: http://www.met.inf.cu/sometcuba/boletin/v04_n01/espanol/art2.htm, 1998
- [16] Levitus S. "Climatological Atlas of the World Ocean" National Oceanic and Atmospheric, Professional Paper No.13, Rocsvile, Md. , 173 pp, 1982
- [17] Mamayev O. I. Temperature-salinity analysis of World Ocean Waters, Elsevier Oceanography Series, American Elsevier Scientific Company, 373 pp, 2010
- [18] Emery W. J. Water Types and Water Masses, Ocean Circulation, Earth and Atmospheric Sciences Courses, University of Colorado, 1556:1567, Online available from: http://curry.eas.gatech.edu/Courses/6140/ency/Chapter11/Ency_Atmos/Ocean_Circ_Water_Types_Masses.pdf, 2003
- [19] Schlitzer, R., Ocean Data View, Online available from: <http://odv.awl.de>, 2012
- [20] Lecha L., Paz L., Lapinel B. "El clima de Cuba" Editorial Academia, La Habana, 196 pp,
- [21] Alfonso A. P. and Naranjo L. R, The 13 March 1993 severe squall line over Western Cuba. Wea Forecasting, vol. 11, 89: 102., 1996
- [22] Mitrani I. Application of the Meteorological Information on Coastal Management in the Havana Mole. Boletín SOMETCUBA. Vol. 3, No. 2, INSMET, La Habana. Online available from <http://www.met.inf.cu/SOMETCUBA/Boletin/>, 1997

- [23] Avila L. A. Hurricane "Juan", 27 October - 4 November 1985, Tropical Cyclone Report, National Hurricane Center. Online available from <http://www.nhc.noaa.gov>, 1985
- [24] Pasch R. J., D. P. Brown, E. S. Blake (2004) Hurricane Charley, 9-14 August 2004, Tropical Cyclone Report, National Hurricane Center. Online available from <http://www.nhc.noaa.gov>, 2004
- [25] Ballester M., J. Rubiera. Resumen de la temporada ciclónica del 2004, Archivos del Centro de Pronósticos del Instituto de Meteorología, La Habana, Online available from <http://www.met.inf.cu/>, 2005
- [26] Pasch R. J., E. S. Blake, H. D. Cobb III, D. P. Roberts. Hurricane Wilma, 5-25 October 2005, 1 Tropical Cyclone Report, National Hurricane Center, consultado el 5 de abril del 2012, Online available from <http://www.nhc.noaa.gov>, 2006
- [27] Ballester M., J. Rubiera Resumen de la temporada ciclónica del 2005, Archivos del Centro de Pronósticos del Instituto de Meteorología, La Habana, On line available from <http://www.met.inf.cu/>, 2006
- [28] González C. Cronología de los frentes fríos que han afectado a Cuba desde la temporada de 1982-1983 hasta la temporada de 1995-1996, Revista Cubana de Meteorología Vol. 6, No. 1, 15:19, 1999
- [29] Pérez Suárez R., M. Ballester , C. González, M. Limia. Los ciclones tropicales de Cuba. Variaciones y tendencias observadas. Memorias de la Conferencia Científica sobre Ciclones Tropicales "Rodríguez in Memoriam", 7-9 mayo 1998, WMO/SOMETCUBA/INSMET, La Habana, 30:3, 1998
- [30] Pérez Suárez R., C. Fonseca, B. Lapinel, C. González, E. Planos, V. Cutié, M. Ballester, M. Limia, R. Vega. Segunda Evaluación de las Variaciones y Tendencias del Clima en Cuba. II Congreso Internacional de Cambio Climáticos de la VIII Convención Internacional sobre Medio Ambiente y Desarrollo, La Habana, Cuba, 4- 8 de julio de 2011, (in digital support), 15 pp, 2011
- [31] Jones P. D., Palutikof J. "Global temperature record" ClimaticResearchUnit, consultado el 18 de marzo del 2010, Online available from <http://www.uea.ac.uk>, 2005
- [32] Curry R. , B. Dockson , I. Yashaev "A change in the freshwater balance of the Atlantic Ocean over the past four decades" Nature, Vol. 426, 826:829, 2003
- [33] Anthes R., R. W. Corell, G. Holland, J. W. Hurrell, M. C. MacCracken, K. E. Trenberth. Hurricanes and Global Warming-Potential Linkages and Consequences, Comments, Bulletin of the American Meteorological Society, 623:628, 2006
- [34] Mitrani I., Díaz O. Particularidades de la estructura termohalina y sus tendencias en aguas Cubanas , Revista Cubana de Meteorología, Vol. 14, No. 1, 54:73, 2008
- [35] Mitrani I.; O. O. Díaz; A. Vichot; J. A. Rodríguez; D. Martínez; J. M. Vihalva (2014) Los eventos extremos, impactos en el Caribe y la lluvia en la Amazonia, Cuba a Brazil no Seculo XXI, Vol.1, No. 1, 75-80, Editorial Blucher, Online available from <http://www.proceedings.blucher.com.br/article-list/cbs21-224/list/development> , 2014
- [36] Martínez D., I. Borrajero, A. Bezanilla, A. Centella. The occurrence of tropical cyclones in the Caribbean and Mexico and global warming. Application of a regional climate model. "Rev. Ciencias de la Tierra y el Espacio", 12, Online available from http://www.iga.cu/publicaciones/revista/cte_12/CTE12.html, 2011