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Salinity Fluctuations around New Providence Island in response to Hurricane Irma

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ABSTRACT. Salinity anomalies in the near-shore region around New Providence were recognized through surveys before and shortly after the arrival of hurricane Irma in 2017. Prior to Irma, the observations revealed that the northern salinity values were slightly lower compared to the southern section. There is evidence that the salinity in the southern shore is very much regulated by precipitation and bank water from the wider shelf and as a result, wide salinity ranges can be formed along the coast. Tidal action seems to be responsible for the major transport of high salinity water towards the coast and contributes to the salt budget in the southern marsh area. High salinity water from the marsh region may also occasionally be an additional source of high-density water that contributes to the water in the offshore region. Observations show that the southern marsh may have occasionally elevated salinity but this may change sporadically in response to precipitation that freshens the marsh region.

Keywords: Coastal survey, hurricane Irma, salinity fluctuations.

1. INTRODUCTION

Despite the fact that the Bahamas is a grouping of islands with a long tropical coastal environment, not much research on near-coastal processes in the Bahamas have been documented although oceanographic observations have been made over the past century for water temperature, water level, and circulation. However, no comprehensive records exist for any important environmental parameter in the coastal regime (**BEST, 2001**).

Salinity anomalies seem to be common in the Bahamas archipelago and some of these anomalies were earlier recorded west of Eleuthera Island where salinity was as high as 38 and in the area south of New Providence Island, where bank water salinity was found to reach a maximum of 42‰ (**Busby and Dick, 1964**). It was concluded that strong thermal gradients were present on the surface from deep to shallow water. Busby and Dick (**1964**) pointed out that the water from the Atlantic arriving in the Bahamas region had typically a surface salinity around 36.5‰ but a strong horizontal thermal gradient can be present at the surface that can rapidly respond to variations in atmospheric conditions. Observations by **Morse et al.** (**1984**) also showed that a complex salinity distribution is present in the northern Bahamas Banks and indicated that probably, transport of high salinity water from the south is not randomly distributed over the bank with salinity greater than 40‰. It is thought that the high salinity of bank water is a result of semi-restricted interchange between the surface water of the deep channels with a salinity of around 36.5‰ and the shallow waters over the bank. An analogy can be demonstrated with data from **Hickey et al.** (**2000**) along the Exuma banks where dense salty water is formed year-round over shallow water. Plumes can spread laterally at distances of tens of kilometres from their source.

In the past, during the time of infrastructure development on New Providence, the surfaces were transformed to highly impervious ones. As a result, discharge of large amounts of surface runoff from roads, parking lots, and buildings were observed (**Diamond, 2011**). In addition, the northern coastal area is also situated at higher elevations and flooding extends towards the shore at lower elevations with an anticipated discharge into the near shore leading to occasional freshening of surface water.

Rainfall data are based on a rather limited network of a few weather stations in New Providence. However, a significant difference between the eastern and western part of the island is observed. There is also a precipitation gradient north/south as evidenced by rainfall data. For example, the southern station at Coral Harbor showed in the yearly average for 2004 about 45 cm

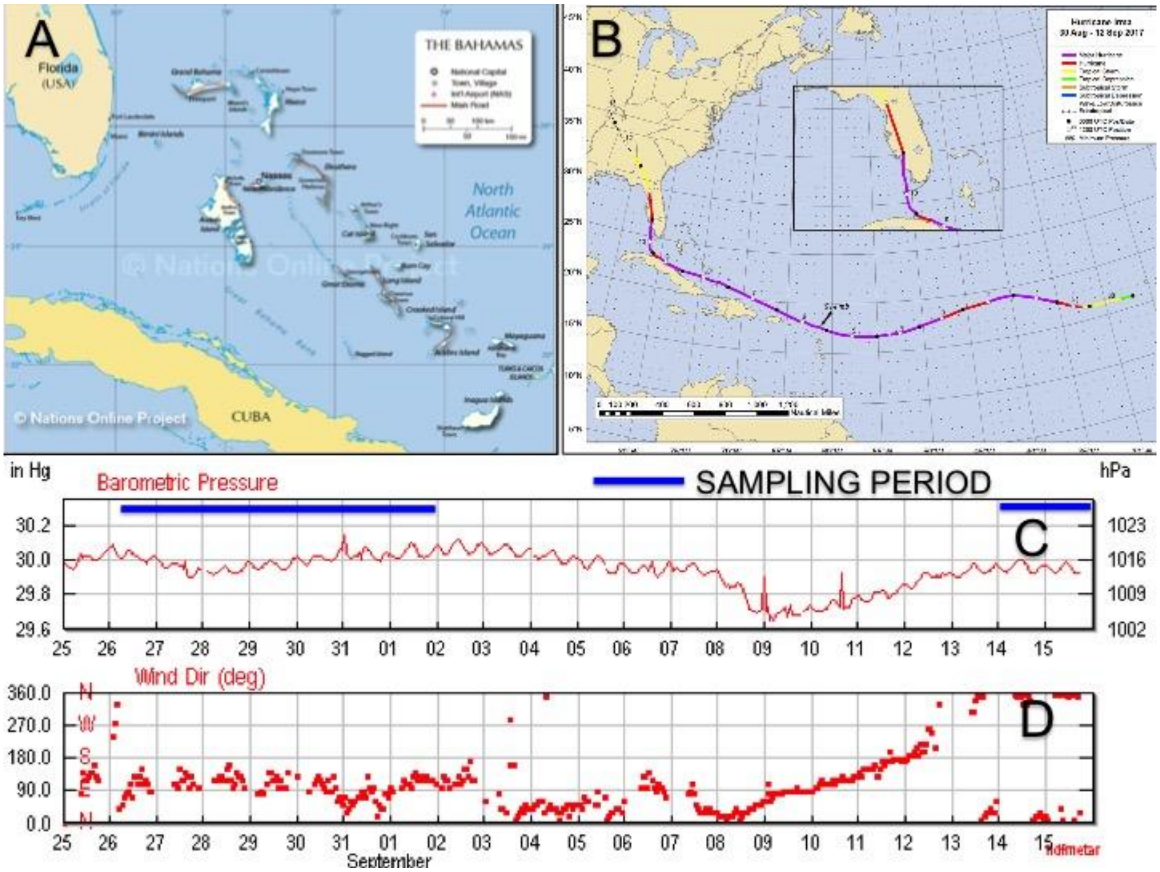

Figure 1. 1A. Location map of the Bahamas. 1B. Track of Hurricane Irma in 2017 by NOAA. 1C. Barometric pressure and 1D. Wind direction as reported at Nassau International airport during salinity sampling before and after hurricane Irma.

of rainfall, whereas the more northern station at the airport had a yearly rainfall of about 114 cm (**Sealey, 2005**). As an outcome, it can be expected that freshening of the near shore area occurs in response to the intensity of precipitation.

2. OBSERVATIONS

For a preliminary assessment on salinity changes in the near-shore water, a survey around New Providence was made in 2017 to recognize possible anomalies. The salinity measurements allowed estimates with an accuracy of about one part per thousand. Coincidently, the first survey was finished just before hurricane Irma reached the vicinity of the Bahamas and for comparison; the same survey was carried out shortly after Irma passed the region. Aside the shortcomings of this semi-quantitative estimates, the opportunity to have such data collected around New Providence before and shortly after the hurricane, justifies a documentation but with the understanding that more sophisticated studies are needed in the future to support some of these findings.

The first survey stretched over eight days during a period of mainly easterly winds and showed typical diurnal variations but without any gusts or significant changes in pressure as shown in **Figure 1**. As indicated in **Figure 1**, when hurricane Irma entered the Bahamas region, there was a decrease of barometric pressure, increase in wind speed and occurrence of gusty winds.

The development of Irma from a tropical storm to a major hurricane occurred within less than two days and can be considered as an unusual event because the storm developed as a Category 5 storm with catastrophic strength. Extensive damage was the result of Irma's impact on Antigua and Barbuda, Anguilla, Cuba, Dominican Republic, Haiti, Puerto Rico, St. Barthelemy, Saint Maarten, Turks and Caicos, British and US Virgin Islands and the southern part of the Bahamas. Irma's center did not pass over Providence but the barometric pressure, as shown in **Figure 2**, led to increased wind speed and swell and sealevel change along the coast of the Bahamas. Unfortunately, no tidal gauge measurements were available for the period during which hurricane Irma was in the vicinity of New

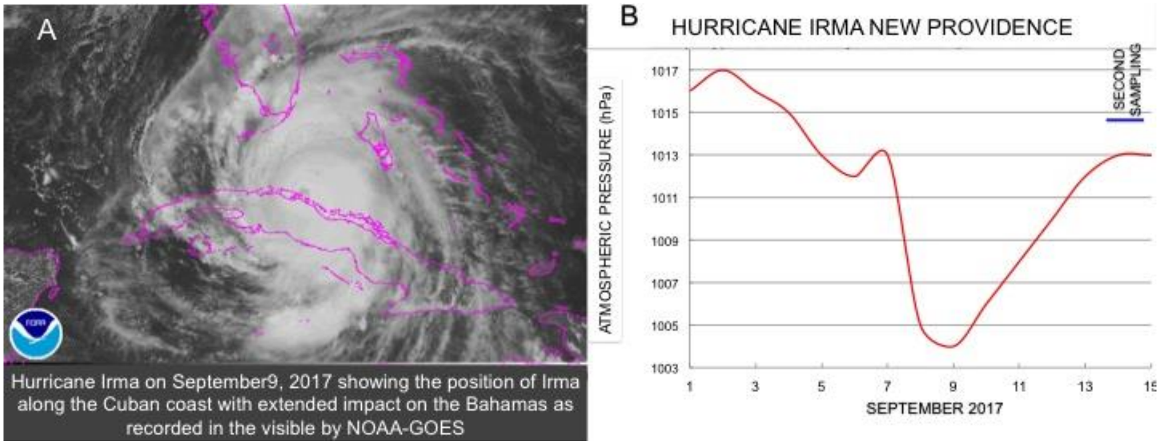

Figure 2. Hurricane Irma on September 9, 2017. 2A: Position of Irma along the Cuban coast with extended impact on the Bahamas as recorded in the visible by NOAA-GOES. 2B: Barometric pressure graphed from data recorded at the meteorological station Nassau International Airport.

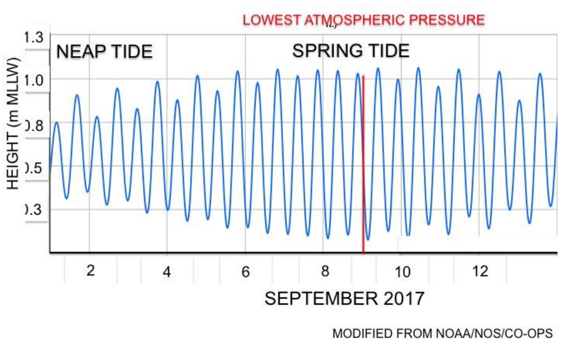

Figure 3. Predicted tides for New Providence. The red mark shows the day of lowest barometric pressure that stretched roughly over one tidal cycle. Modified from NOAA/NOS/CO-OPS. In the Bahamas, the tides represent a composite of the predominating Atlantic semi-diurnal tide and the local semi-diurnal and diurnal tides but the resulting tidal range, in general, does not exceed one meter.

Providence but the predicted tides shown in **Figure 3** indicated that the lowest barometric pressure coincided closely with the highest spring tidal elevation.

The two salinity surveys, one before and the other shortly after hurricane Irma, and a difference map are shown in **Figure 4**. Prior to Irma, the observations revealed that the northern salinity values were slightly lower compared to the southern section before the passing of Irma. Furthermore, a sample from the near-shore water north of New Providence indicated higher salinity at about 500 m offshore, at a depth of about 10 m, where the salinity was around 36‰ compared to surface salinity values around 33‰.

The rainfall data at the time of our salinity observations from 2 August to 15 September 2017, are presented in **Figure 5**, and show the potential freshening of the surface water by precipitation and runoff from the island.

A summary of the estimated salinity data for the north and south, before and after hurricane Irma, is listed in **Table 1**. Before arrival of Irma, the northern shore had an average salinity of 33.4‰ with a standard deviation of 1.1, whereas the southern part of the island had an average salinity of 36.4‰. After Irma passed, the northern coastal region showed an increase in salinity of about 2.6‰ whereas the southern part had an increase of about 0.6 only. Considering the analytical error of the measurements, the variations of salinity are significant and indicate that the southern salinity fluctuations may be governed by different processes compared to those in the northern part of New Providence.

The salinity in the southern shore of New Providence seems to be regulated by the dynamics of the adjacent shallow bank water where low bathymetry enhances the effect of evaporation exceeding precipitation. Therefore, elevated salinities are formed through currents together with tidal action that transports high saline water to the near shore area. To support the assumption that high salinity water from the offshore can enter the near-shore, a tidal creek, Bonefish Creek that is connected to Bonefish Pond, was selected for monitoring salinity in response to tidal changes. Measurements revealed elevated salinity values but they however could change quickly. This can be demonstrated with measurements in October when the creek discharged lower salinities from the marsh region as shown in **Figure 6**.

An example of the presence of high saline water is shown with measurements as documented in **Figure 7**. Observations for current velocity and

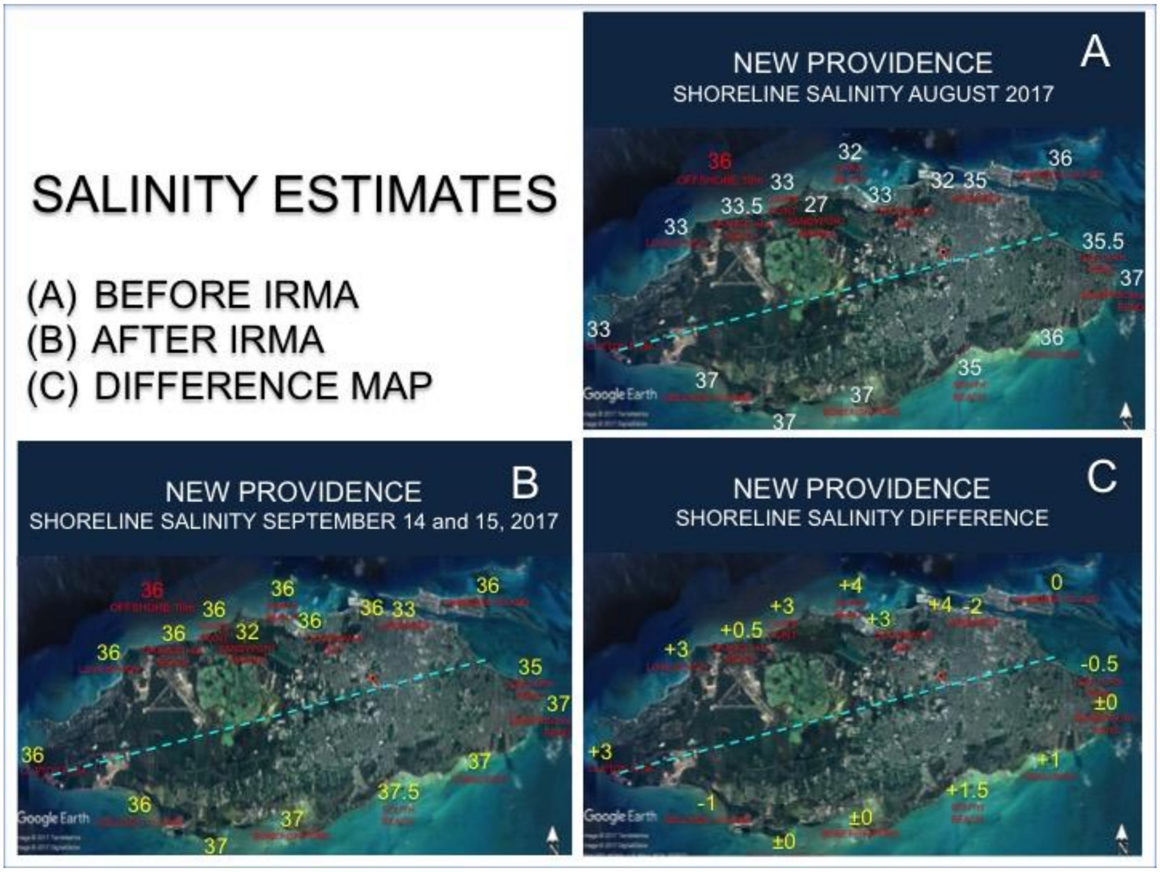

Figure 4. Salinity values in the near shore around New Providence. 4A shows salinities before Irma and Figure 4B shows values for the same sampled locations after Irma. 4C shows the difference salinity between the two surveys. Figures 4A and 4B also include the sample from the offshore region that was collected at a depth of approximately 10 m and had a salinity of 36‰.

direction as well as averaged salinities show that during ebb tide the outrunning water had a slightly higher salinity of about 36 compared to the incoming tide with an average salinity of approximately 34.

Table 1. Summary of salinity measurements around New Providence 2017.

Time	Location	Salinity	St Dev
Before Irma	North	33.4‰	1.1
	South	36.4‰	
After Irma	North	36.0‰	0.5
	South	37.0‰	

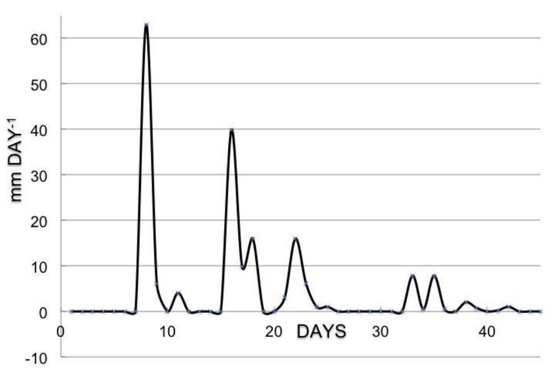

Figure 5: Precipitation during salinity sampling from 2 August to 15 September 2017 in New Providence based on data from the Nassau International airport meteorological station.

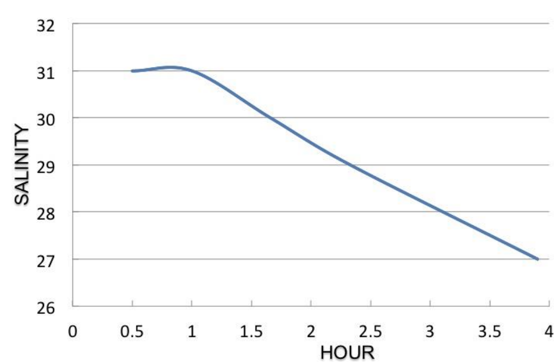

Figure 6. Salinity measurements in outrunning tide shortly after slack tide in Bonefish Creek taken on 5 October 2017.

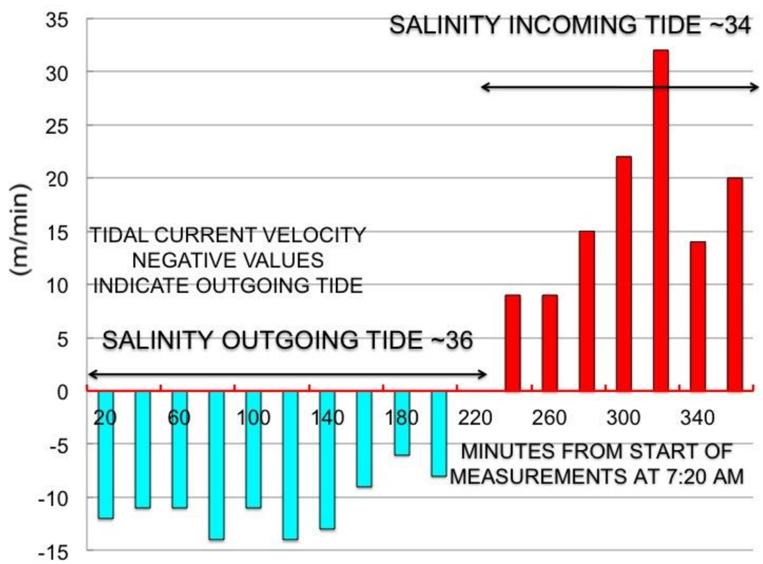

Figure 7: Tidal current velocity and direction and average salinity in Bonefish Creek on 28 October 2017

3. CONCLUSION

The observed salinity changes in the northern part of New Providence after Irma seem to be dominated by precipitation and runoff of fresh water from the island and mixing between surface water of the lagoon and the Atlantic water. However, other processes like upwelling may have an impact on changing the salinity in the North. Without additional oceanographic measurements, the interpretation of our data has to be viewed against observations by other researchers that worked in the vicinity of New Providence. Our salinity survey implies that the salt variations along the southern coast might be occasionally influenced by bank water. This interpretation can be supported with observations that bank water is characterized by strong salinity gradients and the presence of tidal currents (**Shonting, 1970**). Therefore, it is quite possible that our observed elevated salinity data are a result of analogous processes. Also, dominant easterly winds introduce Ekman transport of bank water toward the shore in the south of New Providence. Contrary, in the north we would observe an offshore transport. Therefore, elevated salinity could be expected in the south while the salinity in the north would be characterized mainly by Atlantic water within salinities of 36 to 36.5‰. However, we showed that processes in the marsh region in the south might cause quick salinity fluctuations in the near-shore water in response to meteorological changes.

As salinity values around New Providence are not well-documented, coastal anomalies or events in the marine environment may have gone unnoticed in the past. Monitoring of the coast, therefore, is essential in order to fully understand the environmental changes around New Providence in relation to its potential impact on the coastal ecosystem. This is of particular importance with respect to global change and the need to assess the impact of forecasted sealevel increase along the Bahamian coastline.

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