Coastal Resilience Workshop

Sea Level Rise Indicators in Broward County: A Quick Look at Tidal Records and Recurring Flood Events

Samantha Danchuk
Environmental Planning & Community Resilience Division, Broward County

C. Reid Nichols
Southeastern Universities Research Association, Washington, DC

L. Donelson Wright
Southeastern Universities Research Association, Washington, DC

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Samantha Danchuk [1], C. Reid Nichols[2], and L. Donelson Wright [2]
[1] Environmental Planning & Community Resilience Division, Broward County
[2] Southeastern Universities Research Association, Washington, DC
*Corresponding author: SDANCHUK@broward.org

Introduction

Numerous authors ([1], [2], and [3]) report sea level rise along the South Florida Atlantic Coast. Sea level rise is occurring locally, but is hard to quantify since it is caused by a number of factors including melting glaciers, thermal expansion of water, subsidence or the compaction from sediment loads, and localized depression from the extraction of ground water.

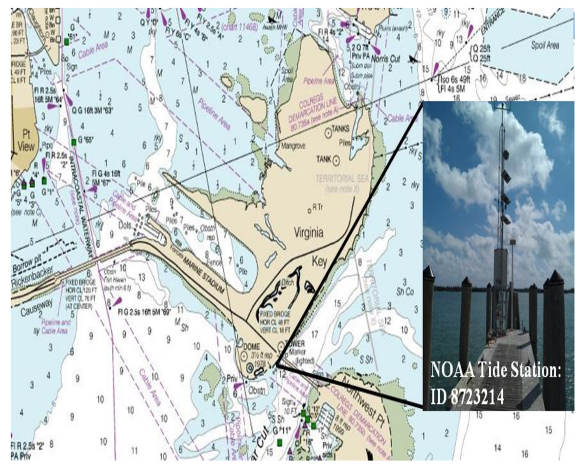

Figure 1. Virginia Key tide station that is located at the end of the University of Miami Rosenstiel School of Marine and Atmospheric Science pier (NOAA Chart 11465).

The long-term NOAA tide gages provide the necessary information to determine vertical datums such as Mean Sea Level (MSL) and Mean Lower Low Water (MLLW) and rates of sea level rise through the analysis of water level fluctuations referenced to benchmarks. For these reasons, we took a look at water level fluctuations occurring at NOAA Tide Station 8723214 located in Virginia Key, FL (Fig. 1). MLLW is 3.1 m.

Methods

NOAA conducted harmonic analysis on water level fluctuations at Virginia Key to determine the water's response to tidal forces. Results do not consider factors such as the piling of water by winds or storm surge. Harmonic constants were obtained to characterize the tide based on the amplitudes of the M_2, S_2, K_1, and O_1 constituents or partial tides. The average amplitude at Virginia Key, Florida includes an M_2 of 0.298m, S_2 of 0.052m, K_1 of 0.031m, and O_1 of 0.028m. The Formzahl (F) of the tide is given by the ratio of the main diurnal to semidiurnal tidal constituents, in accordance with the classic formula [4]:

$$F = (O_1 + K_1)/(M_2 + S_2)$$

F > 3 = Diurnal
1.5 < F < 3.0 = Mixed diurnal dominant type
0.25 < F < 1.5 = Mixed semidiurnal dominant type
F < 0.25 = Semi-diurnal

Tidal characteristics in this area are mixed, predominantly diurnal, with an average F of about 0.169. In this mixed diurnal dominant type of tide the mean range of Spring tides can be estimated as 2 (K_1+0_1), which equals 0.118m at Virginia Key.

Sea level rise is relative and is a component of the nontidal or residual that can be obtained by subtracting tide predictions from the observed water levels. Oceanographers and geodesists working at NOAA take into account variations in the height of the land that are caused by local geologic processes. We can also see the impacts of local changes by looking at the residuals in the tidal record and then study the difference to see what is driving the nontidal fluctuations.

Regional contributions to non-tidal water levels include long-term changes in global mean sea level, atmospheric-pressure and wind induced changes, fluctuations in offshore Ekman transport caused by changes in Gulf Stream transport intensity, storm surge, wave-induced set up, and land sinking. For Florida as a whole, the rise in mean sea level over the past century has been around 21 cm [1], but this rate is likely accelerating due the steric effects of warming sea water. The USACE estimates that by 2030 sea level will be roughly 18 cm higher than at present while [1] concludes that by 2050 mean sea level in South Florida could be on the order of 50 cm higher. These estimates do not take account of any unexpected glacial melting or calving in Antarctica or Greenland. Local factors can also include changes in temperature and salinity which can increase or decrease water density and more importantly the impact of favorable winds which can pile water in particular locations.

To get a feel for sea level rise in Broward County, we have taken a quick look at water fluctuations from the nearest tidal reference station and associated times of flooding in Broward County. Table 1 provides a list of some of the extreme water levels from the last year that have been measured at Virginia Key, the closest tidal reference to compare water levels for Fort Lauderdale.

Table 1. Ten highest and lowest water levels at Virginia Key during the period from September 2, 2014 to September 2, 2015 refenced to Station Datum (0.00).

Highest (m)	Date	Time (L)	Lowest (m)	Date	Time (L)
4.171	Oct 7, 2014	8:36am	2.956	Jun16, 2015	3:48pm
4.151	Oct 7, 2014	8:06pm	2.997	Jun 17, 2015	4:36pm
4.148	Oct. 6, 2014	7:42am	3.005	Jul 11, 2015	12:06pm
4.139	Nov 5, 2014	7:12am	3.009	Mar 21, 2015	4:48pm
4.123	Oct 8, 2014	9:30am	3.009	Jun 15, 2015	3:06pm
4.113	Nov 4, 2014	6:36am	3.009	Jul 5, 2015	6:36pm
4.112	Sep 30, 2014	1:48pm	3.011	Jun 19, 2015	6:06pm
4.109	Dec 5, 2014	8:00am	3.012	Mar 6, 2015	2:24am
4.108	Oct 7, 2014	8:55pm	3.012	Jun 18, 2015	5:18pm
4.108	Oct 9, 2014	10:24am	3.018	Jun 30, 2015	2:20pm

The majority of these tides occur at or just after new moon and full moon when the tide-generating force of the sun acts in the same direction as that of the moon, reinforcing it and causing the greatest rise and fall in tidal level.

During these periods of higher high tides, places such as Mola Avenue and Isle of Capri Drive off of Las Olas Boulevard, one of the lowest areas in Fort Lauderdale, experience recurring flooding. King tides (i.e., perigean spring tides) bring unusually high water levels several times per year, and they can cause local tidal flooding. Owing to sea level changes that we see in the residual record there is a relative rise in sea level surrounding Fort Lauderdale, Fl. The extent of the foreshore area along places such as Mola and Riva Canals has been increased as indicated in Fig. 2.

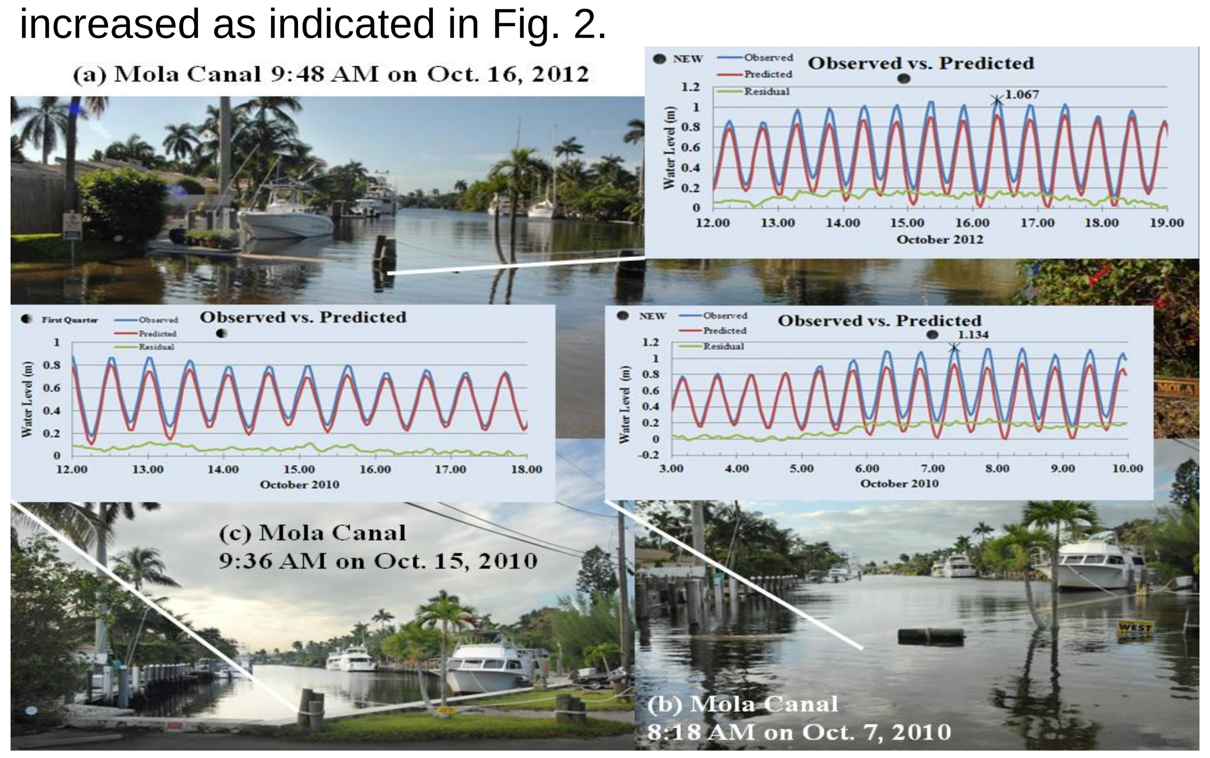

Figure 2. Recurring flooding in Fort Lauderdale. Spring tide flooding is depicted in panels (a) an (b). Neap tide conditions are depicted in panel (c). Water levels are referenced to MLLW. Lands that are at risk for coastal flooding are expected to have increased periods of flooding, especially during perigean spring tides and severe storms owing to sea level rise (Images are courtesy of the Broward County Environmental Planning and Community Resilience Division and water levels were obtained online from http://1.usa.gov/1L4DrCZ).

Fig. 3 and 4 show the effect of the tides at Virginia Key when the sun, moon, and Earth are in alignment (at the time of the new or full moon) and one week later, when the sun and moon are at right angles to each other (at the time of the first and third quarter moon). During new and full moons the solar tide has an additive effect on the lunar tide, creating extra-high high tides, and very low, low tides—both commonly called spring tides. During the first and third quarter moon phases the solar tide partially cancels out the lunar tide and produces moderate tides known as neap tides.

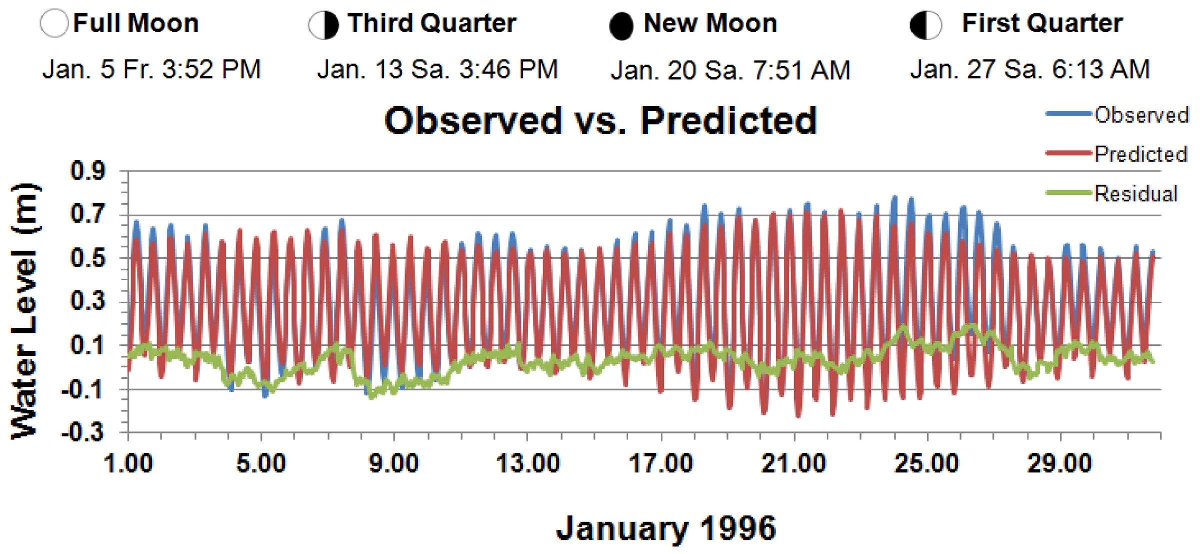

Figure 3. Virginia Key, Florida water level fluctuations. Predicted (tidal), observed, and residual (nontidal) water levels are depicted relative to MLLW. Water levels were obtained online from http://1.usa.gov/1L4DrCZ).

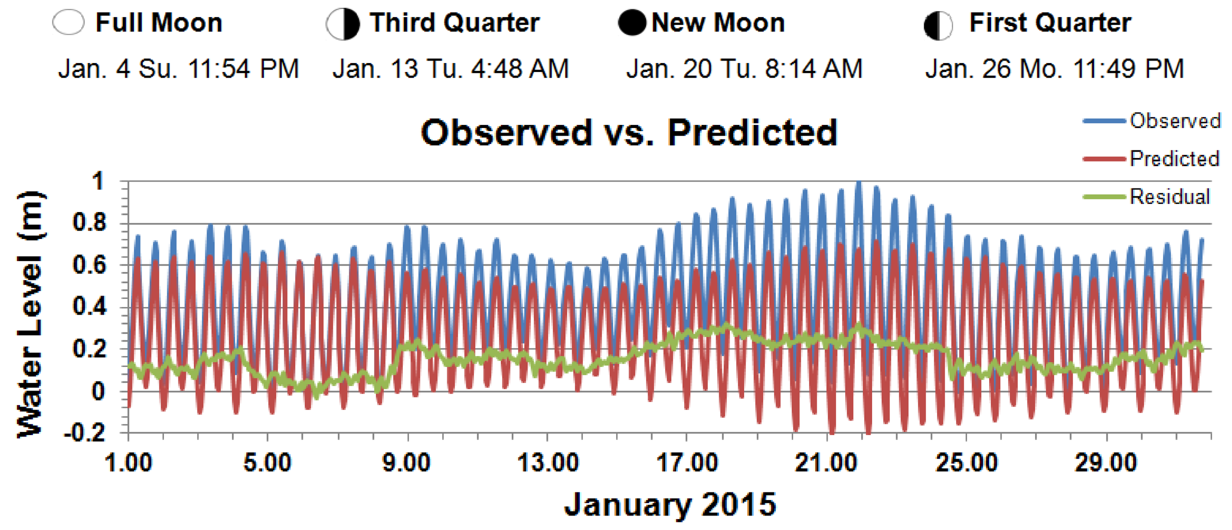

Figure 4. Virginia Key, Florida water level fluctuations. Predicted (tidal), observed, and residual (nontidal) water levels are depicted relative to MLLW (Water levels were obtained online from http://1.usa.gov/1L4DrCZ).

The residuals during January 1996 ranged from -0.14 to 0.19 m with an average difference between observations and astronomical predictions of 0.03 m.

The residuals during January 2015 ranged from -0.03 to 0.32 m with an average difference between observations and astronomical predictions of 0.16 m.

Conclusions

Tides vary on timescales ranging from hours to years due to astronomical forces. To make accurate records, tidal reference stations measure the water level over long periods of time. Tide gauges ignore variations caused by waves with periods shorter than minutes. While tides are usually the largest source of short-term water level fluctuations, sea levels are also subject to forces such as wind and barometric pressure changes, resulting in storm surges, and subsidence, especially near the coast.

Images of flooding along with the graphs showing the excess water levels above astronomical tides suggest that nontidal factors contribute to recurring flooding. Fig. 3 and Fig. 4 provide a record of water level trends across the fortnightly neap-spring tidal cycle for January 1996 and 2015, respectively. The increase in nontidal water level fluctuations is 0.13 m.

Since average daily water levels are rising, flood tides are extending further inland than in the past. King tides accentuate the impact of sea level rise in coastal regions such as Fort Lauderdale. This directly impacts quality of life and property value for residents living in low lying areas. We can estimate the amount of flooding that will occur by looking at the tidal and nontidal forces that impact sea level. These factors are occurring at different temporal scales and include sea level rise, storm surge even from the passage of favorable fronts, and the timing of astronomical higher high tides.

References

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