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Report on Collection and Analysis of Tidal Data from Boston Harbor, Meetinghouse Pond, Chatham Fish Pier and Outermost Harbor: June, 2016 – September, 2018

by

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for

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INTRODUCTION

The continuous change of channels, inlets and landforms of the barrier beach complex separating the Pleasant Bay/Chatham Harbor estuarine system from the greater Atlantic Ocean in turn produces changes in tidal and wave patterns within the estuary. The breaching of Nauset Beach during a severe northeasterly storm on January 2, 1987, ended a long period of growth of the barrier beach - a century of incremental southward extension. New channels were formed as well as shoals, and a second breaching in 2007 produced another tidal inlet north of that formed in 1987 (e.g., Giese, Mague and Rogers, 2009). On April 1, 2017, the breaching of northernmost South Beach produced a channel ("Fools Inlet") adjacent to the 1987 inlet, thereby providing tidal flow and navigation between Chatham Harbor and previously separated systems to its south and west.

The altered tide and wave patterns within this dynamic system are affecting its ecology, human use and management. Since tidal monitoring can assist understanding of the changing system and enable improved management, we have compiled and analyzed tidal data from the following locations: Meetinghouse Pond, at the extreme head of the Chatham Harbor/Pleasant Bay system; Chatham Fish Pier, which lies between the two tidal inlets at the mouth of the system; and, at Outermost Harbor Marina since March, 2017, (added in anticipation of the breaching of South Beach which occurred on April 1, 2017). During the course of the study it was determined that some pronounced changes of the local Pleasant Bay/Chatham Harbor tides relate directly to regional tidal characteristics. To help delineate these regional influences, limited tidal data from Boston Harbor have been included in this report.

In summary, we report here results of our study of tidal data recorded between June, 2016, and September, 2018, at four stations: two within the Chatham Harbor/Pleasant Bay estuary system, one adjacent to the new "Fools Inlet", and a one in Boston Harbor. The original tide readings at all four stations were recorded at 6-minute intervals, except for occasional periods of instrument malfunction. Details of the ongoing tidal study that includes this time period are presented in an earlier and more extensive report (Giese, 2012). The present report includes

discussion of the new results in context of our previous reports in this ongoing study, and plots of station data extend back in time to 2012.

METHODS

The objective of the analysis was to focus attention on patterns of sea level, high and low tide levels, and tidal range change within the Pleasant Bay/Chatham Harbor estuary at annual and inter-annual time scales.

Meetinghouse Pond, Chatham Fish Pier and Outermost Harbor

Tidal data collected during this reporting period (June, 2016 – September, 2018) were recorded by Onset HOBO pressure recorders installed at Nauset-East Marina on Meetinghouse Pond in Orleans, and at Chatham Fish Pier in Chatham (Fig. 1). We also report tidal data recorded from March, 2017, through September, 2018, by Onset HOBO pressure recorders installed at the Outermost Harbor Marine Marina in Chatham (Fig. 2).

Boston Harbor

The Boston Harbor data were recorded on a NOAA tide recorder and made available on the NOAA tides and water levels website (www.tidesandcurrents.noaa.gov).

Analysis

Initial tidal data from stations within the estuary were corrected for effects of atmospheric pressure using data from HOBO atmospheric pressure recorders established at both Chatham Fish Pier and Meetinghouse Pond to reduce error due to the distance between the tidal and atmospheric pressure-recording instruments.

The sea level data were then adjusted to the vertical geodetic datum, NAVD88, by means of precision GPS surveys. The instrument-provided tide levels were periodically checked against visual readings of a nearby tide staff and compared to

the now repaired NOAA tide gauge at Chatham Fish Pier. Times are reported as local standard time.

Statistics for each data set were calculated using MATLAB software. Using the six-minute data as input, mean sea level (MSL), mean high and low water (MHW and MLW), and mean tidal range (MTR) were derived for the individual time series.

Table 1. Abbreviations used in the report

CCNS	Cape Cod National Seashore
CCS	Center for Coastal Studies
GPS	Global Positioning System
MHW	Mean High Water
MLW	Mean Low Water
MSL	Mean Sea Level
MTR	Mean Tidal Range
NAVD88	North American Vertical Datum of 1988
NOAA	National Oceanic and Atmospheric Administration

Figure 1. Location of tide recorders at Meetinghouse Pond and Chatham Fish Pier.

Figure 2. Location of tide recorders at Chatham Fish Pier and Outermost Harbor.

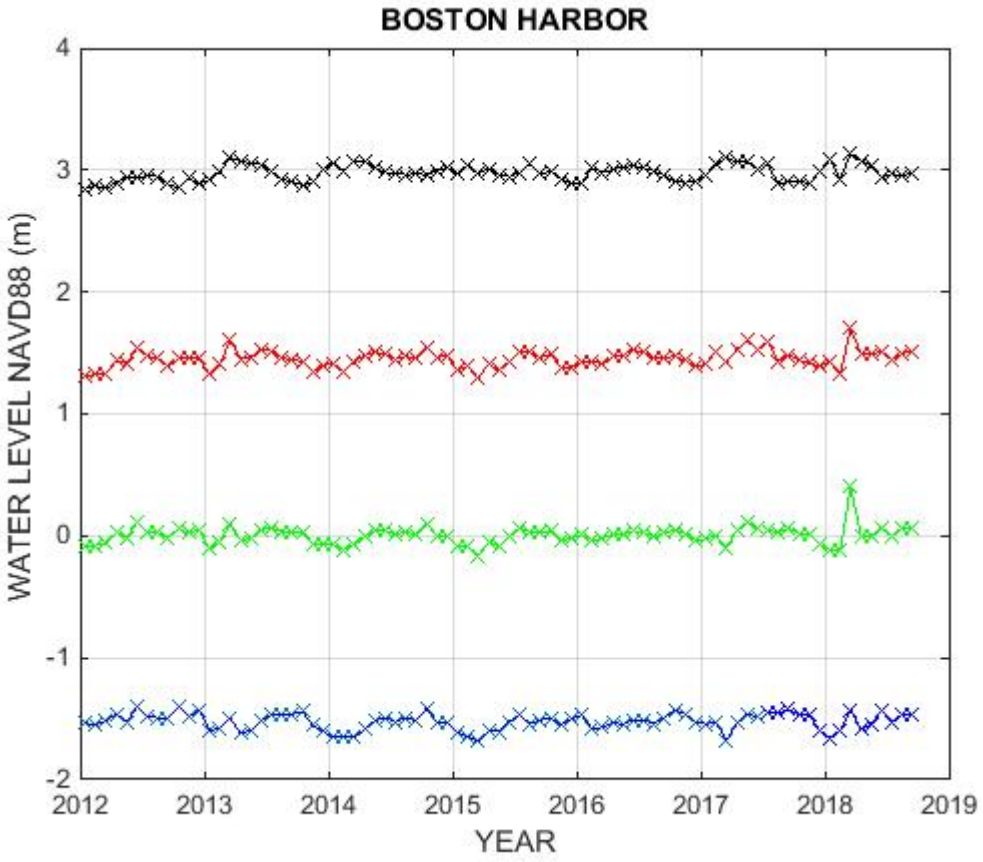

Figure 3. Summary data from Boston Harbor NOAA tide recorder from January 2012 to September 2018. Mean Sea Level (Green), Mean High Water (Red), and Mean Low Water (Blue) are given in NAVD88 (meters). Tide Range (Black) is also given in meters.

Table 2. Summary data from Chatham Fish Pier tide recorder from June 2016 to September 2018. Mean Sea Level (MSL), Mean High Water (MHW), and Mean Low Water (MLW) are given in NAVD88 (meters). Tide Range (Range) is also given in meters.

	Chatham			
Month	MSL	MHW	MLW	Range
Jun-2016	0.13	0.89	-0.67	1.55
Jul-2016	0.10	0.85	-0.72	1.57
Aug-2016	0.07	0.81	-0.72	1.52
Sep-2016	0.12	0.83	-0.63	1.46
Oct-2016	0.17	0.83	-0.54	1.37
Nov-2016	0.15	0.80	-0.55	1.35
Dec-2016	0.11	0.76	-0.58	1.34
Jan-2017	0.14	0.80	-0.53	1.33
Feb-2017	0.17	0.81	-0.49	1.30
Mar-2017	0.10	0.78	-0.57	1.35
Apr-2017	0.19	0.85	-0.46	1.31
May-2017	0.23	0.88	-0.42	1.30
Jun-2017	0.20	0.84	-0.44	1.28
Jul-2017	0.15	0.89	-0.57	1.46
Aug-2017	0.12	0.87	-0.62	1.49
Sep-2017	0.19	0.93	-0.55	1.48
Oct-2017	0.13	0.88	-0.61	1.49
Nov-2017	0.14	0.89	-0.59	1.48
Dec-2017	0.06	0.84	-0.68	1.52
Jan-2018	0.07	0.90	-0.70	1.59
Feb-2018	0.02	0.84	-0.71	1.55
Mar-2018	0.35	1.21	-0.44	1.66
Apr-2018	0.12	0.98	-0.62	1.60
May-2018	0.10	0.94	-0.67	1.61
Jun-2018	0.17	0.97	-0.61	1.58
Jul-2018	0.10	0.90	-0.69	1.59
Aug-2018	0.18	0.98	-0.62	1.60
Sep-2018	0.21	1.01	-0.58	1.58

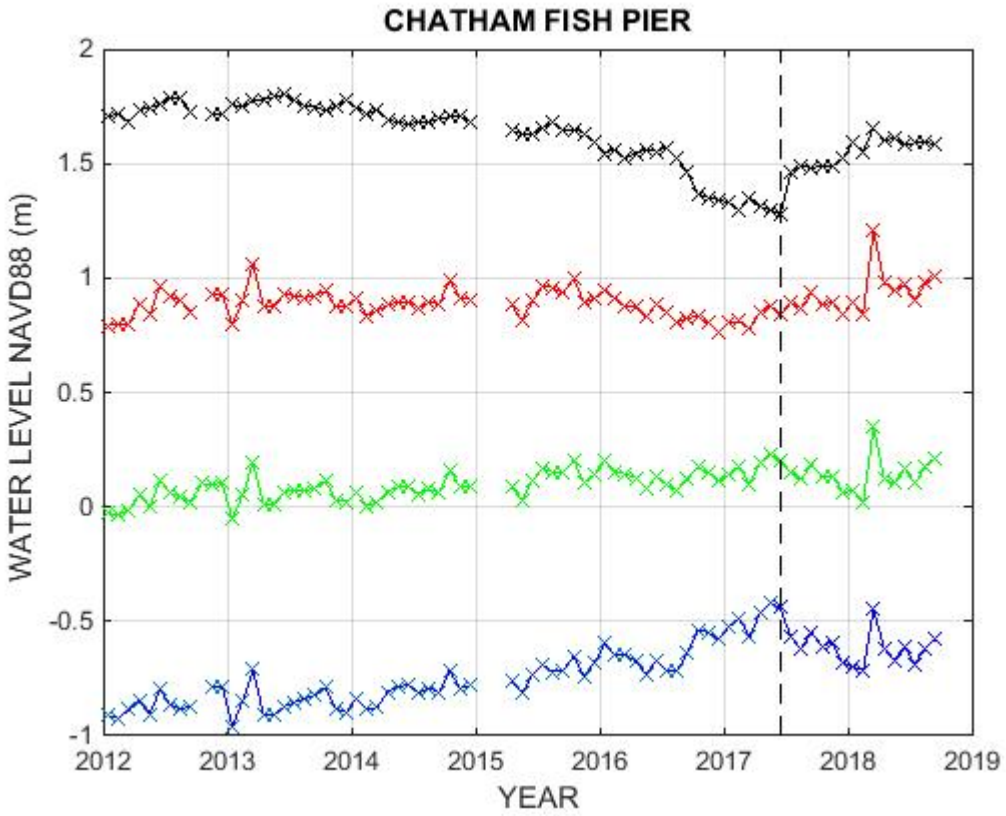

Figure 4. Summary data from Chatham Fish Pier tide recorder from January 2012 to September 2018. Mean Sea Level (Green), Mean High Water (Red), and Mean Low Water (Blue) are given in meters (NAVD88). Tide Range (Black) is also given in meters. Dashed line: June 2017.

Table 3. Summary data from Meetinghouse Pond tide recorder from June 2016 to September 2018. Mean Sea Level (MSL), Mean High Water (MHW), and Mean Low Water (MLW) are given in NAVD88 (meters). Tide Range (Range) is also given in meters.

Meeting House Pond				
Month	MSL	MHW	MLW	Range
Jun-2016	0.19	0.86	-0.35	1.21
Jul-2016	0.20	0.86	-0.34	1.19
Aug-2016	0.19	0.85	-0.34	1.18
Sep-2016	0.22	0.86	-0.31	1.17
Oct-2016	0.24	0.86	-0.29	1.15
Nov-2016	0.16	0.78	-0.35	1.14
Dec-2016	0.14	0.74	-0.37	1.12
Jan-2017	0.23	0.84	-0.26	1.11
Feb-2017	0.25	0.85	-0.26	1.11
Mar-2017	0.16	0.75	-0.32	1.06
Apr-2017	0.31	0.89	-0.18	1.07
May-2017	0.36	0.95	-0.14	1.09
Jun-2017	0.32	0.91	-0.16	1.07
Jul-2017	0.18	0.80	-0.32	1.12
Aug-2017	0.16	0.77	-0.34	1.10
Sep-2017	0.15	0.77	-0.36	1.13
Oct-2017	0.20	0.80	-0.30	1.10
Nov-2017	0.18	0.79	-0.32	1.11
Dec-2017	0.11	0.72	-0.38	1.10
Jan-2018	0.09	0.75	-0.42	1.17
Feb-2018	0.06	0.68	-0.43	1.11
Mar-2018	0.32	1.04	-0.27	1.31
Apr-2018	0.18	0.82	-0.34	1.16
May-2018	0.16	0.79	-0.36	1.15
Jun-2018	0.23	0.88	-0.30	1.18
Jul-2018	0.18	0.80	-0.33	1.13
Aug-2018	0.21	0.86	-0.31	1.18
Sep-2018	0.22	0.85	-0.30	1.15

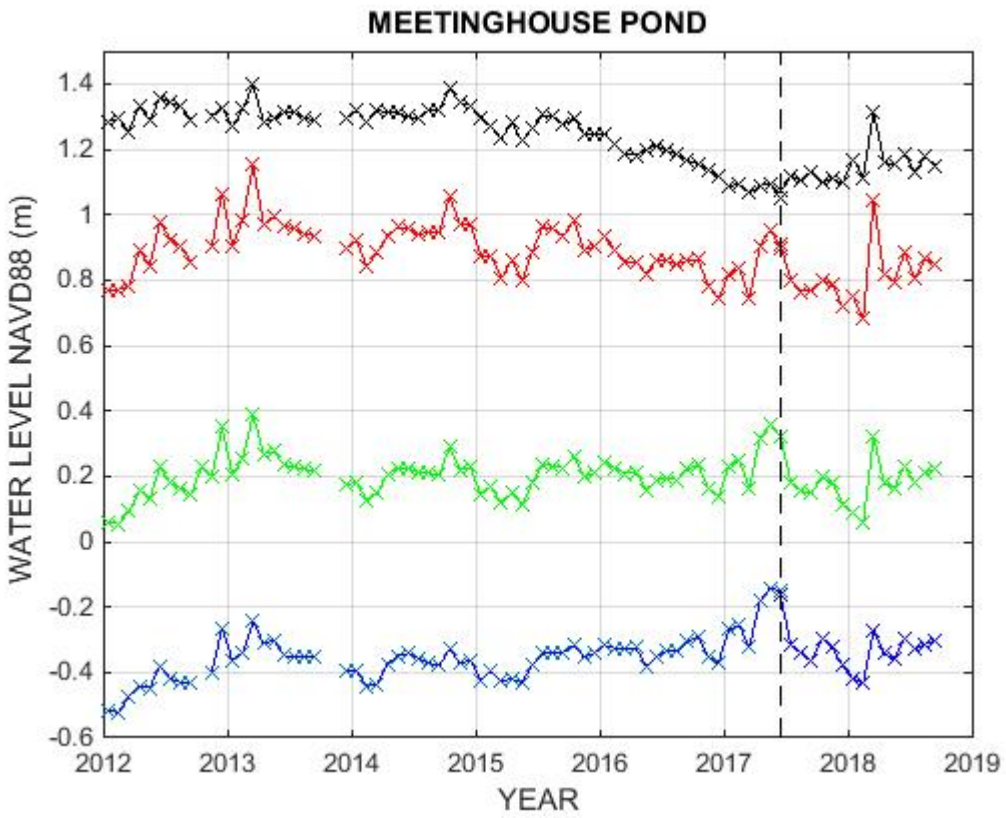

Figure 5. Summary data from Meetinghouse Pond tide recorder from January 2012 to September 2018. Mean Sea Level (Green), Mean High Water (Red), and Mean Low Water (Blue) are given in NAVD88 (meters). Tide Range (Black) is also given in meters. Dashed line indicates June 2017.

Table 4. Summary data from Outermost Harbor tide recorder from March 2017 to September 2018. Mean Sea Level (MSL), Mean High Water (MHW), and Mean Low Water (MLW) are given in NAVD88 (meters). Tide Range (Range) is also given in meters.

Outer Most Harbor				
Month	MSL	MHW	MLW	Range
Mar-2017	-0.15	0.55	-0.81	1.36
Apr-2017	-0.01	0.77	-0.71	1.48
May-2017	0.06	0.84	-0.65	1.50
Jun-2017	0.04	0.81	-0.67	1.48
Jul-2017	0.01	0.79	-0.74	1.53
Aug-2017	-0.01	0.78	-0.75	1.53
Sep-2017	0.05	0.82	-0.68	1.50
Oct-2017	0.00	0.79	-0.75	1.54
Nov-2017	0.01	0.79	-0.73	1.51
Dec-2017	-0.07	0.73	-0.82	1.55
Jan-2018	-0.07	0.78	-0.83	1.61
Feb-2018	-0.11	0.72	-0.85	1.57
Mar-2018	0.20	1.10	-0.59	1.69
Apr-2018	-0.01	0.91	-0.77	1.67
May-2018	-0.01	0.90	-0.81	1.71
Jun-2018	0.06	0.92	-0.74	1.67
Jul-2018	-0.02	0.85	-0.85	1.70
Aug-2018	0.04	0.92	-0.80	1.73
Sep-2018	0.05	0.94	-0.78	1.73

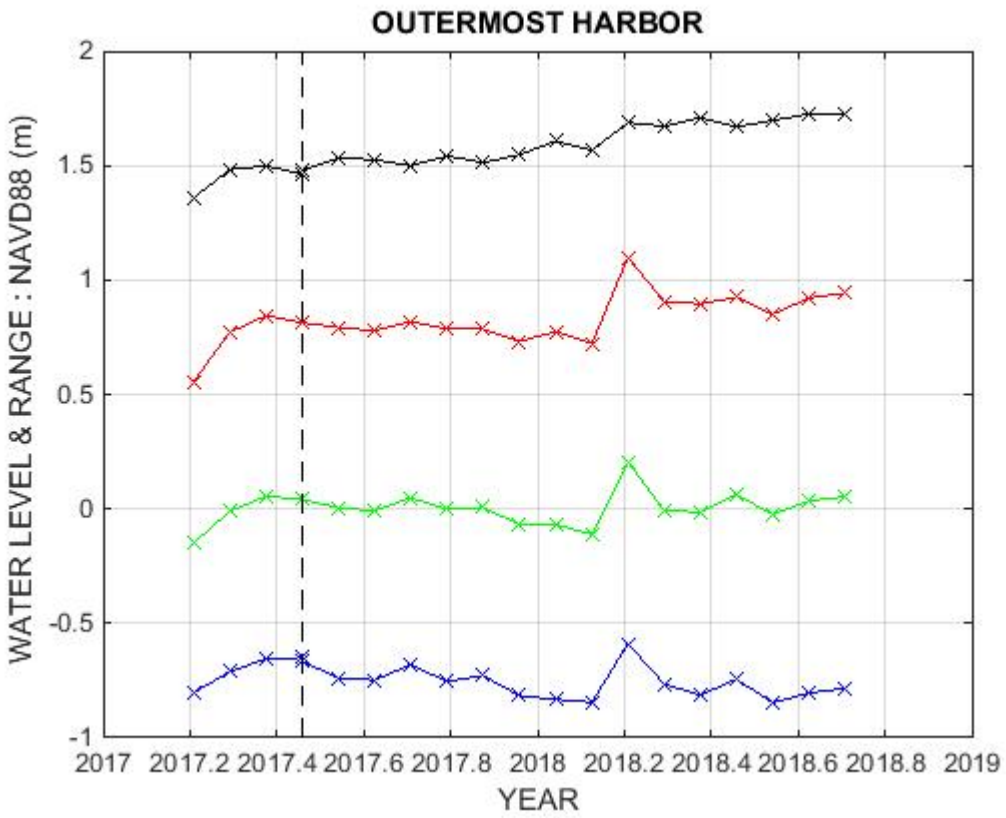

Figure 6. Summary data from Outermost Harbor tide recorder from March 2017 to September 2018. Mean Sea Level (Green), Mean High Water (Red), and Mean Low Water (Blue) are given in NAVD88 (meters). Tide Range (Black) is also given in meters. Dashed line indicates June 2017.

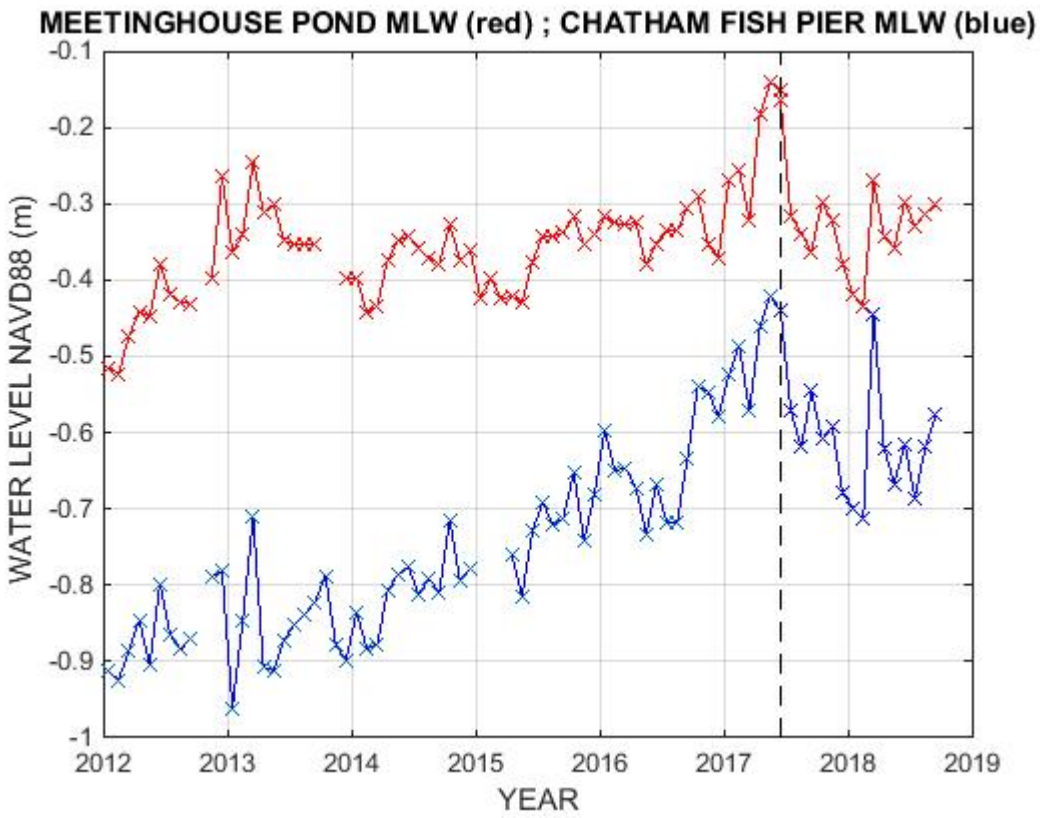

Figure 7. Mean Low Water from Meetinghouse Pond (Red) and Chatham Fish Pier (Blue) from tide recordings from January 2012 to September 2018. Values are given in NAVD88 (meters). Dashed line indicates June 2017.

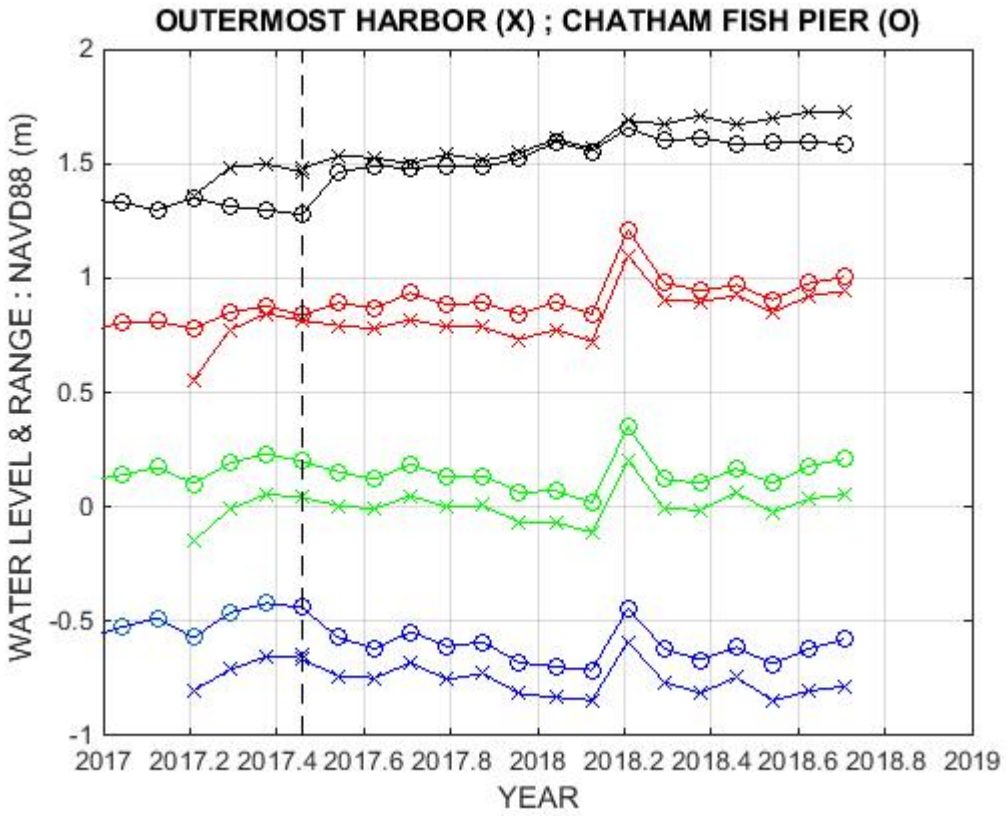

Figure 8. Summary data from Outermost Harbor (X) and Chatham Fish Pier (O) tide recorders from January 2017 through September 2018. Mean Sea Level (Green), Mean High Water (Red), and Mean Low Water (Blue) are given in meters (NAVD88). Tide Range (Black) is in meters. Dashed line indicates June 2017.

DISCUSSION

The tidal results presented above, together with those presented and discussed in previous reports, bear a significant relationship to trends of geomorphic change of the Pleasant Bay-Nauset Beach system, and they point to additional changes that may occur in the decade ahead.

Boston Tides and Anomalous Regional Sea Levels. The single most striking event recorded in our time series of monthly tide data is the abrupt, short-lived regional sea level rise that occurred in March, 2018 (e.g., Fig. 3). With that event, Boston monthly mean sea level reached its highest level in the almost 100-year history of official tide recording, slightly exceeding the previous maximum reached in March, 2010 (Fig. 9).

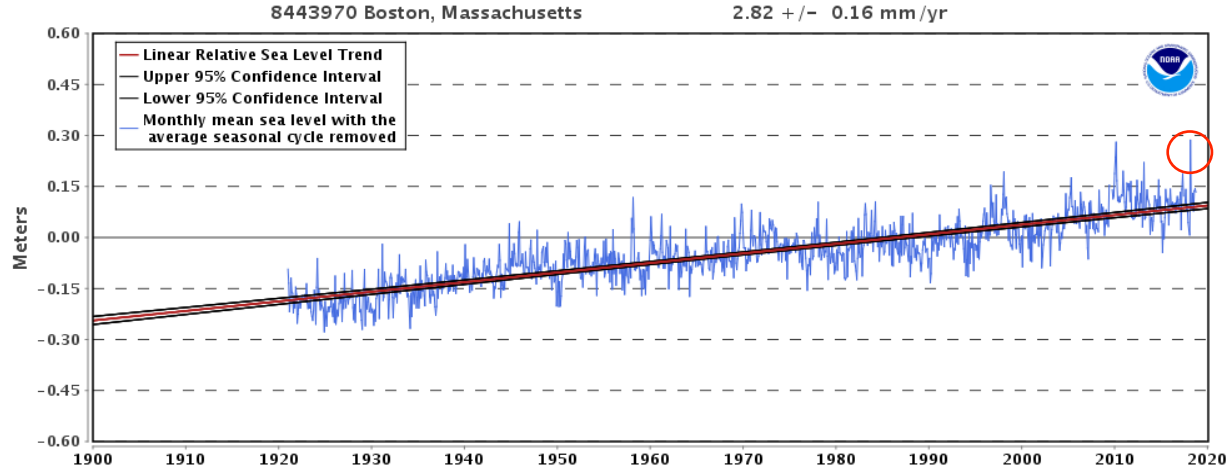

Figure 9. Historic monthly sea levels for Boston adjusted by removal of seasonal trends (NOAA, 2018). The maximum, the mean monthly sea level for March 2018, is indicated by the red circle.

This sea level anomaly occurred throughout the U.S. northeast coast. Tidal stations from Portland, Maine, to New York City recorded increases ranging from 0.2 to 0.3 meters between February and March, 2018. In that regard, if not in its longevity, this event is reminiscent of the multiyear regional sea level anomaly discussed in our August, 2012, report as well as those reported by others (e.g., Sweet, et al., 2014). Local impacts of the 2018 sea level regional anomaly are treated in the following discussion.

Chatham Fish Pier Tides and Reversal of Decreasing Tide Range. Previous reports (e.g., Legare and Giese, 2016) discussed the multi-year trend of increasing low water levels and decreasing tide range at Chatham Fish Pier that became pronounced in 2013. The new data reveal that this trend abruptly reversed between June and July, 2017, particularly with respect to tide range (Fig. 4). By September, 2018, the range at Chatham Fish Pier had increased 0.3 m (1 ft.) above that of June, 2017. This change was concurrent with a major geomorphic reconfiguration of the northern terminus of North Beach Island and the North Inlet complex of shoals and channels (T. Keon, personal communication and Fig. 10).

Figure 10. Aerial photographs showing changes in configuration of North Inlet between June and October, 2017. The breakup of the NW-trending spit on northern North Beach Island made way for a more efficient ebb tidal channel along the southern margin of the North Inlet complex of shoals and channels (courtesy of T. Keon).

Ebb Channel Reconfiguration. Summarizing previous discussions, for several years following the 2007 breaching of Nauset Beach seaward of Ministers Point (i.e., the opening of North Inlet), tidal flows through the new inlet were primarily incoming flood tides, and the main ebb channel connecting Pleasant Bay and Little Pleasant Bay to the open sea continued southward through Chatham Harbor to the system's major (1987) tidal inlet, South Inlet. Ebb flow in the channel was enhanced by increasing tidal range at Meetinghouse Pond which reached a maximum in 2012, having increased approximately 0.3 m (1 ft.) following the 2007 breaching due to a combination of the increased flood tides and a regional sea level anomaly (Giese, 2012).

As a result of scouring by increased ebb flows through South Inlet, Chatham Fish Pier experienced decreased low tide levels until 2012 (Legare and Giese, 2016); however beginning then and continuing into 2017, Chatham Fish Pier low tides began a steady 5-year rise, ending only in mid-2017 (Figs. 4 and 7). Initially Meetinghouse Pond low tides rose also, but the rising ended in 2013 and that change marked the beginning a three-year sustained drop in the elevation difference between Meetinghouse Pond and Chatham Fish Pier low water levels.

As discussed in our previous two reports, we suggest that until 2013, six years following initiation of North Inlet, South Inlet dominated the system's tidal hydraulics. However, we suggest that a turning point occurred in 2013 initiating a decrease in the relative dominance of South Inlet. Decreasing low water elevation differences between Meetinghouse Pond and Chatham Fish Pier following 2013 and continuing into mid-2017 indicate a continuing decrease of flow in the ebb channel through Chatham Harbor south to South Inlet, and a corresponding increase in ebb flow through North Inlet. It seems likely that the breaching of South Beach at "Fools Inlet" in April, 2017, and much more importantly, the breakup of northern North Beach Island in June, 2017, resulted in further decoupling the two inlets from a hydrodynamical point-of-view.

However, we suggest that it was not until the anomalous sea level rise event of March, 2018, (see p. 15-16) that the system's ebb channel reconfiguration was completed. The much-discussed unusually swift ebb flows in the vicinity of Ministers Point that occurred in March, 2018 - those associated with extreme coastal erosion there - completed the connection of the system's major ebb channel with North Inlet (Fig. 11), the final major element of the inlet development phase of the century-and-a-half long geomorphic/hydrographic cycle that was initiated in 1987.

Figure 11. August 7, 2018, photograph showing established connection of the ebb tidal channel with North Inlet. Part of Ministers Point can be seen at extreme upper right and Chatham Fish Pier facilities at center upper left.

Looking forward, considerations of morphodynamic/hydrodynamic stability (Giese, Mague and Smith, 2009) suggest that only the final stages of the system's inlet development phase of remain to play out. During the coming decade, North Beach Island will likely follow the path already taken by South Beach in becoming a relic landform. It will become more frequently overwashed by storm tides, and its sediment will episodically be shifted to produce more stable landforms to its south and west, making way for initiation of the inlet migration phase to follow. Likely socio-economic effects of these changes include navigational impacts in the region around South Inlet, including Outermost Harbor and Morris Island Cut, and episodic coastal erosion of the mainland shore presently protected by North Beach Island.

ACKNOWLEDGEMENTS

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This study was supported by the Pleasant Bay Resource Management Alliance, and benefitted greatly from the guidance of its director, Carole Ridley, and the members of its Coastal Resource Work Group. We acknowledge with special thanks the contributions of Ted Keon, Director of Coastal Resources for the Town of Chatham, who kindly reviewed of an early draft of this report and provided comments and aerial imagery revealing the significant tidal impacts associated with the break-up of North Beach Island's northern terminus that began in June 2017 (Fig. 10).

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