Sea Level Variability in Long Island Sound

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ABSTRACT: Sea level variability in Long Island Sound is examined at both tidal and subtidal frequencies over a 1-yr period. The sound is found to be decoupled effectively from the lower Hudson Estuary at tidal frequencies. The predominantly semidiurnal tides in the sound are forced by the oceanic tides transmitted from the mouth. There is a near fourfold amplification of the semi-diurnal tides within the sound due to resonance. Diurnal tides are much weaker in the sound, and there is also no evidence of significant amplification in the interior. At subtidal frequencies, the pressure-adjusted sea level in the interior of the sound is forced by a combination of co-oscillation with coastal sea level at the mouth and direct setup induced by local wind forcing over the surface of the sound. Because the longitudinal axis of Long Island Sound is roughly aligned with the open coast from Montauk Point to Sandy Hook, these two mechanisms work in concert to produce larger subtidal sea level fluctuations in the western sound relative to those in the eastern sound. A linearized, frequency-dependent analytical model is developed to aid the interpretation of field observations.

Introduction

Long Island Sound (Fig. 1) is an elongated estuary bounded on the north by Connecticut and on the south by Long Island, New York. The eastern end of Long Island Sound communicates with the Atlantic Ocean through Block Island Sound, while its western end communicates with the lower Hudson estuary (better known as the New York Harbor) through the East River. The East River is a natural waterway between Battery and Willets Point, with a length of 25.5 km and a mean depth (below MLW) of about 8.4 m.

Previous work (LeLacheur and Sammons 1932) has shown that the water movement in the sound is primarily tidal. Using salt balance calculations, Riley (1967) argued for a two-layer gravitational circulation which superimposes on the tidal circulation. The existence of a large-scale gravitational circulation has also been documented with bottom drifter observations (Gross and Bumpus 1972) and current meter observations (Gordon and Pilbeam 1975). In addition to tidal flow and density-induced motion, the work of Firstenberg (1982) further indicated the existence of substantial low frequency current variability in the sound. Ullman and Wilson (1984) suggested that the observed low-frequency current fluctuations in the sound could be explained in part as a combination of direct atmospheric forcing and free oscillations.

This study examines sea level fluctuations (at both tidal and subtidal frequencies) in Long Island Sound over a 1-yr period. The major objective is to show that one can gain fundamental understanding about the driving mechanisms and response characteristics of the sound across a broad frequency band by examining relatively long sea level observations at key locations. As Long Island Sound is connected to the lower Hudson estuary through the East River, sea level records within the lower Hudson are also examined to assess the importance of coupling between the two estuaries. A simple linear analytical model is developed to aid the interpretation of the variability observed.

Database

Sea surface elevations collected by the National Ocean Service during 1975 were obtained for six stations within the two estuaries (Fig. 1). The year 1975 was chosen because of the availability of uninterrupted series for a majority of the stations selected (Table 1). Only time series with record length of three months or longer were examined. Due to the extensive data gaps at New London, sea level recorded there was not included in the analysis of subtidal variability. Atmospheric pressure variations and wind speeds and directions recorded at Bridgeport, Connecticut, were obtained from the National Climatic Data Center. Wind stress was computed based on a drag coefficient of $C_d = 2.0 \times 10^{-3}$.

The measured sea level fluctuations at all the stations exhibit strong variances at both tidal and subtidal frequencies. Since the basic driving mechanisms and the time scales involved are quite different, tidal and subtidal sea level variability are examined separately. The short-period tidal oscillations of sea level are effectively separated from the long-period subtidal sea level fluctuations by passing the data sets through a Lanczos filter with a cut-off period of 34 h. Details of the character-
Statistics of the filter response can be found in Bloomfield (1976).

**Sea Level Variability at Tidal Frequencies**

To examine the characteristics of astronomical tides in the sound, a least squares harmonic analysis (based on the method described by Dronkers 1964) was performed to determine the harmonic constants for 26 tidal constituents at the sea level stations. Table 2 shows a summary of the harmonic analysis for four major constituents ($M_2$, $N_2$, $S_2$, and $K_1$) which accounted for more than 95% of the tidal variance observed.

The astronomical tides in Long Island Sound are predominantly semidiurnal. Among the semidiurnal tides, $M_2$ is clearly the dominant constituent. One can expect strong spring-neap variations of the mostly semidiurnal tides due to the beat effect between $M_2$ and the weaker but still appreciable $N_2$ and $S_2$ tides. The most striking feature of the $M_2$ tide in the sound is its near fourfold increase in amplitude from the mouth (Montauk Point) to the head (Willets Point). The bulk of the spatial variation in phase of the $M_2$ tide occurs in the eastern part of the sound, while the phase only changes slightly in the western part of the sound.

Such spatial variations in amplitude and phase are also observed for the $N_2$ and $S_2$ tides, but the $K_1$ tide shows only relatively minor increase in amplitude from the mouth to the head of Long Island Sound.

The tides in the lower Hudson estuary are also mostly semidiurnal, with $M_2$ being the dominant constituent. The amplitude of $M_2$ decreases and its phase increases from the mouth of the Hudson (Sandy Hook) up the estuary to the western end of the East River at Battery. The amplitudes of $M_2$ at two ends of the East River are different by about a factor of 2, and the phase lag between them is $96^\circ$. The very different characteristics of tidal re-

**TABLE 1. Summary of the availability of sea level data in 1975.**

<table>
<thead>
<tr>
<th>Station</th>
<th>Data Missing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandy Hook</td>
<td>none</td>
</tr>
<tr>
<td>Willets Point</td>
<td>none</td>
</tr>
<tr>
<td>Bridgeport</td>
<td>none</td>
</tr>
<tr>
<td>New London</td>
<td>1/11-1/13, 1/25-1/27, 2/3-2/28, 3/12-4/30, 9/1-9/30, 12/2-12/31</td>
</tr>
<tr>
<td>Montauk Point</td>
<td>none</td>
</tr>
</tbody>
</table>