Water Level Variations in the Estuary and Gulf of St. Lawrence

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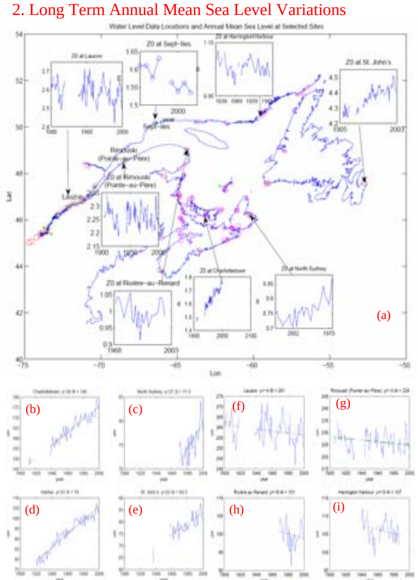
1. Introduction

Fig. 1: The Estuary and Gulf of St. Lawrence is one of the large Canadian inner water bodies, connecting to the Atlantic Ocean through relatively narrow straights. There are five provinces bordering its coasts. Coastal vulnerability due to sea level rising, storm surges and coastal erosion is a major concern in the coastal community. To partially address the concern, a collaborative project has been recently set up, by Maurice Lamontagne Institute, University of Quebec at Rimouski, and Quebec Provincial consortium Ouranos on Climate Changes, to study the sensitiveness and vulnerability of its coastal areas to climate changes. An important part of the project is to study the water level variations, using both statistical and hydrodynamic modelling approaches. Here we present some of our some initial statistical results.

2. Long Term Annual Mean Sea Level Variations



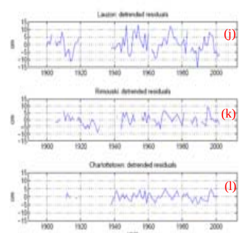


Fig. 2: Long-term annual mean sea level variations are examined throughout the Estuary, Gulf and its vicinities (Fig. 2a). Two types of long-term trends are identified by regression analysis. In the eastern and southern parts of Gulf and its vicinities, the annual sea levels exhibit a steady rising trend with rates ranging from 22 to 33 cm/century (Figs. 2b-e). In the Estuary, the annual sea levels show an opposite trend, falling steadily at rates of 3.4 to 6.4 cm/century (Figs. 2f-i). This result seems to indicate that both the seabed rising and subsidence are taking place respectively in the Estuary and in the Gulf to either offset or enhance the global sea level rising. The annual mean sea level variations also show inter-annual/decadal oscillations becoming progressively stronger from the Gulf to the head of the Estuary, with amplitudes less than 5 cm at Charlottetown to more than 10 cm at Lauzon (Figs. 2j-l).

3. Extreme Value and Return Period Analysis

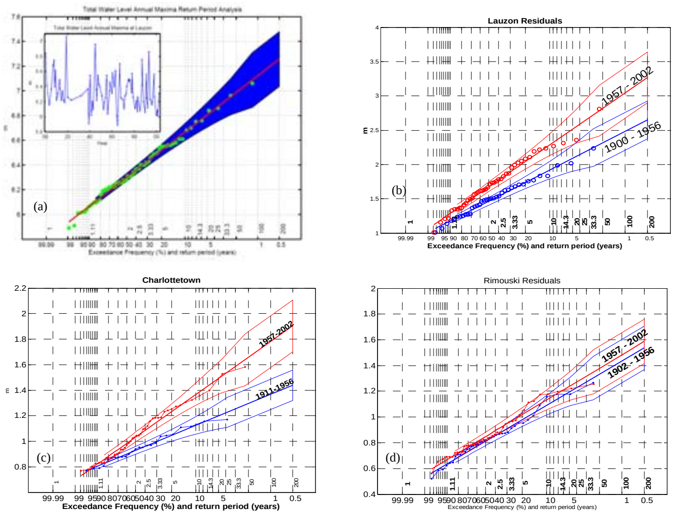


Fig. 3: Extreme value analysis (EVA) is carried out for three sites with century-long water level records: Lauzon (near Quebec City) at the head of the Estuary, Rimouski (Pointe-au-Père) in the middle of the Estuary, and Charlottetown in the lower reach of the Estuary-Gulf system. Annual maximums either of the total water levels (as for Fig. 3a) or of the residuals (non-tidal, as for Figs. 3b-d) and their occurrence frequencies provide the observational data (shown by the dots) to best fit the Gumbel theoretical distribution (shown by the thick lines) on the appropriate logarithmic scale paper (the Gumbel probability paper). Fitting the entire observational period gives the results as shown in Fig. 3a, where the blue zone is a confidence zone of 2/3 probability. We proceeded with the analysis for the two halves of the 20th century to identify any storm surge environmental changes between the two sub-periods, as shown in Figs. 3b,c,d, where the thin lines outline the 2/3 confidence zones. The results for Lauzon and Charlottetown both show a significant shortening of the return periods of storm surge events of the same size in the latter part of the 20th century compared with the first part. An event that used to occur once in 20 years on average now only takes about 4 years to return, and the bigger the events are, the shorter their return periods become. This may indicate that the surge forcing environment has changed in the second half of the century. However, the EVA at Rimouski does not reveal such a significant shift between the first and the second half of the century. Further investigation is required for this inconsistency.

4. Seasonal Variations

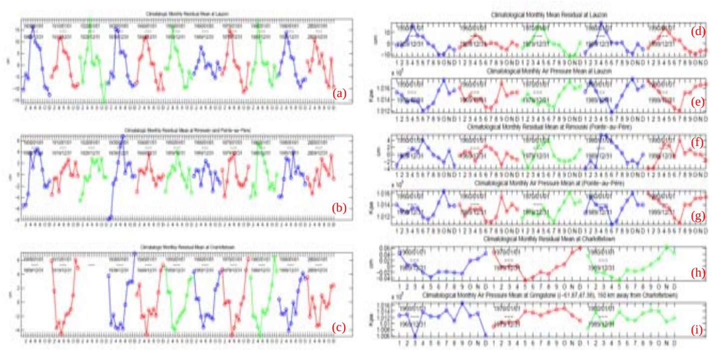


Fig.4: Strong seasonal signals are evident in Figs. 4a, b, c, where the climatologic monthly mean of the residual water levels are plotted at Lauzon, Rimouski (Pointe-au-Père) and Charlottetown. The amplitudes of the variations are near 15cm at the head of the Estuary but decrease to 6 cm at Rimouski and Charlottetown. Cross-examination with the available meteorological records at the same sites or nearby shows that the seasonal variations in the atmospheric pressures can account for 34%, 26% and 12% of the seasonal sea level variations for these 3 stations respectively (Figs. 4d-i). It is interesting to note that from the head of the Estuary to the tail of the Gulf, the inverse barometer effect decreases. Also interesting to note is that the variations in the narrow upper reach and the variations in the broad open lower reach are 180-degree out of phase (compare Fig.4a or Fig.4b with Fig.4c).

5 Century-Record Storm Surge

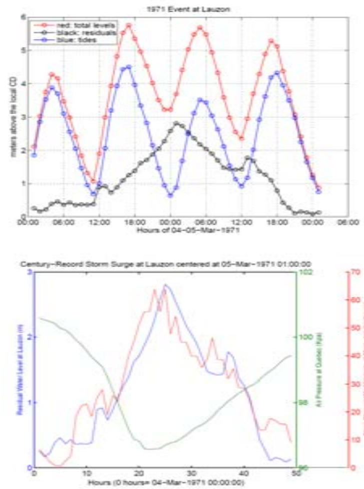


Fig. 5: A century-record storm surge event at Lauzon was identified and examined. This surge lasted from March 4 to 6, 1971 with its peak value of 2.81 m at 1:00 (UTC) on March 5. The peak did not occur at high tide fortunately. Had it occurred 8 hours earlier or 4 hours later, Quebec City would have been flooded heavily (Fig. 5a). This surge was caused by a low-pressure system passing over Lauzon and moving eastward. The associated strong winds blowing along the channel of the Estuary towards Lauzon may also have played its role (Fig. 5b). Due to highly correlated winds and air pressures, more than 80% of the variance of the surge can be explained either by air pressure alone or by winds alone, but only up to 87% by the winds and the air pressure jointly.

6. Summary:

1. Falling and rising of long-term sea levels co-exist in the Estuary and Gulf of St. Lawrence. The rising rates are between 22 to 33 cm/century in the south and east parts of the Gulf and its vicinities. The falling rates are between 3.4 to 6.4 cm/century in the Estuary and northern coast of the Gulf. It seems that the positive and negative post-glacial re-adjustment in the seabed in the different locations either enhances or offsets the global sea level rising.
2. Both Lauzon and Charlottetown show significant shortening of the return period of storm surges in the last half century. An event that used to occur once in 20 years on average now only takes about 4 years to return, and the bigger the events are, the shorter their return periods become. However, such significant change is not seen in Rimouski. Further investigations are needed along this line.
3. There are seasonal variations with amplitudes of about 15 cm at Lauzon and of about 6 cm at Rimouski and Charlottetown. The inverse barometer effect can account for 1/3 of the variations at Lauzon but only 1/10 at Charlottetown. The out-of-phase changes between Lauzon and Charlottetown is an interesting phenomenon, so is the gradational changes in the amplitudes of the annual mean sea levels between the two places.

This project consists of two parts, the statistical part and the hydrodynamic modeling part. Presented here are the initial statistical results. Our next step is to establish a hydrodynamic numerical model, which will allow us to simulate the water level variations under various conditions and gain better understanding of the phenomena reported here.

7 Acknowledgement:

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