17C.3 BAROTROPIC WAVES GENERATED BY STORMS MOVING RAPIDLY OVER SHALLOW WATER

Doug Mercer*, Jinyu Sheng, Richard Greatbatch, Josko Bobanovic
Meteorological Service of Canada and Dalhousie University, Halifax, NS, Canada

1. 1999 AND 2000 EVENTS

On October 25, 1999, an unusual wave event occurred in southeastern Newfoundland, Canada (Figure 1). There were numerous reports of water rising and falling with a period of tens of minutes and peak-to-trough displacement of 2 to 3 m, damaging wharves and causing local flooding. The total event lasted for about one to three hours. Weather conditions were good, with light to moderate winds and no significant waves in any of the harbours affected.

The wave behavior at the various harbours is generally consistent with barotropic shallow water gravity waves. The wavelength is long enough (tens of kilometres) so that most witnesses reported just rises and falls of the water level, although some long, narrow, and shallow harbours reported a tidal bore. Most harbours affected were facing approximately eastward. These characteristics are consistent with tsunami-like waves generated and propagating from the east.

However, the Geological Survey of Canada reported no seismic events in either Eastern Canada or the Atlantic Ocean of sufficient magnitude to produce a tsunami within the previous 24 hours. The next most likely cause is a sufficiently strong underwater landslide or slumping event. While possible, there was no evidence for such an event.

On that day Tropical Storm Jose approached the Grand Banks from the southwest with a translational speed of about 30 m/s or 60 knots (Figure 1). It passed east of the Banks at about 15:30 local time and the coastal effects occurred about 3 hours later. This raises the possibility that the unusual events observed at the coast can be explained by waves generated in the vicinity of the storm and propagating towards the shore. If the wave propagates from the eastern shelf break of the Grand Banks at the average shallow water wave speed for this area about 30 m/s), it would reach the shore at about the right time. Note also that the translation speed of the storm was near the local gravity wave speed over the Grand Banks, suggesting a significant non-isostatic ocean response to the atmospheric pressure forcing by the storm, which we believe generated the waves in question.

On September 25, 2000, a similar event occurred. As before, over the coastal region little wave action prevailed with generally light winds. Areas on the Avalon Peninsula which reported events in 1999 had almost identical descriptions of the events in 2000, with the intensity being a little higher in 2000. Again, there was no evidence of a significant seismic event. On that day, Tropical Storm Helene traveled across the Grand Banks on a similar path to Jose of the previous year, but closer to the Island of Newfoundland (Figure 1). Again, it was a compact storm moving over the Grand Banks with an average speed of about 30 m/s. It is interesting to note that, as in the previous year, the coastal events occurred several hours after the storm crossed the Banks. The fact this happened on both occasions supports the view that the coastal events were a consequence of the offshore storms.

2. BACKGROUND

There has been little or no study of the generation of barotropic shallow water gravity waves by storms traveling over the Grand Banks of Newfoundland. Furthermore, to our knowledge this type of event has not previously been reported in Newfoundland. Nevertheless, there is evidence that translating atmospheric pressure disturbances can generate barotropic gravity waves with significant consequences. For example, Ewing etal. (1954) discuss unusually large and rapid changes in water level around the shores of the Lake Michigan and Lake Erie, which they attribute to translating atmospheric disturbances. In each case, the disturbance was translating at a speed comparable to the local shallow water gravity wave speed in the lake, implying a significant non-isostatic response to the atmospheric pressure forcing. Ewing et al. also suggest that refraction and reflection of the waves by the variable water depth played a role, something we believe is important for explaining the events associated with Tropical Storms Jose and Helene. Similar phenomena have been reported along the Atlantic coast of the U.S. Harris (1956) and Abraham (1961) have noted that Hurricane Carol in1954 traveled northwards over the mid-Atlantic Bight at a speed comparable to the local gravity wave speed and suggest that part of the storm surge associated with Carol was associated with barotropic gravity waves generated by the atmospheric pressure forcing associated with the storm. Also, a large wave at Daytona Beach in July 1992 is discussed by Churchill et al. (1995) who attribute the wave to forcing by an offshore squall line.

3. MODELLING AND RESULTS

To validate our hypothesis we used a barotropic model solving the shallow water equations and forced by surface winds and pressure (Mercer, 2002). We used an idealized storm moving over idealized bathymetries to both validate the model and to qualitatively study ocean responses. Then we modeled the events of 1999 and 2000 using realistic bathymetry.

As expected, there is a strong non-isostatic response that peaks in intensity when the storm moves

*Corresponding author address: Doug Mercer, Newfoundland Weather Centre, PO Box 370, Gander, NF, Canada, A1V 1M6; e-mail: doug.mercer@ec.gc.ca

near the local shallow water wave speed. This form of the response is a wake similar to a ship wake in shallow water, or to an airplane shock wave. The other effect of importance is the wake behaviour in varying water depth. When the wake moves into deeper water, the higher local wave speeds refract or reflect most of the wake back into shallow water . This behaviour is simple and expected. When applied to the events of 1999 and 2000, they give unusual and rather dramatic results.

For example, the 2000 event was modeled by moving an idealized storm along the observed storm track of Tropical Storm Helene. The storm moved quickly onto the Grand Banks, immediately generated a V shaped wake which grew as the storm crossed the banks, and then the storm moved back into deep water, where the shallow water wave speed is much higher than the translational speed of the storm (thus wake generation stops). The wake that was generated crossing the banks is refracted back towards the coast of Newfoundland in a broad U-turn by the higher wave speeds in deeper water. The timing of shore impact, and the areas reporting significant activity are in general in good agreement with the model results.

Other features of the model results are that the pressure forcing is more important than the wind forcing, that the smaller the length scale of the pressure field the shorter the resulting wave period, and that the Coriolis effect is weak for our length scales.

The Newfoundland weather Centre is currently developing an operational prediction system based on the model developed for this research.

4. REFERENCES

Abraham, G., 1961: Hurricane storm surge considered as a resonance phenomenon*. Proc. Conf. Coastal Eng., 7th* , The Hague, 585-602.

Ewing, M.F., F. Press and W.L. Donn, 1954: An explanation of the Lake Michigan surge of 26 June 1954, *Science*, **120**, 684-686.

Harris, H.D., 1956: Some problems involved in the study of storm surges. *National Hurricane Research Project*, Report 4.

Mercer, D., J. Sheng, R. Greatbatch and J. Bobanovic, 2002: Barotropic waves generated by storms moving rapidly over shallow water, *JGR Oceans*, (in press).

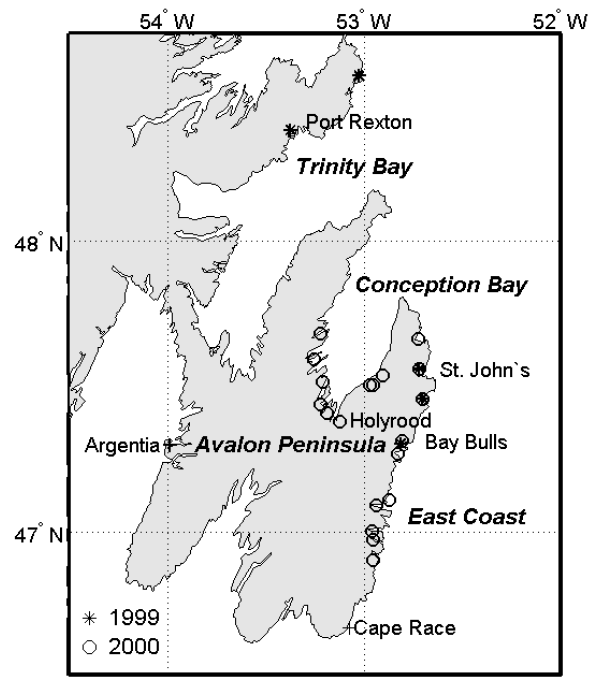

Fig. 1: Southeastern Newfoundland showing locations with reports of wave events in 1999 (stars) and 2000 (circles).

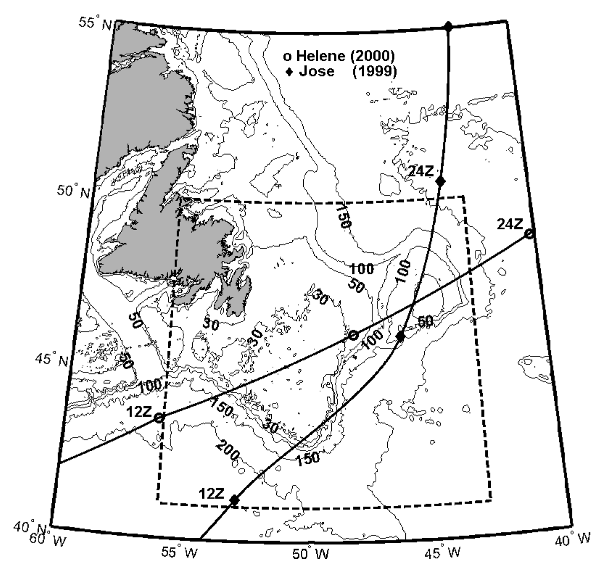

Fig. 2: Map of study area. Newfoundland and Labrador are in grey. Six-hourly storm positions for Tropical Storms Helene and Jose are marked by circles and diamonds, respectively. The contours are shallow water gravity wave speed in m/s. The boundary of the model domain is shown by the dashed box.