



## **A Study of Ocean Waves at Fisherman's Wharf, Victoria Harbour**

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A sequence of very strong wind events on the south coast of British Columbia in December 2006 resulted in some wave damage to the Fisherman's Wharf facility in Victoria Harbour. A hindcast wave modeling study was carried out using the SWAN model to provide quantitative wave information for input to consideration of a breakwater or wave attenuation system built adjacent to the Victoria Harbour facility. The wave study addressed the regional wave conditions in eastern Juan de Fuca Strait to provide open boundary input to a high resolution (10 m horizontal grid) of Victoria Harbour. The high resolution wave model provided computed wind wave generation, current-wave interaction, refraction, diffraction as well as attenuation due to the Fisherman's Wharf floating docks. The model was calibrated and verified for two periods of large wave events measured in March 1976 with wave data available from two temporary Fisheries and Oceans Canada wave stations operated simultaneously in Victoria Harbour. The results from these two cases showed good agreement with independent observations at the innermost wave station located to the west of Fisherman's Wharf. Two cases of very large wave events, which occurred in March 1977 and December 2006, were then simulated using the model. In the first case, observations, with a maximum  $H_s$  of 0.9 m, were available near the Harbour entrance. At Fisherman's Wharf, the  $H_s$  wave heights were always less than 0.40 m on its seaward edge. For the second case of December 12 – 15, 2006 very large wind speeds peaking over 40 knots in Victoria Harbour generated very large waves. The wave model predicted maximum  $H_s$  wave heights of 0.46 m early on December 15 at the seaward edge of Fisherman's Wharf.

## INTRODUCTION

In the second week of December 2006, a sequence of powerful North Pacific Ocean storms crossed Vancouver Island on the south coast of British Columbia, Canada.

The intensification of the storm's winds, in traversing Juan de Fuca Strait, to wind speeds of up to 68 knots, which resulted in widespread power outages due to trees falling across power lines, and homes and vehicles being damaged by fallen trees. In addition, large waves in Victoria Harbour resulted in damage to some of the docks at the Fisherman's Wharf facility (Figure 1) in Victoria Harbour.



Figure 1: Photographs of Fisherman's Wharf, Victoria BC, Canada.

In this paper, we present the results of a hindcast wave modeling study of Victoria Harbour (see Figure 2). The study involved a review of historical wind and wave data sets available over the past 50 years and the implementation and operation of a high resolution numerical wave model (SWAN) to simulate waves at Fisherman's Wharf under extreme wind and waves.

The purpose of the study was to provide quantitative wave information as input to consideration of installing wave protection devices at Fisherman's Wharf.

## HISTORICAL WIND AND WAVE DATA

### Data Review and Selection

Historical measurements of winds and waves over the past 50 years were obtained and reviewed.

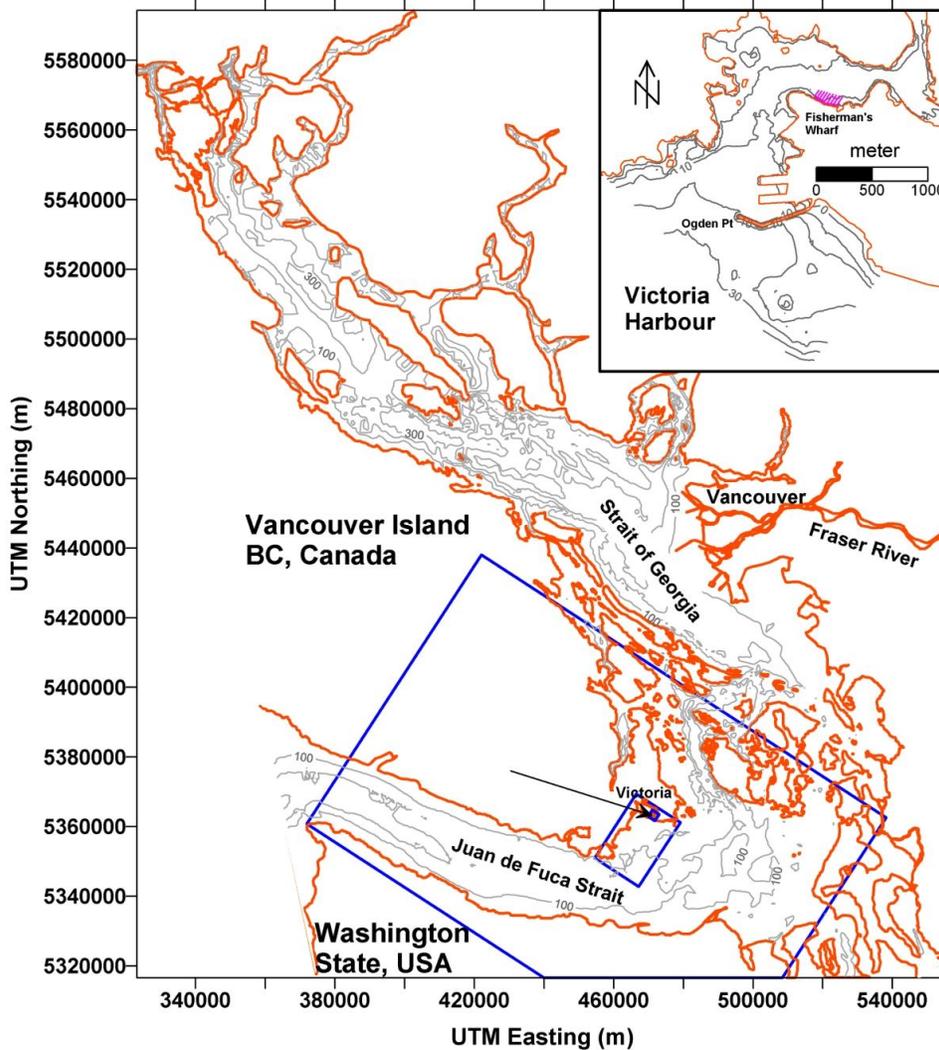


Figure 2: The study area of Victoria Harbour (inset), eastern Juan de Fuca Strait and the southern waters around Vancouver Island BC, Canada.

The key data sets included:

- wind and wave height observations at Race Rocks and Trial Island and other coastal lighthouses (Environment Canada)
- wind measurements in Victoria Harbour (Greater Victoria Harbour Authority and Environment Canada)
- long-standing weather station data sets (e.g. Victoria-Gonzales, Esquimalt Harbour) from Environment Canada and
- long-term wind and wave data sets from the U.S. NOAA (U.S. National Weather Service and the National Data Buoy Center)

The locations of the weather and wave stations are shown in Figure 3 and Figure 6.

Analysis of key long term statistics (including the mean/maximum values and directional distributions) were computed and tabulated by month for wind speed and direction; and wave height, wave period and wave direction (where available).

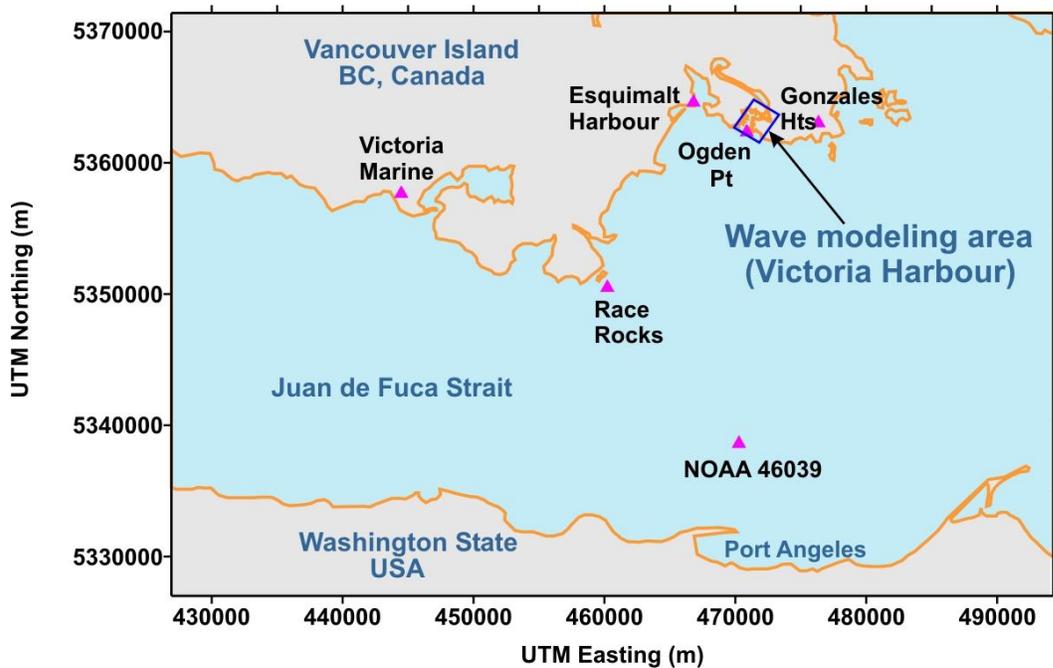


Figure 3: The locations of some of the weather and wave stations in eastern Juan de Fuca Strait. Locations of the wind and wave stations in Victoria Harbour are shown in Figure 6.

### Wind Climatology

Maximum hourly wind speeds attain values of 40 knots (74 km/hr) or more in the fall and winter months (October to March) as shown in Figure 4.

The directional distributions of winds reveal that the largest observed winds (of 40 knots or more) are nearly always from the southwest wind direction, as shown in Figure 5.

Strong winds in eastern Juan de Fuca Strait result from three different large scale weather patterns:

- Pacific Ocean cyclonic weather systems that approach the B.C. coast from the west with strong westerly winds, especially in the fall and winter months.
- Arctic outflow winds in the late fall and winter resulting from high pressure cold continental air masses flowing from the northeast and east to across the Strait of Georgia to Vancouver Island.
- Summertime heating over land and inland waters, resulting in a strong sea-breeze circulation characterized by westerly winds flowing through Juan de Fuca Strait.

Gap Winds: The inflowing air from the west is funneled through Juan de Fuca Strait which represents a gap between the mountain ranges (Overland and Walter, 1981). Gap wind intensification occurs for both the fall and winter Pacific Ocean weather systems and the summertime sea-breeze winds.

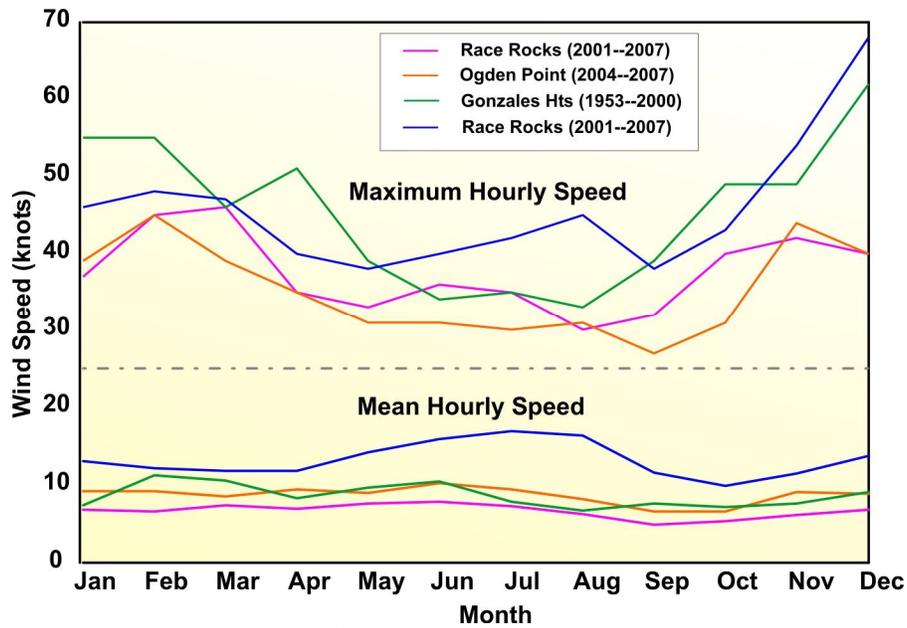


Figure 4: Maximum and mean hourly wind speeds at locations near Victoria Harbour.

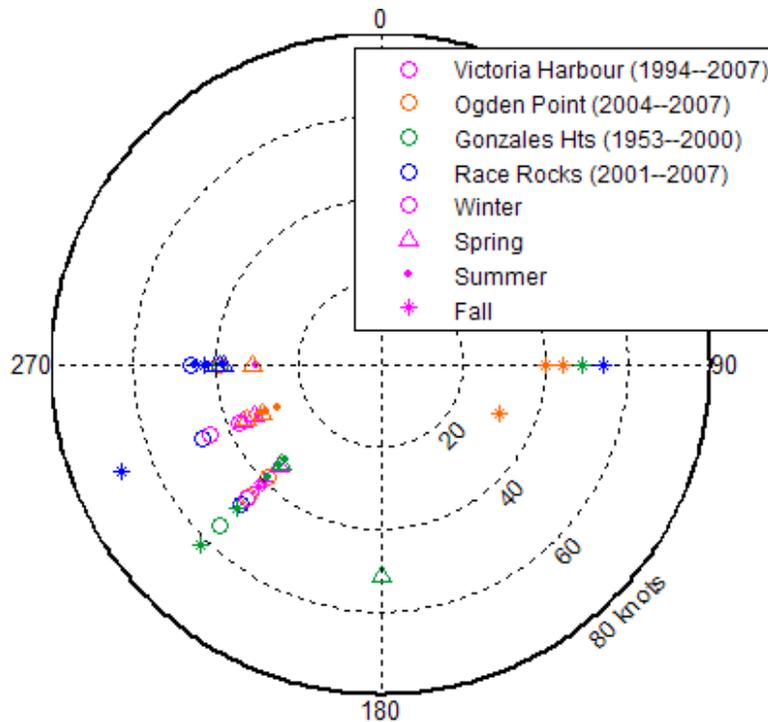


Figure 5: The directional distribution of winds measured at various locations near Victoria Harbour for each season.

### Wave Climatology

The largest wave events occur from November to March. In Victoria Harbour, the available wave data are limited to two waverider buoys, MEDS004 and MEDS095,

operated by the Canadian Department of Fisheries and Oceans from 1975 to 1977. The maximum observed Significant Wave Heights (Hs) were 0.93 m Dec. 1976 at site 4, and 0.61 m on March 18, 1976 at site 5.

In nearby Esquimalt Harbour, the maximum wave height measured over a two year wave record was 0.90 m Hs in December. The largest wave events have peak periods of typically 3 to 5 seconds.

In eastern Juan de Fuca Strait, waves exceeding 1.9 m from November to March, were measured with a peak value of 3.1 m in Feb. 1988. The typical peak periods of 5 to 14 s associated with the largest monthly waves.

## **WAVE MODEL AND METHODS**

### **Regional Modeling**

The regional wave conditions in eastern Juan de Fuca Strait were modeled using SWAN to provide open boundary input to the high resolution model of Victoria Harbour. The model domain area is shown in Figure 2.

SWAN provides the capability to model wind generation of waves, current-wave interaction, wave refraction, diffraction and reflection processes as well as shoaling effects.

The model grid size was 50 m with regional wind forcing and wave forcing on the western boundary provided by ????

### **High Resolution Wave Model of Victoria Harbour**

A numerical nearshore spectral wave transformation model (SWAN) was developed and implemented for this study over the model domain (Figure 6) having an area of 2260 m by 2210 m in total size with a grid size of 10 m. In the model implementation current-wave interaction was included using tidal currents and heights, as computed from tidal analysis components in this region.

### **Wave Energy Transmission Through Floating Docks**

Wave energy can be transmitted and reflected against the floating docks which are about 0.3 m below water surface.

This process was simulated in SWAN using the obstacle command based on:

- each floating dock is represented by an obstacle,
- defined by a straight line with specified wave transmission and reflection coefficients.
- the wave transmission coefficient, *trcoef*, is estimated based on wave energy flux for linear wave theory.

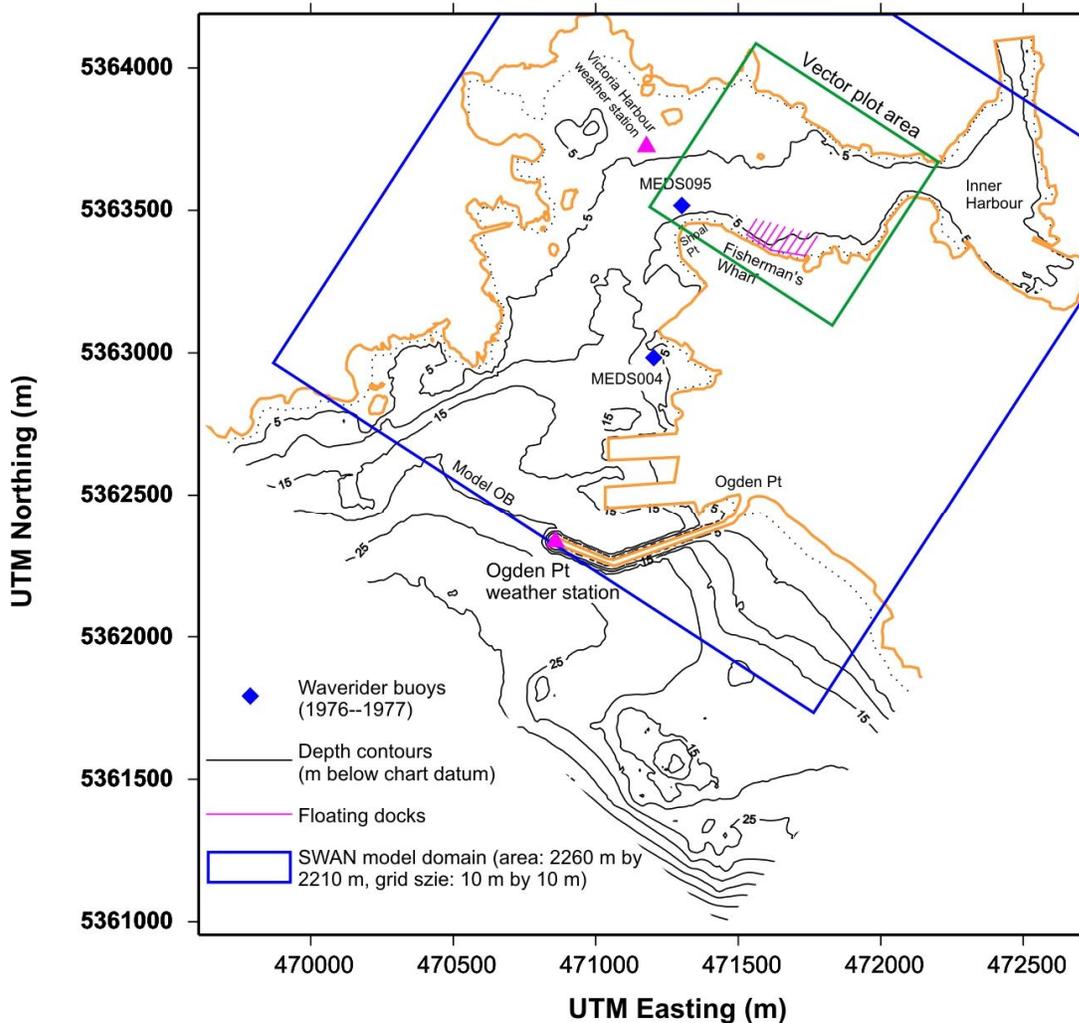


Figure 6: The model domain for the high resolution SWAN wave model of Victoria Harbour. Also shown are the locations of the wind and wave measurements sites used in the present study.

## WAVE MODEL RESULTS

### Wave Model Calibration and Verification

The model was calibrated and verified for two periods of large wave events measured in March 1976 with wave data available from two temporary Fisheries and Oceans Canada wave stations operated simultaneously in Victoria Harbour.

The results from these two cases showed good agreement with independent observations at the innermost wave station located to the west of Fisherman's Wharf as shown in Figure 7.

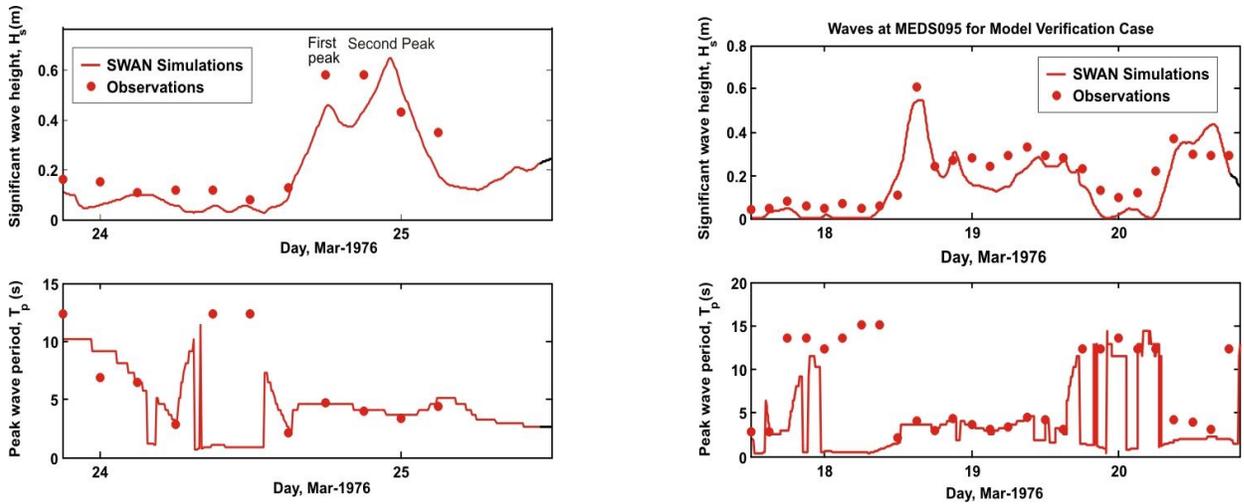


Figure 7: Comparisons of modeled and observed significant wave heights and peak periods for the model calibration and verification cases.

### Modeling for Extreme Wind and Wave Conditions

Two cases of very large wave events, which occurred in March 1977 and December 2006, were simulated using the model.

For the first very large wind/wave event, of March 1977, the observations are available near the harbour entrance at the waverider buoy MEDS004. The observed maximum  $H_s$  at MEDS004 is up to 0.9 m, and model  $H_s$  wave heights are in very good agreement with the data.

At Fisherman's Wharf, the  $H_s$  wave heights were always less than 0.4 m on its seaward edge and less than 0.3 m within the Wharf area. The large reduction of  $H_s$  from 0.9 to < 0.4 m results from the large waves passing to the north and west of Fisherman's Wharf.

The second very large wind/wave event modeled, occurred during December 12 – 15, 2006. This period was characterized by very strong winds, with speeds peaking over 40 knots in Victoria Harbour (and nearly 70 knots at Race Rocks) and distinctly different wind directions varying from E to SW to W, generated very large waves.

The wave model predicted maximum  $H_s$  wave heights of 0.46 m early on December 15 at the seaward edge of Fisherman's Wharf and  $H_s$  wave heights peaking at 0.32 to 0.4 m within Fisherman's Wharf (Figure 8).

Note the importance of the locally generated wind waves associated with winds from the east (Dec. 12) and the west (Dec. 15) as compared to the more common southwesterly winds (Dec. 13). The larger wind fetches of the Dec. 12 and Dec. 15 events result in larger wave heights and shorter wave periods.

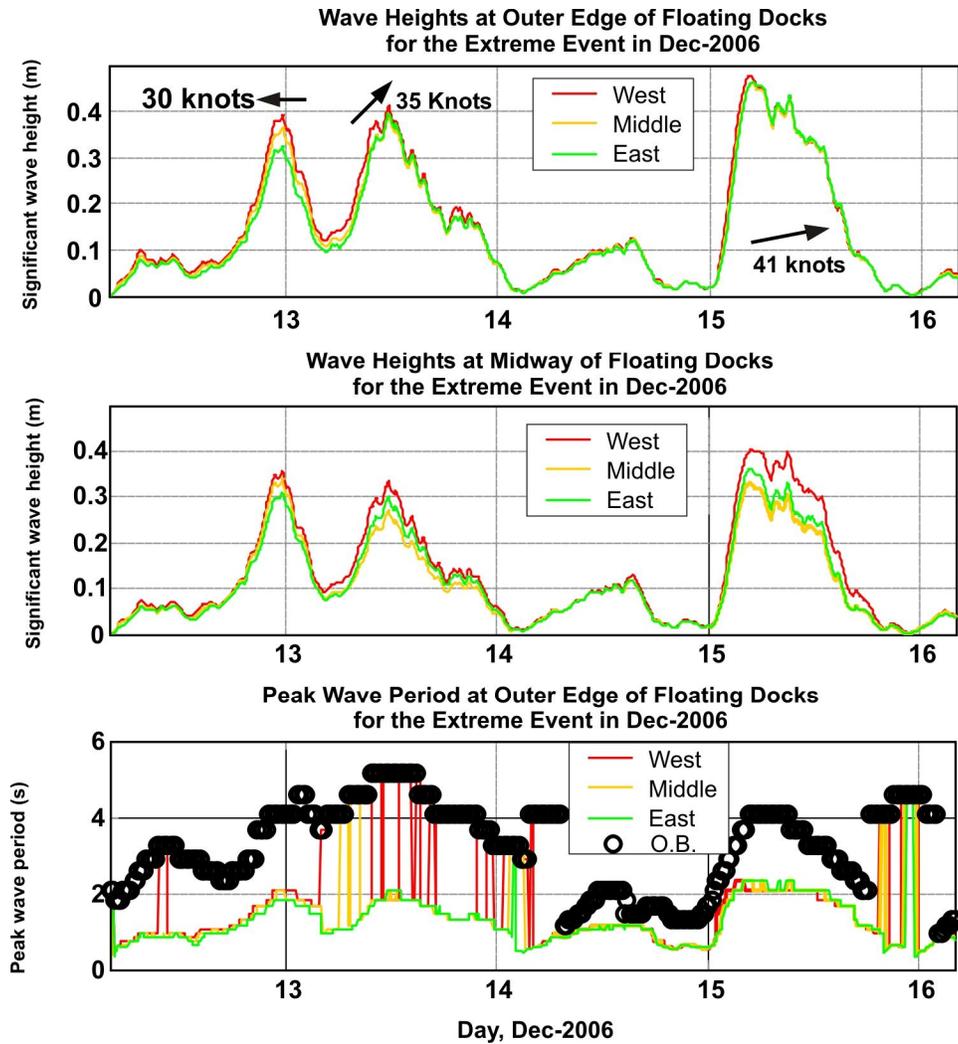


Figure 8: The high resolution wave model results from Dec 12-15, 2006 at the West, Middle and Eastern sides of Fisherman's Wharf, Victoria Harbour. Also shown are the local wind speeds and directions at the times of the maximum wave heights.

The model predictions of wave directions and heights at the time of the very large waves of early Dec. 15, 2006 are shown for the large domain of Juan de Fuca Strait and for Victoria Harbour.

## SUMMARY AND CONCLUSIONS

The numerical wave model demonstrates the sensitivity of the waves at Fisherman's Wharf to the local wind direction along the south shore of the Harbour.

For winds from the southwest or more to the south, the waves at the Wharf are due to local winds blowing off the shoreline and remain small at < 0.3 m Hs even under very strong winds.

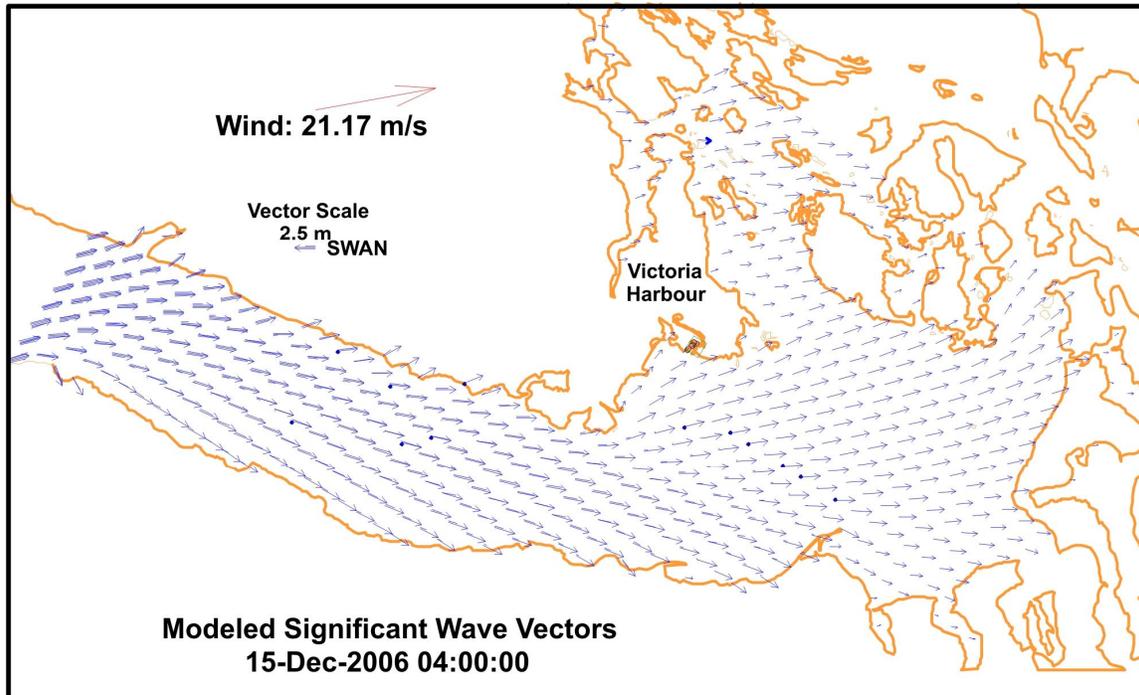


Figure 9: Details of wave model results for Juan de Fuca Strait at 0400 Dec. 15, 2006.

However for winds originating from the WSW – W direction, the wind fetch is larger and the wave heights at Fisherman’s Wharf can be larger by about 50%.

Easterly winds, although less frequent and not as large in magnitude as southwest to west winds, have larger wind fetches and can result in significant wave heights of 0.4 m as demonstrated from the model simulations for the easterly wind event of Dec. 12-13, 2006.

Over all, the extreme WSW – W wind events, such as the one occurred on December 15, 2006, are expected to generate the largest waves at Fisherman’s Wharf with a typical peak wave period of 3 – 4 seconds and significant wave heights of up to 0.5 m.

The wave heights on the seaward edge of Fisherman’s Wharf are nearly uniform with those on the western side slightly larger than at eastern side.

Within the Wharf area, the wave heights in the middle are less than those at the western and eastern sides with the wave heights at the eastern side at intermediate levels.

## REFERENCES

Overland, J.E. and B.A. Walters, Jr., 1981. Gap Winds in the Strait of Juan de Fuca. Monthly Weather Review. Vol. 103, p. 2221-2233.

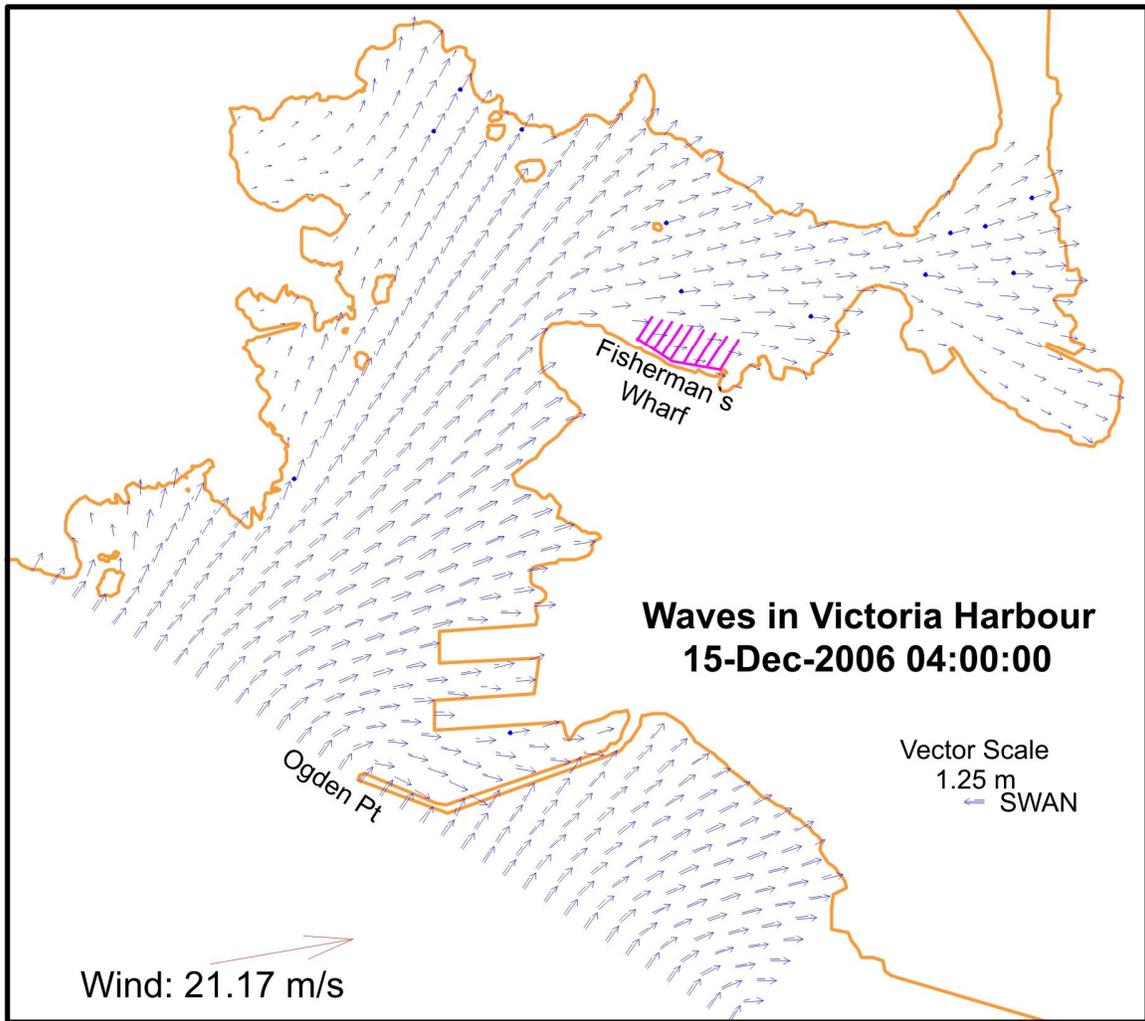


Figure 10: Details of wave model results for Victoria Harbour at 0400 Dec. 15, 2006.