WAVE AND CURRENT FORECAST SYSTEM FOR THE MOUTH OF THE FRASER RIVER

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1. INTRODUCTION

The Fraser River, the largest river in British Columbia, discharges into the Strait of Georgia in a direction that is approximately perpendicular to the direction of tidal currents and winds in the Strait. Consequently, the wave field in the vicinity of the river mouth is changed considerably due to wave-current interactions. Because of concerns regarding navigational safety, prompted in part by a vessel capsize in 2002, MSC obtained funding under the SAR program to develop a forecast system for waves in this region, to be incorporated into the local marine forecast.

Hay and Company Consultants was contracted to develop a wave-current prediction system for the region off Sand Heads, to be used in an operational setting at the Pacific Weather Centre. The original strategy was to perform modelling over a range of conditions, in order to develop look-up tables or nomograms of wave and current conditions for the forecasters, based on forecast winds and tides. With advances in computer technology and model speed, it became possible to develop a model suite that runs daily to produce maps of wave-current conditions for the forecast period, which the forecasters can then incorporate into their bulletins. The forecast system includes observing instrumentation for waves at Sand Heads, a web-cam mounted at Sand Heads, and a suite of numerical models that will generate the forecasts. A discussion of the numerical models forms the basis of this paper.

2. OCEANOGRAPHY OF STRAIT OF GEORGIA / THE PHYSICAL SETTING

The Strait of Georgia (Figure 1) is by far the most important marine region of British Columbia. Global commercial shipping traffic travels through the Strait to the Fraser River Port and Vancouver Harbour. The Strait is also home to one of the largest commercial salmon fisheries in the world, as well as a large recreational fishery. The Strait of Georgia lies between the Coast Mountains of mainland British Columbia and Vancouver Island. On average, it is 222 km long and 28 km wide, with a surface area of 6800 km^2. The average depth is 155 m; while the maximum depth is 420 m, only 5% of the total area has depths greater than 360 m (Thompson, 1981).

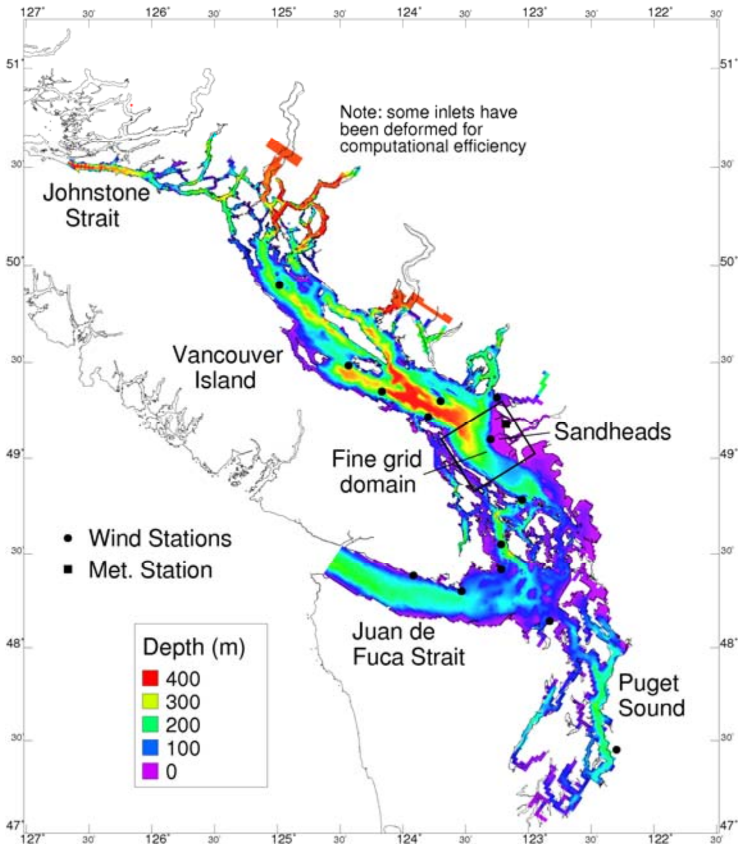

Figure 1. Bathymetry of Strait of Georgia. Wind and met. stations providing observational data to the hindcast model runs are indicated.

To the north, the Strait of Georgia is linked to the Pacific Ocean via several narrow, long channels, notably Discovery Passage and Johnstone Strait, and by the broader Queen Charlotte Strait. To the south it is linked to the ocean via Juan de Fuca Strait (see Figure 1). The eastern coastline is characterized by deep and long fjords, while the western coastline is more regular with few inlets. The largest freshwater discharge into the Strait is the Fraser River, with an important secondary contribution from the Squamish River, and smaller discharges from rivers on Vancouver Island, and rivers that drain into the inlets of the eastern coast and Puget Sound.

Tides in the Strait of Georgia are mixed, mainly semidiurnal. The tidal range near at Point Atkinson is 5.1 m. Except in passes and narrows, tidal streams in the Strait of Georgia are typically weak, and their presence is often masked by wind-generated currents, river runoff and internal tidal effects.

Prevailing winds in the main channel of the Strait of Georgia are predominantly from the northwest in summer and from the southeast in winter. The funneling effects of Juan de Fuca Strait, Puget Sound, and the Fraser Valley impact the overall wind pattern in the Strait of Georgia. For example, southeasterlies can turn to easterlies off the Fraser River.

Temperature and salinity in the Strait of Georgia are primarily governed by estuarine processes: the Fraser River and other freshwater enters at the surface, and oceanic water from the Pacific enters as a deep inflow in Juan de Fuca Strait. Surface circulation in the Strait of Georgia is dominated by the Fraser River plume, especially in the summer months. During low river discharge and frequent strong wind mixing from December to April, salinity in the upper layer increases with depth from 27-28‰ near the surface to 29.5‰ near 50 m depth; areas under direct influence of the Fraser River may have surface salinities of 25‰. The Fraser River freshet in late May causes a layer of brackish water with salinity less than 15‰ to form in the top few metres in most of the central and southern Strait. Near-surface temperatures warm from 5-6ºC in winter up to 15ºC in May. During the freshet, the increased stability created by the brackish layer allows further warming, and in July patches of water in the mid-Strait can exceed 20ºC. By August, the Fraser River runoff has decreased and salinities begin to gradually increase. Although buoyancy and momentum effects associated with the Fraser River plume have a large effect on surface currents, tide and winds are also important, so that surface currents represent a complex combination of river plume, wind-driven and tidal currents. As the Fraser River plume spreads, predominantly to the north, it mixes with the adjacent underlying water, forming an intermediate layer, that has a preferential seaward movement, carrying water of intermediate salinity, typically 29 ‰ or less, seaward. This flow is opposite in direction to the saline inflow from Juan de Fuca, which causes a salinity maximum in the lower waters in about July (Crean et al, 1988).

Wave heights in the Strait of Georgia are limited by fetch more so than by strength and duration. A program of wave observations in Burrard Inlet, off Roberts Bank, and off Sturgeon Bank, yielded wave statistics for the area near Sandheads. During the 26 months of observations, the significant wave height never exceeded 2.1 m off Roberts Bank or 2.7 m off Sturgeon Bank, while maximum wave heights were 3.3 and 4.0 m. The majority of waves in the open Strait off the Fraser River have periods in the range of 2 to 4 s (Thompson, 1981).

The highest and steepest waves in the Strait of Georgia occur where strong currents oppose waves generated by gale force winds over long fetches. One such rip occurs seaward of Steveston Jetty and North Arm Jetty of the Fraser River during west to northwest gales. Extremely dangerous rips are created during the summer freshet or near low tide when currents of the river can reach 2.5 m/s in the main channel. Near the river mouth, shoaling further amplifies wave heights, creating rougher conditions than in adjacent waters. Numerous boats have capsized and occupants drowned when attempting to enter the river during a northwest wind (Thompson, 1981).

3. WAVE-CURRENT INTERACTION

As noted above, waves and currents at the Fraser River mouth frequently interact in such a manner as to provide dangerous conditions of wave height, wave steepness and current shear. The interaction of waves and currents to produce increased wave severity, is well-documented (Jonsson, 1990). For example, wave-current interactions in the Columbia River entrance make it one of the most hazardous navigational regions in the world. Wave height can easily be doubled in a few hours from slack to ebb.

The theory describing this interaction has also been presented in several papers (Komen et al., 1990). From a kinematic point of view, an observer travelling at the speed of the ambient current would see waves whose intrinsic properties k and σ satisfy the dispersion relation:

$$\sigma^2 = gk \tanh (kh).$$

An observer in a fixed coordinate system would see wave waves whose frequency n is given by:

$$n = \sigma + \boldsymbol{k}\cdot\boldsymbol{U}.$$

We see two significant aspects of the interaction in this equation: first, the waves only interact with the co-linear component of the current. Second, the frequency is shifted, and if $\boldsymbol{k}\cdot\boldsymbol{U}$ is sufficiently large and negative, for instance, the frequency, and hence propagation of wave energy past a point, reduces to zero. This aspect suggests the dynamical consequences of wave-current interaction: if a wave field encounters a region where the adverse component of velocity increases, say, then the number of waves per unit time decreases, and the wave height will have to increase, to preserve energy flux.

The dynamics of wave-current interaction can be summarized by the action balance equation (Hasselman et al., 1973)

$$\frac{\partial}{\partial t}N + \frac{\partial}{\partial x}c_x N + \frac{\partial}{\partial y}c_y N + \frac{\partial}{\partial \sigma}c_\sigma N + \frac{\partial}{\partial \theta}c_\theta N = \frac{S}{\sigma}$$

In the above, N is the action density, i.e., the energy density divided by frequency; the second and third terms represent propagation in geometric space; and the fourth and fifth terms represent propagation in wave frequency and wave direction space. The term S/σ represents all source and sink terms, such as wind input, wave-wave interaction and shoaling. This is the equation that the numerical model SWAN solves.

Komen et al. (1994) provide a detailed analysis of wave current interactions, summarized here. In wave-current interactions, it is the sensitivity of waves to variations in currents that matters, i.e. the interaction primarily involves the current gradients. The most dramatic effect is found when waves propagate against the current. For a sufficiently large current, wave propagation is prohibited and wave reflection occurs. Without spatial and temporal variability of currents, their effect on waves could be removed by a simple uniform translation of the waves to a coordinate system moving with the current. Inhomogeneity and unsteadiness have different effects on a wave field. Consider a wave moving from an area at rest into an increasing adverse current. Relative wave period and wavelength decrease, resulting in increase in significant wave height. If the current is following rather than adverse, the modulations are reversed.

Another case is a spatially uniform current field, which initially has zero current, then begins to move. All the wave properties remain unchanged, except for the absolute period measured by an observer, which is Doppler shifted. In practice, the situation is more complicated, as currents are neither steady nor homogeneous, so all parameters are affected. Also, real spectra contain wave components with many frequencies and directions, which may obscure the monochromatic behaviour described above. Finally, the interactions can change the wave steepness significantly, which can impact all source terms in the wave energy balance equation.

Wave-current interactions are important in the Strait of Georgia due to the strong currents that occur at the mouth of the Fraser. In fact, the overturning of the Cap Rouge II in 2002, with loss of five lives, was a strong incentive for the Vancouver office of the Meteorological Service of Canada to implement procedures to improve wave and current observations and forecasts at the river mouth. The balance of this paper outlines the numerical modelling and forecast components of this overall study.

4. MODEL FRAMEWORK

Three processes are simulated by the model suite: winds, currents, and waves. The forecast system starts with Environment Canada's 2.5 km GEM-LAM mesoscale atmospheric model. The 36-hour wind forecast is used to drive a sequence of wave and current models, as follows. The wave field is first forecast over a 1-km grid of the entire Strait of Georgia / Juan de Fuca Strait using a parametric model (Donelan, 1977). Simultaneously, currents are forecast over the same 1-km grid, using H3D, Hay & Company's proprietary three-dimensional circulation model. Data from the 1-km H3D circulation model is then used to drive a 200-m grid H3D circulation model of the region around the mouth of the Fraser River, extending west to the Gulf Islands, and north and south to Point Grey and Tsawwassen respectively. Finally, waves from the parametric model, currents from the 200-m grid model, and winds from the 2.5 km wind model, are fed to a third-generation wave model, SWAN (Booij et al., 2004), to provide forecast waves, including wave-current interactions, valid for a 24-hour period.

A parallel implementation of the same models is run continuously in hindcast mode using observed wind data, so that each forecast starts from a continuous hindcast, to avoid introducing any error or bias from the forecasts. The circulation hindcast was spun-up starting from January 1, 2003. The forecast system has been recently installed at the Pacific Storm Prediction Centre and is presently being tested before being made operational.

Marine forecast bulletins are issued at 04:00 PST (12Z), with information for the following 24 hours (i.e. 12Z to 12Z+24). To compensate for the computational time lag between receiving observed data, running the hindcast, and running the forecast, a 30-hour run is required to provide each 24 hour forecast. First, at 08Z, the four circulation and wave models run a 6-hour forecast for 06Z to 12Z on the present day, using the previous day's GEM-LAM forecast data. The 6-hour forecast is initiated using the hindcast data. When the new GEM-LAM data arrives (at roughly 10Z), the four models continue the forecast for the following 24 hours, i.e. starting at 12Z on the current day. The model simulations are complete by 11Z, giving the forecasters some time to interpret the results and incorporate them in their marine bulletin. The model sequence is illustrated in Figure 2.

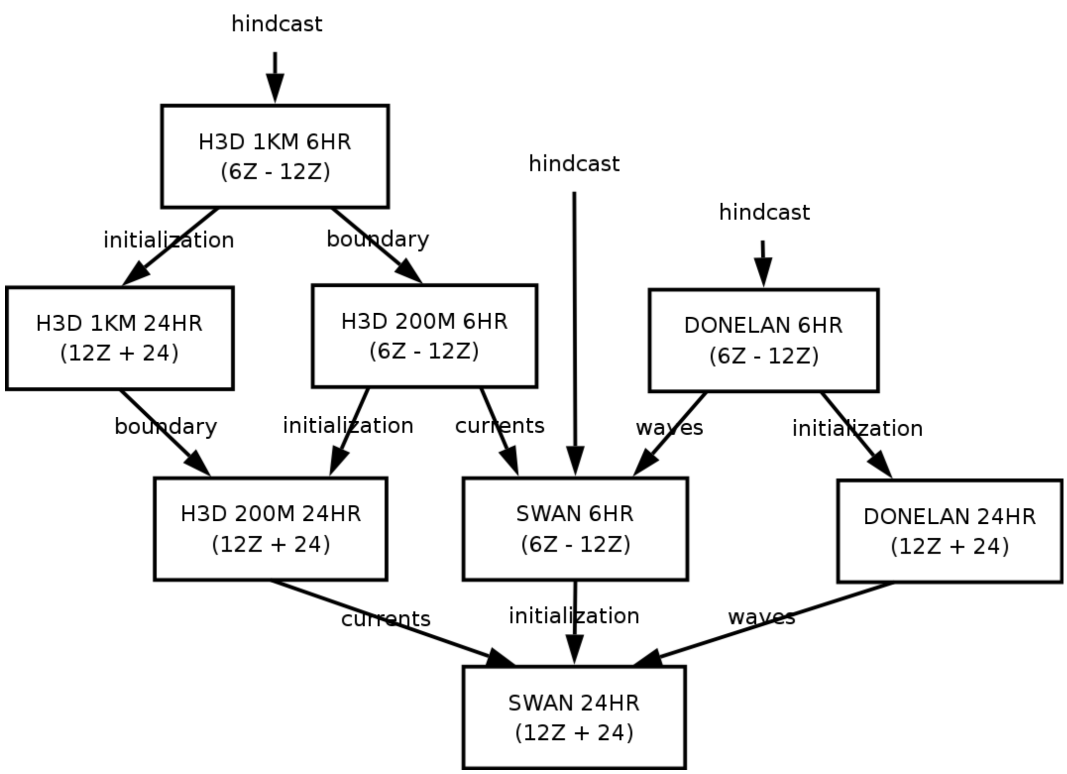

Figure 2. Sequence of model runs to produce 24-hour wave forecast. The GEM-LAM model (not shown) provides forecast winds to all of the models. The 1 km H3D model provides boundary conditions of water levels, currents, temperature and salinity to the 200 m H3D model. The Donelan model provides boundary conditions of wave height, period and direction to the SWAN model. The fine-grid H3D circulation model provides currents to the fine-grid SWAN wave model. A parallel set of models runs continuously in hindcast mode, ingesting observations each hour to provide an up-to-date set of initial conditions for the 30-hour forecast runs.

5. CIRCULATION MODELLING

Currents in the Strait of Georgia / Juan de Fuca Strait are simulated using Hay & Company's proprietary three-dimensional hydrodynamic model, H3D. This model is derived from GF8 (Stronach, Backhaus and Murty, 1993), developed for Fisheries and Oceans Canada. Model validation is presented in Stronach et al. (1993). An extensive application of an operational version of this model to the St. Lawrence Estuary is described in Saucier and Chasseé, (2000). H3D is a three-dimensional time-stepping numerical model that computes the three components of velocity (u,v,w) on a regular grid in three dimensions (x,y,z), as well as such scalar fields as temperature and salinity.

The spatial grid may be visualized as a number of interconnecting computational cells collectively representing the water body. Velocities are determined on the faces of each cell, and non-vector variables, such as temperature or salinity, are situated in the centre of each cell. All cells have identical x and y dimensions. In the vertical, the cells are usually configured such that they are relatively thin near the surface and increase in thickness at depth. The increased vertical resolution near the surface is needed because much of the variability (stratification, wind mixing, inputs from streams and land drainage) is concentrated near the surface. The selection of grid size is based on consideration of the scale of the phenomena of interest, the extent of the grid domain, and available computational resources.

H3D is a semi-implicit model, using the numerical scheme described in Backhaus (1983), using the staggered Arakawa C-grid (Arakawa and Lamb, 1977). It uses only two time levels, and computes internal and external modes at the same time. To allow for better simulation of features such as river plumes in conjunction with large tidal excursions, the number of layers is allowed to increase and decrease as water levels rise and fall: new layers are successively turned on as the water level rises, and are then allowed to drain as the water level falls. This feature allows plumes that have vertical dimensions of one or two metres to be resolved in the presence of tidal ranges of five metres, certainly an important consideration given the tidal ranges in the Strait of Georgia and the Fraser River flow. This has been shown to work well for simulations of the Fraser River as it enters the Strait of Georgia, as evidenced in Figure 3. Also, a flood-dry algorithm allows the water layers to appear and disappear over the shallow foreshore banks during the tidal cycle.

Two separate H3D implementations are required in this model system. A 1-km resolution model of the entire Strait of Georgia and Juan de Fuca Strait (SoG/JdF) provides boundary conditions for a nested 200-m grid fine resolution model of the area off Sandheads (Figure 1). The following discussion provides characteristics common to both models.

- The principal driving force is due to water level fluctuations, primarily tidal, derived from water level variations at the open boundaries of the model. Tidal fluctuations are computed from tidal constituents for the open boundaries of the 1-km model (Johnstone Strait and Juan de Fuca Strait), and are provided from the 1-km grid model to the 200-m grid model as a time series.
- Wind forcing causes both currents and water level differences. Consideration of wind forcing is also important since wind energy has a significant impact on vertical mixing, and hence scalar distributions. For the hindcast mode, wind stresses acting at the water surface are derived from wind records collected from coastal Environment Canada stations and moored buoys (shown in Figure 1). For the forecast mode, wind data is provided on a 2.5-km grid from the GEM-LAM mesoscale atmospheric model. In both cases, the data is processed into hourly time-series of over-water winds at the observation points, and then interpolated in two

dimensions to the model grid.

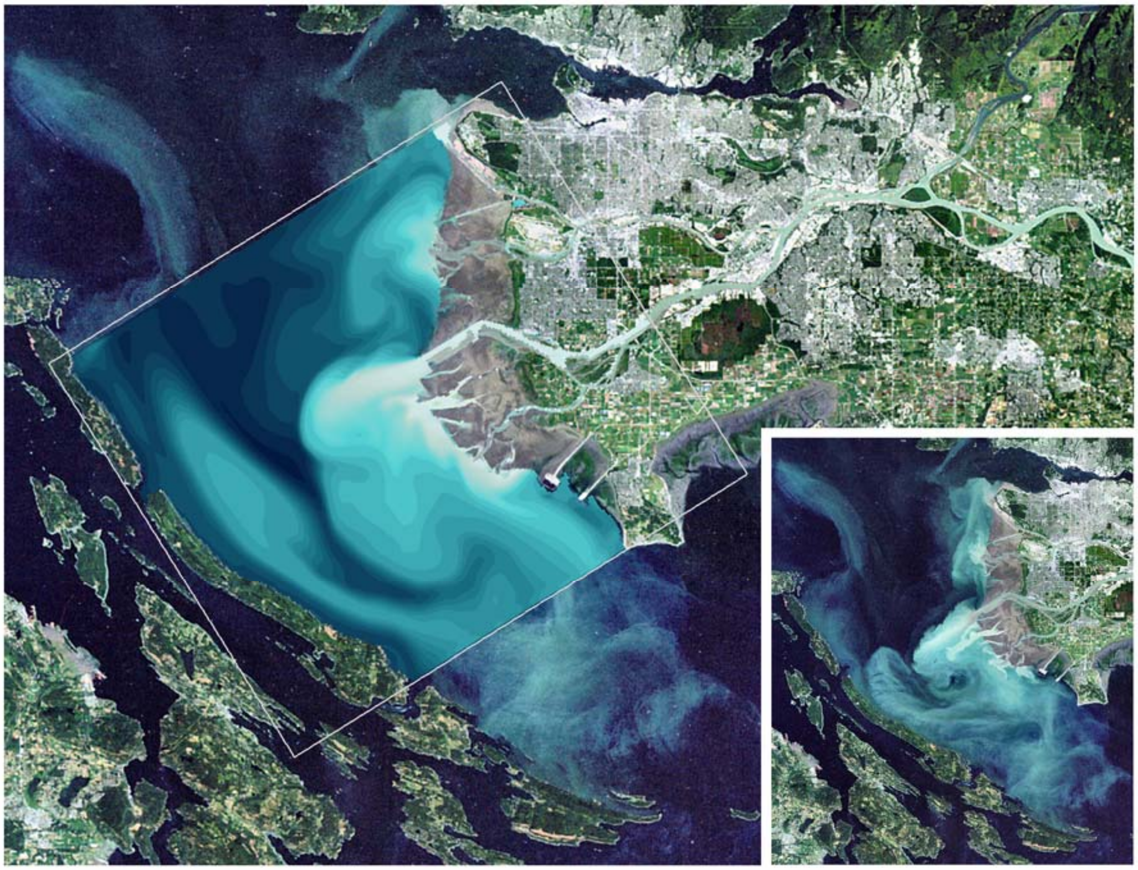

Figure 3. Model output overlaid on satellite photo; inset shows original photo. The photo and model show the silt-laden Fraser River plume circulating in the Strait of Georgia on July 30, 2000. Time of day inferred from tidal elevation is 12:00 PST. The 1-km and 200-m nested H3D models were spun up for one month. A source of fine sediment was specified at the upstream limit of the Fraser River. The model replicates very well the distribution of the sediment plume and eddies in the Strait.

- It is important to keep the temperature field realistic because of its effects on density and hence circulation. Besides winds, other meteorological data are also required in order to compute heat flux into the water body. In most applications, data is limited for calculating heat flux across the water surface. Reasonable estimates can be made from wind speed, wet bulb and dry bulb air temperatures, and cloud cover or insolation. In this implementation, observed data from Vancouver Airport are applied over the model domain. In the summer, heat input leads to increased temperature stratification. In the winter, when salinity stratification is often minimal, cooling can lead to static instabilities and overturning in the upper part of the water column. Since the model is run over all seasons, the ability to simulate winter cooling is important. To treat winter cooling effectively, H3D includes a convective overturning mechanism, so that if, for instance, the surface cell in a particular water column cools to the point that it is denser than the cell beneath it, H3D will vertically mix the water in these two cells, thus propagating the cooling process downward. H3D's ability to simulate both summer heating and winter cooling can best be seen in simulations conducted for freshwater lakes, (e.g. Zaremba et al., 2005), where temperature is the only scalar affecting density.

- The model incorporates inflows from major rivers in Canada and the US. These inflows contribute mass and momentum to the water body, and introduce fresh water to the Strait, an important source of stratification. The boundary condition at each river is represented by a time varying flow rate. For all rivers other than the Fraser River, the flow rate is interpolated from monthly mean values calculated from analysis of long-term records. To capture the Fraser River input, the 1 km three-dimensional model is coupled to a one-dimensional model of the Fraser River which propagates daily flow records at Hope to New Westminster, the upstream limit of the Fraser River in the 1-km model. The Fraser River flow is provided from the 1-km model to the 200-m model as boundary conditions of currents, temperature and salinity.

- Turbulence modelling is important in determining the correct distribution of velocity and scalars such as temperature and salinity. The diffusion coefficients for momentum and scalars at each computational cell depend on the level of turbulence at that point. H3D uses a shear-dependent turbulence formulation in the horizontal, (Smagorinsky, 1963) and a shear- and stratification-dependent formulation in the vertical for momentum, a procedure referred to as the Mellor-Yamada Level 2 scheme (Mellor and Yamada, 1982), a local boundary layer simplification of the full turbulence closure model. These parameters have been shown to work well when simulating the annual cycle of salinity and temperature in the Strait of Georgia, which has been calibrated and validated in previous projects (e.g., Stronach, Backhaus and Murty, 1993). For scalars, such as salinity, constant horizontal eddy diffusivity is used, and the vertical diffusivity is similar to the vertical eddy viscosity, but scaled by a fixed factor of 0.1, a value found to work well for coastal waters of British Columbia.

- The model operates in a time-stepping mode over the period of simulation. The time step is variable, depending on the maximum velocity present in the model at that particular timestep. During each time step, values of velocity, temperature, and salinity are updated in each cell. Data are archived (saved to disk) on an hourly basis, so that a manageable amount of data is generated for subsequent analysis for forecasts.

- The model is initialized with salinity and temperature fields obtained by interpolating observations for 2003 archived at the Institute of Ocean Sciences. The coarse-grid model was spun up from January 1, 2003, and the fine-grid model was spun up from January 1, 2006. In addition, historical data from IOS is used to provide time-varying boundary conditions for temperature and salinity at the open boundaries of the coarse grid model (Johnstone Strait and Juan de Fuca Strait).

For this study, H3D is implemented in a nested configuration, as mentioned above. The coarse (1-km) grid and fine (200-m) grid models are run separately. One-way communication from the 1-km grid model to the 200-m grid model is implemented using binary direct access files. The coarse grid SoG/JdF model thus provides the necessary hydrodynamic boundary conditions to the fine grid Sandheads model (Figure 4). The currents from the 200 m model are exported on an hourly basis for input into the SWAN wave model, which computes the wave-current interactions.

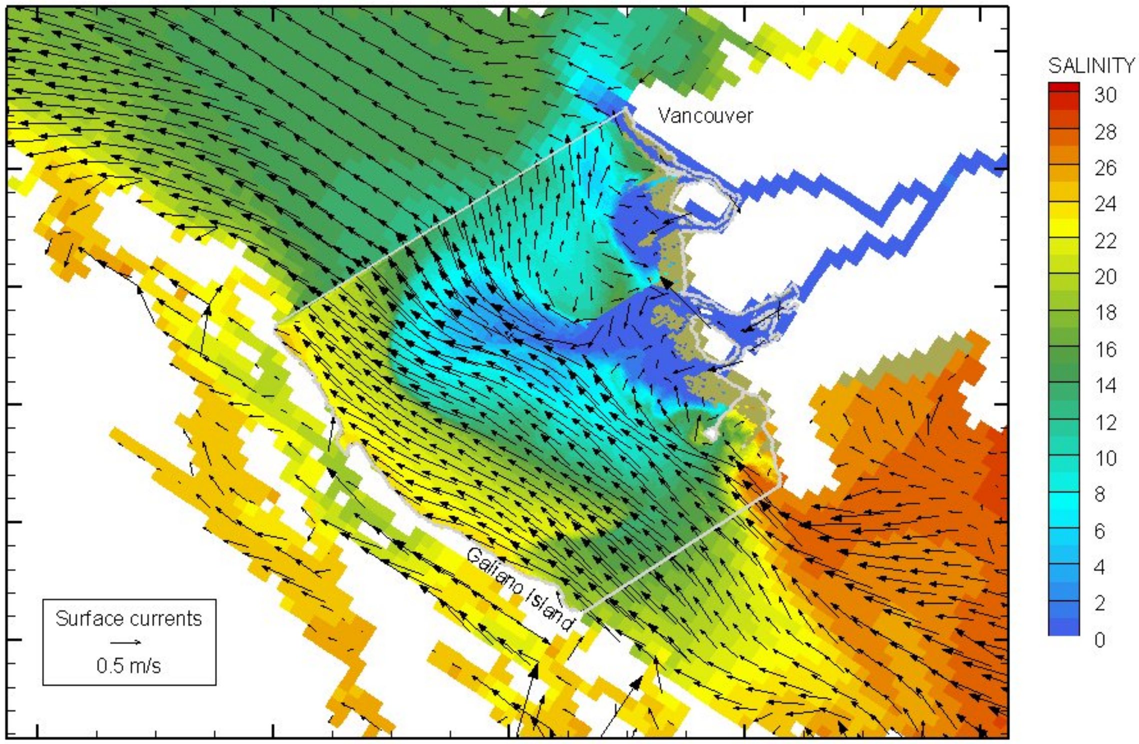

Figure 4. Surface currents and salinity (i.e. top 1 m of water column), for 1-km and nested 200-m H3D models. Note rotation angle of 24.5° between the two grids. The figure shows every second vector for the 1 km model and every eighth vector for the 200 m model. Large vectors in the Fraser River have been blanked in the 1-km model. Simulation time is 13:00 PST on June 13, 2003, during the peak of the Fraser River freshet, about 2 hours after high tide (drying banks in light brown). The figure shows the front of fresh water flowing from the Fraser River into the Strait of Georgia, with more saline water intruding from Juan de Fuca Strait. The current and salinity fields of the two models match well along the boundaries.

6. WAVE MODELLING

Two wave models are used in the forecast system. The Donelan deepwater wave model is run for the entire Strait of Georgia, and provides boundary conditions for the nearshore wave model SWAN.

6.1 DEEPWATER WAVE MODEL – DONELAN

The Donelan model is a two-dimensional parametric wave prediction model that is suitable for use in enclosed basins where all waves are locally generated (as opposed to swell propagating from the open sea). The model computes deep-water waves only; that is, the effects of shoaling and refraction are not incorporated. The model was validated against wave data in the Strait of Georgia, and produces remarkably accurate hindcasts (Figure 5). It should be noted that two parameters (eddy diffusivity and frequency parameter) were modified from the values suggested by Donelan to calibrate the model in the Strait of Georgia.

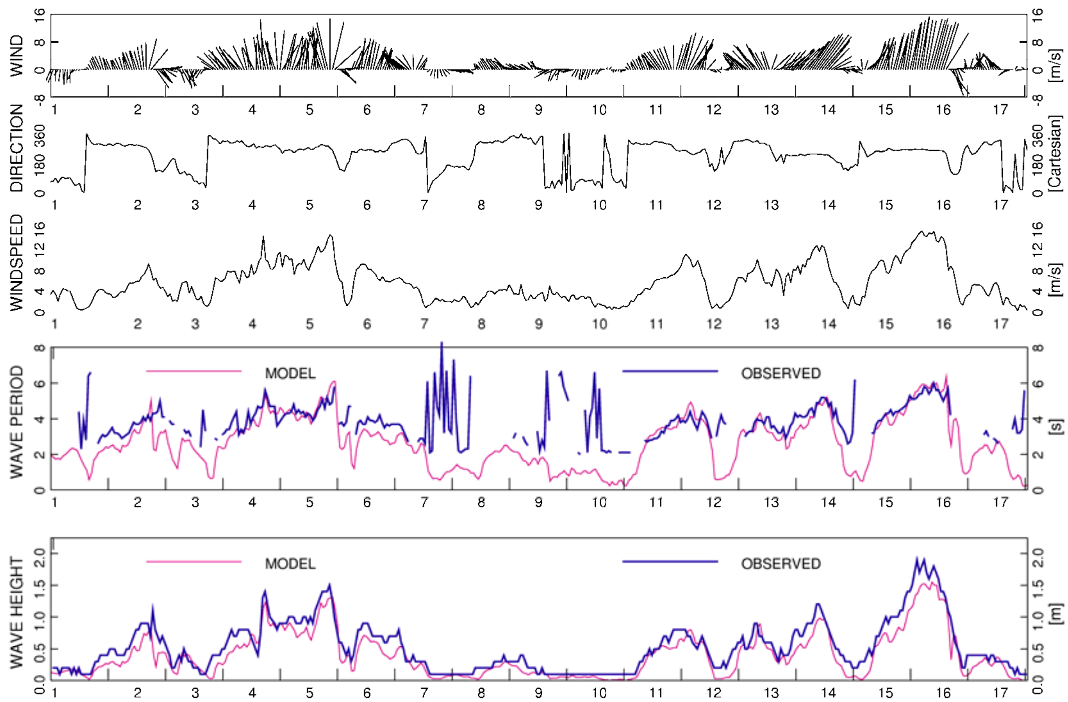

Figure 5. Hindcast of waves at Halibut Bank, December 1 to 17, 2003. Observed data is from the Halibut Bank buoy. Anomalous wave period records have been removed. The Donelan model was run for the entire Strait of Georgia, and modelled data extracted at Halibut Bank. Winds for the model were interpolated from a network of AES stations. Plotted winds were extracted from the interpolated field at Halibut Bank.

The model requires a two-dimensional, time-dependent wind field as input. In this case, in hindcast mode the wind field over the model domain is developed from the following Environment Canada stations: Ballenas Island, Discovery Island, Entrance Island, Grief Point, Halibut Bank, Kelp Reef, Point Atkinson, Race Rocks, Sandheads, Saturna Island, Sentry Shoal, Sheringham Point, and Sisters Island, as well as Smith Island and Seattle-SeaTac in the US (see Figure 1). The effects of fetch (distance from shore) and duration (length of time the wind has been blowing) on the wind-generated wave field are automatically incorporated in the model.

The Donelan model provides estimates of wave height, wave period and wave direction at all grid points in the basin, typically for every hour of the simulation period (Figure 6). In the operational mode, the Donelan model output is extracted along the boundaries of the 200 m resolution grid (indicated by dashed lines in Figure 6) on an hourly basis and applied as boundary conditions to the SWAN wave model.

6.2 NEARSHORE WAVE MODEL – SWAN

The SWAN model (Booij et al., 2004) is a third-generation wave model used to determine wave transformations as the deepwater waves enter the shallower nearshore areas. The model is based on the wave action balance equation with sources and sinks. It utilizes a finite difference scheme to compute random, short-crested wind-generated waves and allows for spectral wave input at specified boundaries. SWAN incorporates physical processes such as wave propagation, wave generation by wind, whitecapping, shoaling, wave breaking, bottom friction, sub-sea obstacles, wave set-up and wave-wave interactions in its computations. SWAN is also capable of simulating wave-current interactions, a main reason for selecting it for use in the forecast system.

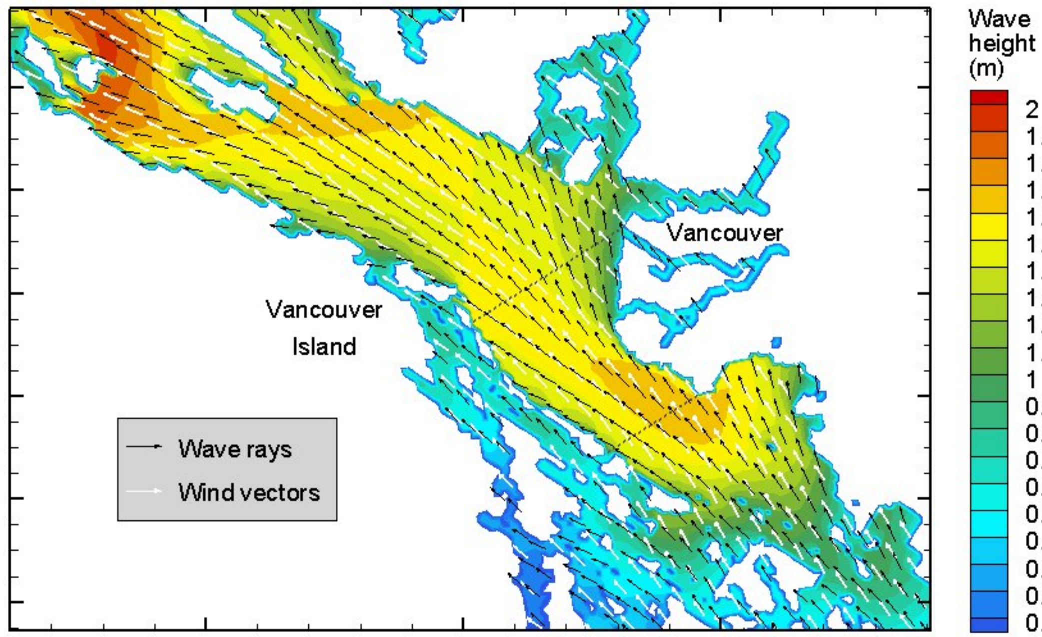

Figure 6. Donelan model output of wave height and direction for 10:00 PST December 16, 2003, along with the forcing wind field. Note: entire model domain not shown. The wave rays (black) are shown for every fourth grid cell while the wind vectors (white) are shown for every fifth cell. Vectors have uniform length. Dashed lines indicate boundaries of the 200 m resolution grid.

SWAN is implemented in non-stationary mode to replicate the growth and decay of storm waves. All input data are provided on an hourly basis. The deepwater waves from the Donelan model at selected grid points along the northern and southern boundaries of the 200 m grid are used as the boundary conditions for SWAN. A two-dimensional wind field is provided as input to the model by interpolating the data from the AES network for hindcast mode, and interpolating from the 2.5-km GEM-LAM data for forecast mode. Surface currents over the SWAN model domain are supplied from the 200 m H3D hydrodynamic model.

To validate the SWAN model, the grid was extended northward to encompass the Halibut Bank wave buoy. The simulation was run for December 2003, using boundary conditions from the Donelan validation run. The SWAN wave height matches observations closely, but the peak period is somewhat low (Figure 7). Parameters were adjusted to attempt to increase the peak period, but this occurred at the expense of the agreement between modelled and observed wave height, hence the parameters were set back to default values.

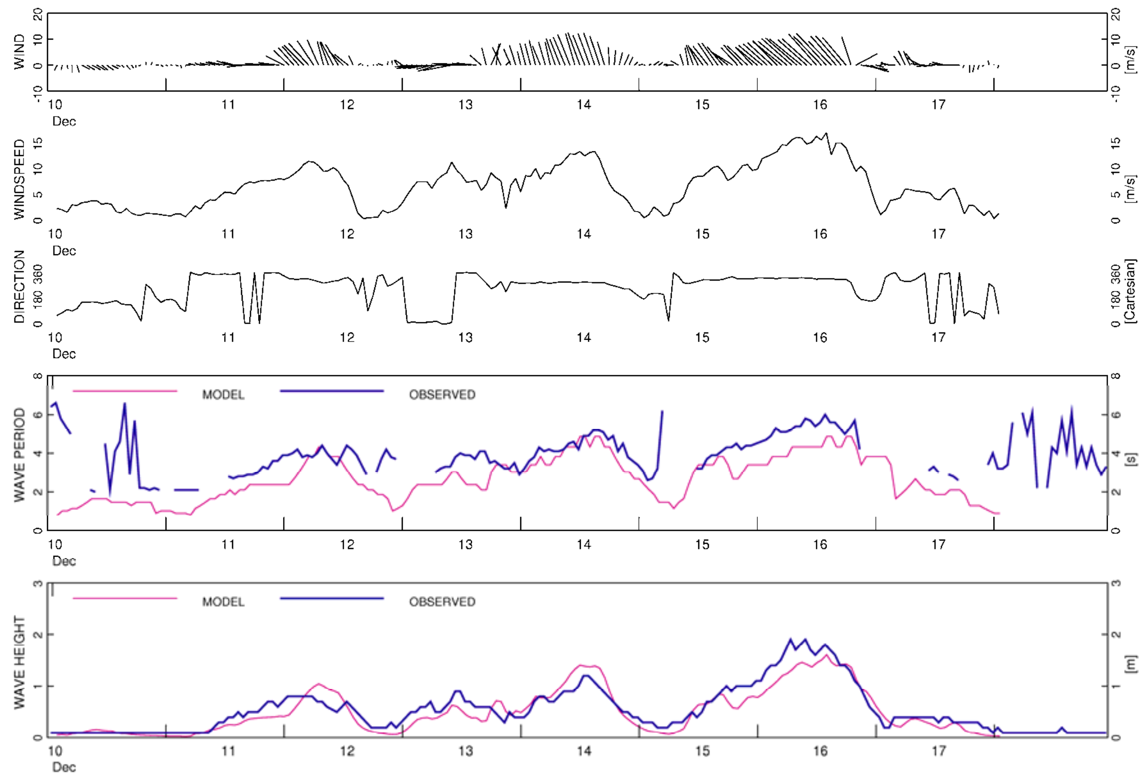

Figure 7. Validation of SWAN model against Halibut Bank observations. Winds and observed waves are same as Figure 5. Model data is extracted from SWAN run at Halibut Bank location.

6.2.1 FORECAST APPLICATION

SWAN computes a wide range of wave parameters over the specified grid. Relevant parameters to describe the wave field for the marine forecast were selected for graphical output (Figure 8) using the commercial software package Tecplot, and are provided on an hourly basis. The forecaster's display shows four maps of wind, wave and current fields. The top left panel shows the wind field, with the contour shading showing wind speed, the unit arrows showing wind direction. Bathymetry is shown by contour lines. The top right panel shows wave height and direction. Wave height is shown by contour shading, and wave direction by unit vectors. The bottom left panel shows a contour map of wave period. The bottom right panel shows a contour map of wave steepness and current direction, again using unit vectors. We note in this panel that the impact of the Fraser River currents, around the river mouth, is to reduce wave steepness, because of the enhanced velocity component in the direction of wave propagation at this particular time. Using built-in features of Tecplot, the forecasters are able to query the results for each hour of the 24-hour forecast, in order to summarize the forecast for a worded marine bulletin.

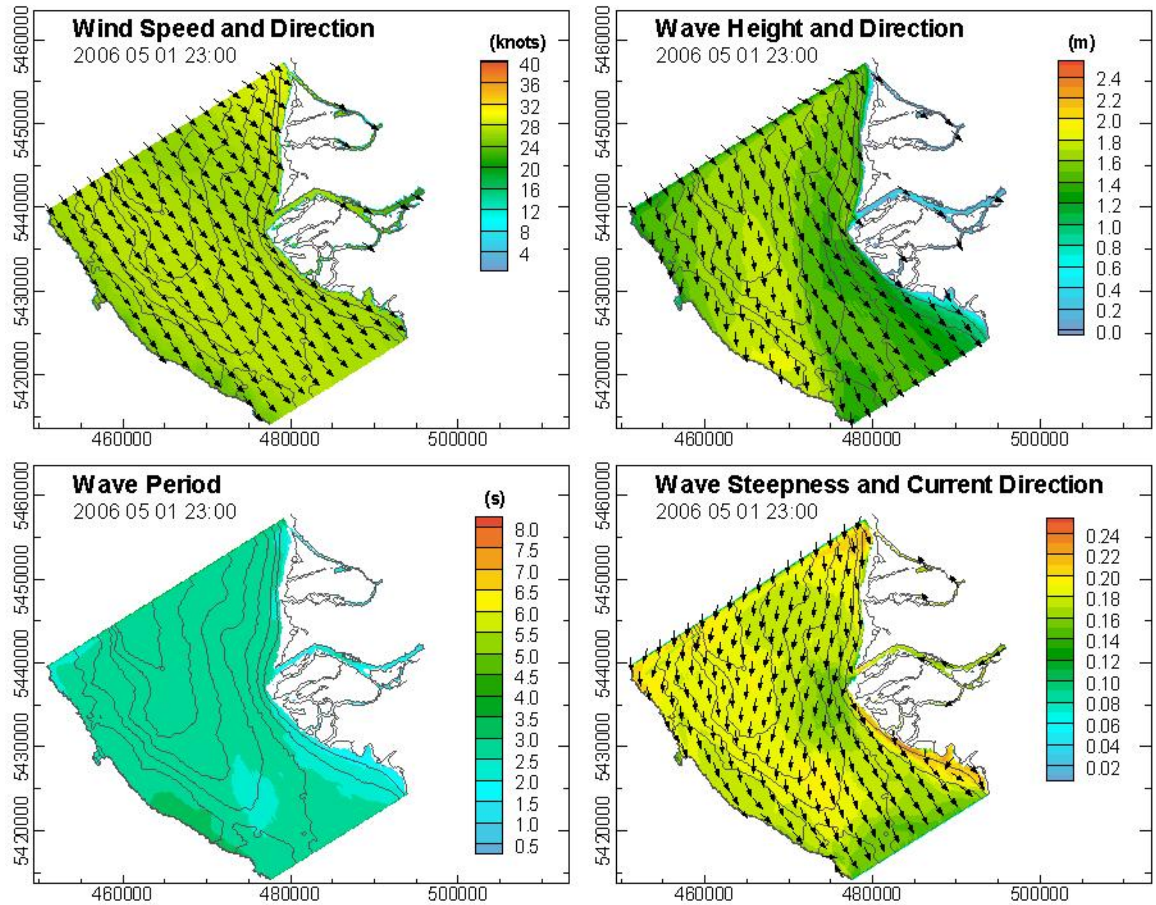

Figure 8. Graphical output from forecast system. The SWAN wave model produces hourly plots which the forecasters summarize in the marine bulletin.

6.3 WAVE-CURRENT INTERACTION

The fields shown in Figure 8 did not indicate significant wave-current interactions, at the particular time selected for display. As an example of the potential impact of these interactions in the Strait of Georgia, a synthetic case was generated, using an artificial steady wind field of 17.5 m/s from the northwest. A constant wave field of northwest waves with 2.7 m height and 6 s period was applied at the north boundary. For the case with currents, the flow field corresponding to the freshet peak of the Fraser River was applied to the SWAN model. Figure 9 shows a comparison of the wave height and direction for the case of no wave-current interaction in the left panel, and the effect of including the wave-current interaction in the right panel. On the right panel, the currents are shown as white vectors, with length scaled according to speed. We note that a flood current is running northward, into the incident wind, and deflecting the river plume to the northwest. The colour contoured field is wave height, which we note grows in intensity as the wave proceeds south. The contour lines in this plot are current speed, which help illustrate that as the opposing current increases in speed, moving with the wave field, the wave height increases, to about 3.3 m, and then, as the wave proceeds south past the river mouth, the spatial structure in the field of wave height bears considerable relationship to the contoured speed values, and in particular their gradients, such as at the region near the south, where wave height grows to about 3.6 m.

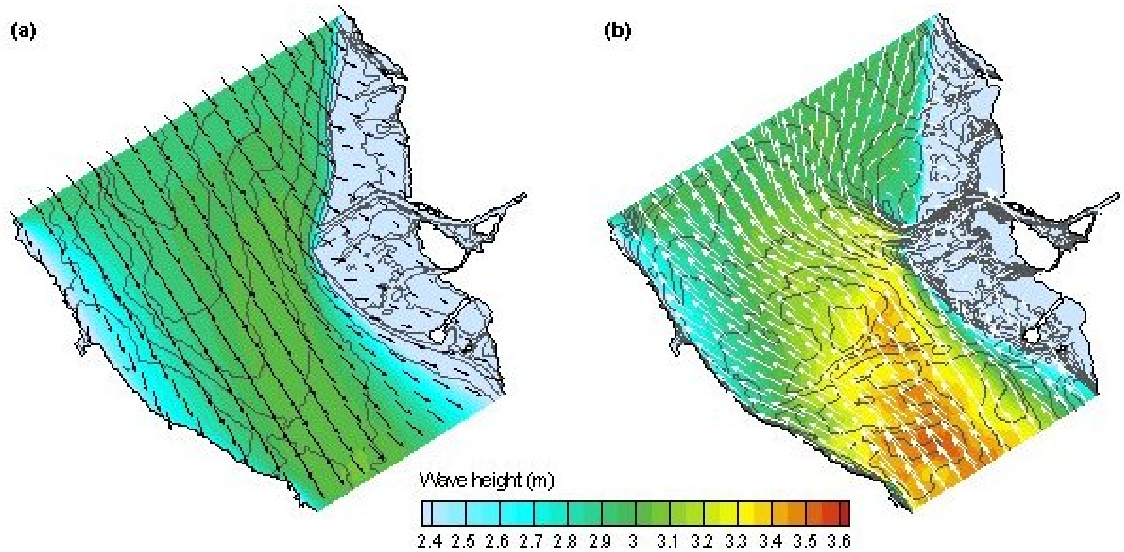

Figure 9. SWAN model results without and with currents, with a synthetic storm. (a) No currents; panel shows wave rays (vectors), wave height (colour contours) and bathymetry (line contours). (b) Currents from H3D model at 12:00 PST on June 13, 2003 were applied to SWAN model; panel shows currents (vectors and line contours), and wave height (colour contours).

7. CONCLUSIONS

An operational system has been developed that combines a three-dimensional circulation model and a third-generation wave model to provide wave and current forecasts for a 24 hour period in the south-central region of the Strait of Georgia, including the mouth of the Fraser River. The various validations for the individual component models give confidence in their use as stand-alone systems. The pair of diagrams in Figure 9 illustrates that SWAN appears to be correctly implementing wave-current interactions. Further confidence in the modelling system will be built up as the data collection program begins to provide data for validation.

8. REFERENCES

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