At coastal boundaries, the partial slip boundary condition, an approximation to no slip, is used. Partial slip allows one to include the frictional effects of lateral boundaries without the restrictive resolution required to represent the lateral boundary layer under no slip conditions. A lateral eddy viscosity of 20 $m^2\ s^{-1}$ parametrizes horizontal friction and a lateral eddy diffusivity of 20.5 $m^2\ s^{-1}$ is used. Bottom friction is represented by a quadratic law for the bottom momentum flux with drag coefficient $C_D = 5 \times 10^{-3}$. Vertical turbulence and mixing is calculated through the $k-\epsilon$ configuration of the generic length scale (GLS) turbulence closure (Umlauf & Burchard, 2003) with background vertical eddy viscosity and diffusivity set to 1×10^{-4} $m^2\ s^{-1}$ and 1×10^{-5} $m^2\ s^{-1}$ respectively. Details on the NEMO implementation of the partial slip lateral boundary condition, quadratic bottom friction law, and GLS turbulence closure scheme are provided by Madec et al. (2012).

The ocean surface is forced with momentum and heat fluxes from a 33-km global atmospheric reforecasting model suitable for use in ocean modelling (Smith et al., 2014). Forecasts from the period of 2002-2012 are available. One simulation employs the western Canada component of the High Resolution Deterministic Prediction System (HRDPS), a nested 2.5 km resolution atmospheric model provided by Environment Canada (Environment Canada, 2014b). In addition to momentum and heat fluxes, forcing due to ~~the local~~ surface atmospheric pressure is also included ~~by~~ in the ocean momentum equation (Madec et al, 2012). ~~Thus~~ In the open ocean, the ~~ocean response to~~ surface atmospheric pressure primarily ~~for~~ induces ~~calculating~~ an inverse barometer sea surface height (IB),

$$\eta_{IB} = -\frac{1}{g\rho_0}(P_s - P_0), \qquad (1)$$

where g is the acceleration due to gravity, ρ_0 is a reference density set to 1035 kg m^{-3}, P_s is the sea level atmospheric pressure from the atmospheric model, and P_0 is a reference sea level pressure (set to 101,000 Pa). The ~~gradient of η_{IB} is scaled by g and added to the forcing terms in the ocean momentum equations (Madec et al., 2012)~~. Since the atmospheric model employs a terrain following vertical coordinate the model surface pressure has been corrected to sea level using (Holton, 1992)

$$P_s = P_1\left(\gamma\frac{z_1}{T_1} + 1\right)^{\frac{g}{\gamma R}},$$

In ~~shelf seas~~, coastal and shelf seas ~~deviation from~~ the atmospheric pressure forcing can also induce significant non-~~IB~~ sea surface height, as demonstrated in

where P_1 and T_1 are the model pressure and temperature at height z_1, R is the ideal gas constant, and γ is a temperature lapse rate set to 0.0098 K m^{-1}. ~~Since the model domain does not include~~ the open Pacific Ocean, pressure gradients ~~between the open ocean and the semi-enclosed Salish~~ Sea and their effect on the sea surface height ~~cannot be accounted for~~. Previous studies ~~in~~ for the Hudson Bay and Labrador Shelf system ~~have argued that oscillations in the sea surface~~ height can be explained, ~~in part, by the response to the pressure gradient between these regions~~ (de Young, Lu, & Greatbatch, 1995; Wright, Greenberg, & Majaess, 1987).

1987 first

Note
If IB is included in OBC, I think this model includes the full atmospheric forcing (local & non-local)

River input provides a significant volume of fresh water to the Salish Sea and can influence stratification, circulation, and primary productivity. However, most rivers in the domain are not gauged so parametrizations were required to represent river flow. Morrison, Foreman, and Masson (2011) provides a method for estimating freshwater runoff in the Salish Sea region based on precipitation. Monthly runoff volumes for each watershed for each year from 1970 to 2012 were acquired from Morrison et al. (2011), as well as monthly averages. Freshwater runoff from each watershed was divided among the rivers in that watershed. The area drained by each river was estimated from Toporama maps by the Atlas of Canada and watershed maps available on the Washington State government website. The watersheds included in our model were Fraser (which represents approximately 44% of the freshwater input into our domain), Skagit (12%), East Vancouver Island (North and South) (12%), Howe (7%), Bute (7%), Puget (6%), Juan de Fuca (5%), Jervis (4%) and Toba (3%). The monthly flow from each river was input as a point source from 0 to 3 metres at the model point closest to the mouth of each river. Incoming water was assumed to be fresh and at surface temperature. A total of 150 rivers were parametrized by this method and their locations are indicated by the green dots in Figure 1.

Initial conditions for temperature and salinity were taken from a CTD cast in the middle Strait of Georgia taken in Sept 2002 (Pawlowicz, Riche, & Halverson, 2007). Conditions were initially uniform horizontally and velocity was initialized at zero. The model was spun up for a 15.5 months from the initial conditions above, starting Sept 16, 2002, using atmospheric forcing from 2002-2003, climatological temperature and salinity and sea surface height at the boundaries, Are you sure about this? IB not corrected in the η at tide gauge used?

the stations.

4.b *Factors Contributing to Storm Surges*

Next, an assessment of the factors that are most important in the storm surge forcing conditions is presented for the Feb 2006 storm surge (Figure 4). Several simulations were done: First, a simulation with all the forcing conditions, including tides, atmospheric forcing, rivers, and sea surface height anomaly at the open boundary (or remote forcing). Second, a simulation with all forcing except the atmospheric forcing. Third, a simulation with all forcing except the remote forcing. Fourth, a simulation with only wind forcing, ~~that is no remote forcing and no~~ but excludes local atmospheric pressure forcing. Comparisons between these simulations indicate the relative importance of the remote forcing, the local wind forcing, and the local atmospheric pressure forcing. Finally, a simulation without tidal forcing was performed to study the importance of the tide-surge interaction. Contributions due to stratification and bathymetric resolution will be left to a future study.

non-local atm pre. forcing is included in OBC

First, it is clear that the sea surface height anomaly at the open boundary contributes most significantly to the surge at each of these locations (Figure 4). When the sea surface height anomaly is not included as a forcing condition, the surge drops from a maximum 82 cm to 11 cm at Point Atkinson and its maximum occurs eight hours later. A similar drop in the maximum surge and delay in timing of the maximum surge is observed at the other locations. When atmospheric forcing is neglected, almost all of the surge amplitude is accounted for in remote forcing.

The contribution to the surge due to atmospheric forcing is small and appears to be geographically dependent, most likely due to the effects of the local winds. Removal of the atmospheric forcing leads to a drop of about 2.5 cm in the maximum surge at Point Atkinson and 2.3 cm at Campbell River. By contrast, the surge amplitude increases by 4.8 cm at Victoria and 3.6 cm at Patricia Bay when atmospheric forces are neglected. The southeasterly winds over the Strait of Georgia could be acting to push water away from the southern tip of Vancouver

Island, resulting in a slight decrease in the surge amplitude at Victoria and Patricia Bay when wind effects are included in the model. A simulation with only wind forcing produces a surge of 7.8 cm at Point Atkinson, a small fraction of the total observed surge, and only centimetres at the other locations. Note that this wind-induced surge occurs well after the peak surge occurred in both the observations and simulations with full forcing.

A simple steady state argument balancing the wind stress with the pressure gradient can be used to calculate the slope of the sea surface in a body of water with a constant depth D (Pugh, 2004):

$$\text{slope} = \frac{C \rho_{air} U^2}{g \rho D}, \tag{4}$$

where C is the coefficient of friction, ρ_{air} is the density of air, g is the acceleration due to gravity, U is the wind speed, and ρ is the density of water. Given $C = 10^{-3}$, $\rho_{air} = 1.23$ kg m^{-3}, $\rho = 1035$ kg m^{-3}, wind speed $U = 20$ m s^{-1}, and depth $D = 100$ m, the slope of the sea surface is approximately 5×10^{-7}. At Point Atkinson, a westerly wind can act over a small distance of approximately 50 km, giving a sea surface elevation on the order of centimetres in agreement with the model findings. Since the Strait of Georgia is not a constant depth and is up to 400 m deep, this calculation is only an approximation. Choosing a larger depth would result in an even smaller estimate for the sea surface elevation caused by wind stresses. Further, northwesterly winds would induce the largest elevations at Point Atkinson due to the large distance over which the winds can act.

Next, the surge amplitude decreases by a few centimetres at all four locations if local atmospheric pressure is not included in the surface forcing. ~~Other~~ findings have reported ~~the inverse barometer effect due~~ to atmospheric pressure ~~contributes up to~~ $^1/_3$ ~~of the total surge amplitude~~ (Murty et al., 1995). Note that in these simulations ~~the removal of the atmospheric pressure in~~ the surface forcing does not entirely remove the inverse barometer effect ~~from the model results~~ since the sea surface height anomaly at the open boundary ~~includes an inverse barometer component. As such, these simulations indicate~~ the effect ~~of the local atmospheric pressure forcing~~

This is smaller than the ~~IB~~ sea level change calculated by eqn (1), approximately 1 cm rise in sea level associated with 1 hPa surface drop in atmospheric pressure.

In open sea or hurricanes this is reasonable. Note you really need pressure gra

~~but not the inverse barometer entirely. The contribution due to the inverse barometer can be~~ calculated with equation ~~(1) or by the approximation~~ that 1 ~~hPa drop in pressure corresponds~~ to 1 cm rise in sea ~~level~~. In this event, the pressure at the Vancouver International Airport dropped to about 99 000 Pa (Environment Canada, 2014a), corresponding to a 20 cm rise in sea level. that the IB sea level may contribute to 1/3 of the total surge amplitude.

magnitude consistent

This ~~inverse barometer contribution~~ is ~~more in line~~ with the findings of (Murty et al., 1995) ~~but~~ In our model, because the ~~remote~~ influence of remote atmospheric ~~does not alter the conclusion that the remote forcing contributes most significantly. Further,~~ the pressure forcing is ~~already~~ included in the ~~total~~ open sea level at the ~~model calculates the local atmospheric pressure forcing using a spatial gradient, and since the~~ open boundary, the above tests simply suggest that the local ~~spatial scale of the low pressure system is large compared to the domain the local atmospheric~~ atmospheric pressure generates a ~~smaller~~ sea level change ~~pressure should not contribute greatly.~~ smaller than the IB response. This is related to the small spatial scale of the model domain. ~~The reason for reduced amplitude of sea level due to a~~

too long

These comparisons point to the importance of including, as a forcing condition at the open boundary, the surge entering the domain from the Pacific Ocean. Storms travelling over the Pacific Ocean towards the west coast of the northern United States and Canada can induce elevated sea levels along the coastline which then enter the Salish Sea system through the Strait of Juan de Fuca. In a model domain that does not include the Pacific Ocean, this effect must be included as a boundary condition. Previous simulations by Murty et al. (1995) suggest that the surge entering the system through the Strait of Juan de Fuca contribute most significantly to storm surges in this domain, consistent with the results of the present study.

Next, an assessment of the importance of including the tide-surge interaction, which is important in shallow regions due to nonlinear effects and bottom friction (Bernier & Thompson, 2007), is presented for this hindcast (Figure 5). The most significant differences occur at Point Atkinson where the maximum of the surge-only case is 8.7 cm higher than maximum modelled residual, about 10% of the total surge amplitude. In contrast, the tide-surge interaction at Victoria is hardly noticeable. Indeed, a spatial map of the difference between the modelled residual and surge-only simulation (Figure 6) indicates that the tide-surge interaction is more pronounced north of the San Juan and Gulf Islands. The passages between these islands are known for vigorous tidal mixing, which may have a nonlinear effect on the surge propagation. However, the effect is a relatively small overestimate of the surge elevation and no changes