Appendix J. ORCA Buoys and Moorings

ORCA Buoys

Model predictions for 2006, 2008, and 2014 were qualitatively compared to observations at Oceanic Remote Chemical Analyzers (ORCA) buoys. Five buoy stations were selected for this report which are located within SSM's domain: three in Hood Canal (Dabob Bay, Hoodsport, and Twanoh), one in South Puget Sound (Carr Inlet), and one in Puget Sound's Main Basin (Point Wells). ORCA stations are maintained through a collaborative effort between the University of Washington (UW) ORCA Group and the National Oceanic and Atmospheric Administration (NOAA) Pacific Marine Environmental Laboratory (PMEL) (http://orca.ocean.washington.edu/prod_PugetSound.shtml). Buoy observations were available for all model run years (2006, 2008, and 2014) at Twanoh and Hoodsport, and for 2014 only at Carr Inlet, Dabob Bay, and Point Wells. Data was collected by the ORCA buoy profilers at approximately 1 meter intervals from the surface for each station. Deployment depths did not exceed the values shown in Table J1. We plotted near surface and near bottom data for each station. In certain cases data was either limited or non-existent for bottom depths, which was addressed by selecting the nearest depth from the bottom with data. Water quality observations (temperature, salinity, and dissolved oxygen) at each station were compared with SSM outputs by matching sample depths with appropriate model depths. Observed data was matched with the most representative model depth. For example, if a sample depth was greater than layer 1, but did not exceed the depth of layer 2, then the sample would be placed into model layer 2.

Data Limitations

Data from ORCA buoys is considered to be preliminary. Use of ORCA data comes with a disclaimer notifying users that the data is being accessed in its raw form, is considered to be preliminary, and is only partially calibrated. As a result of the preliminary status, no error statistics were performed, and the data was only qualitatively compared with SSM output.

Model Limitations

Representation of model bathymetry can differ significantly from actual bathymetry at certain locations, and that is the case at both Dabob Bay and Hoodsport ORCA stations. Model bathymetry at these stations is considerably shallower relative to actual bathymetry (Table J1). This tends to skew observations towards being matched with model predictions in bottom layers, rather than being dispersed throughout several layers.

Table J1: Actual and model bathymetry for ORCA stations with deployment depths.

Station	Actual Bathymetry[1]	Model Bathymetry	Maximum Deployment Depth
Carr Inlet	50m	51m	45m
Dabob Bay	108m	72m	105
Hoodsport	122m	73m	120m
Point Wells	100m	131m	50m
Twanoh	32m	36m	30m

1. Bathymetry from 10m resolution NOAA DEM files: https://www.ngdc.noaa.gov/mgg/coastal/coastal.html

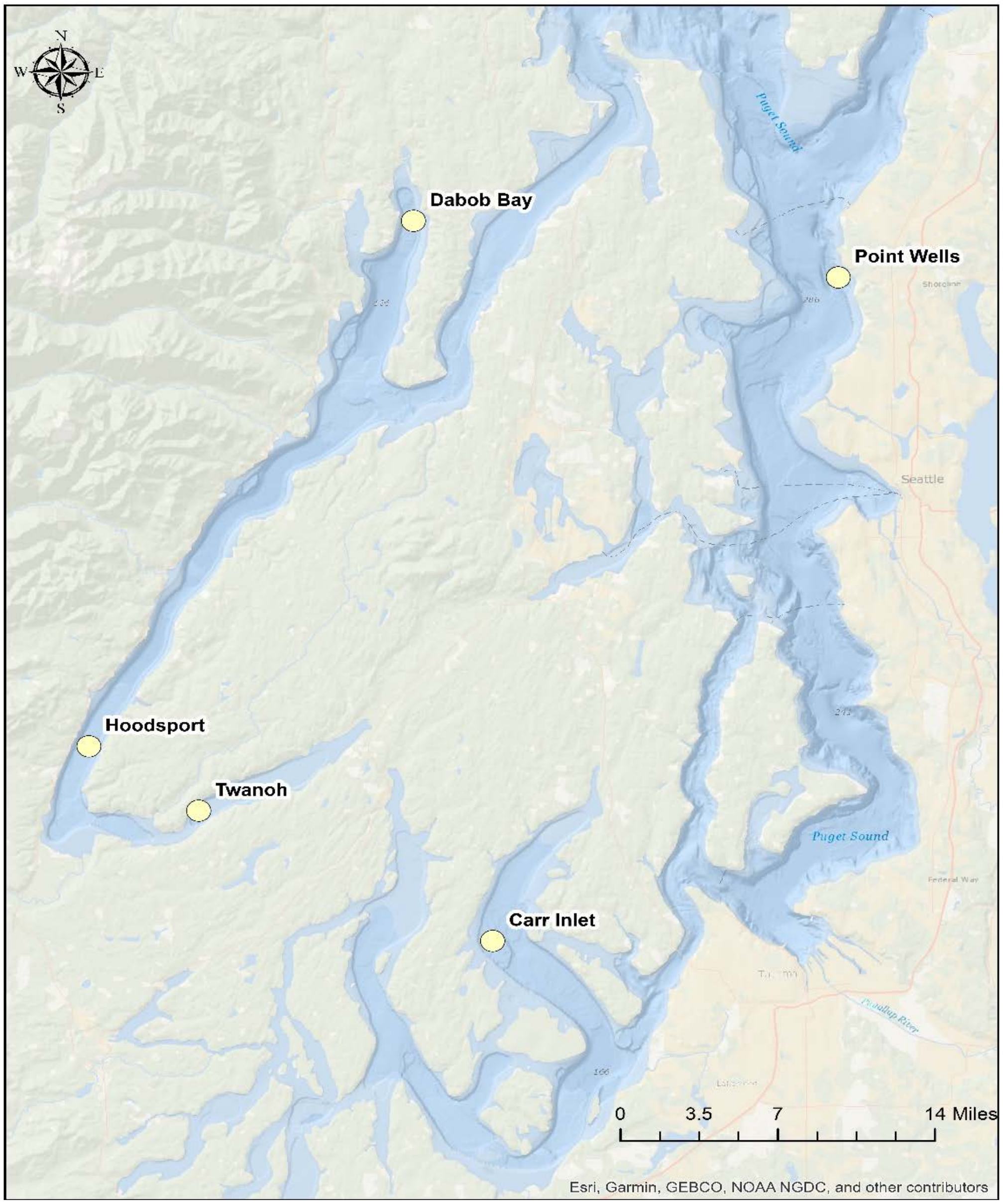

Figure J1: Map of ORCA stations selected for this study

Results and Discussion

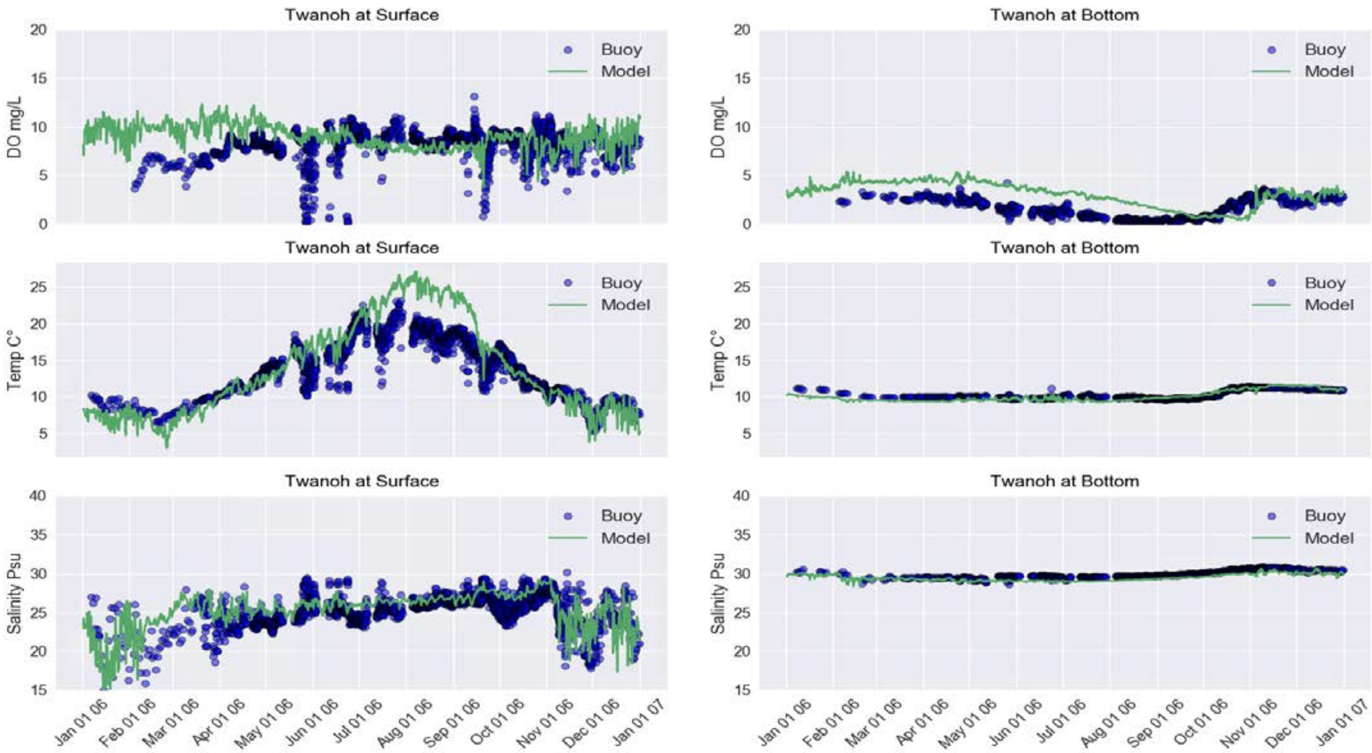

Figure J2: 2006 SSM vs. Twanoh buoy data for DO, temperature, and salinity at surface and bottom layers. Model results are captured at a 1 hour frequency while ORCA data collection frequency largely varies.

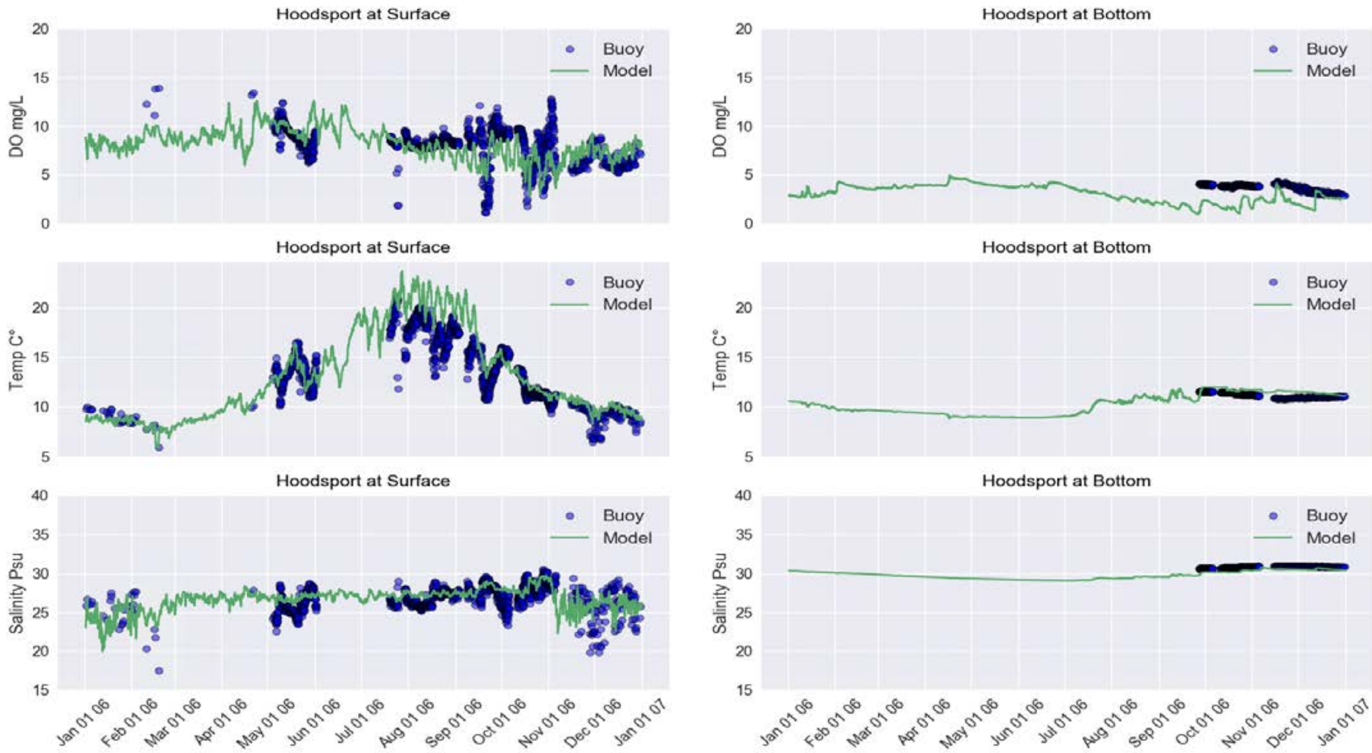

Figure J3: 2006 SSM vs. Hoodsport buoy data for DO, temperature, and salinity at surface and bottom layers. Model results are captured at a 1 hour frequency while ORCA data collection frequency largely varies.

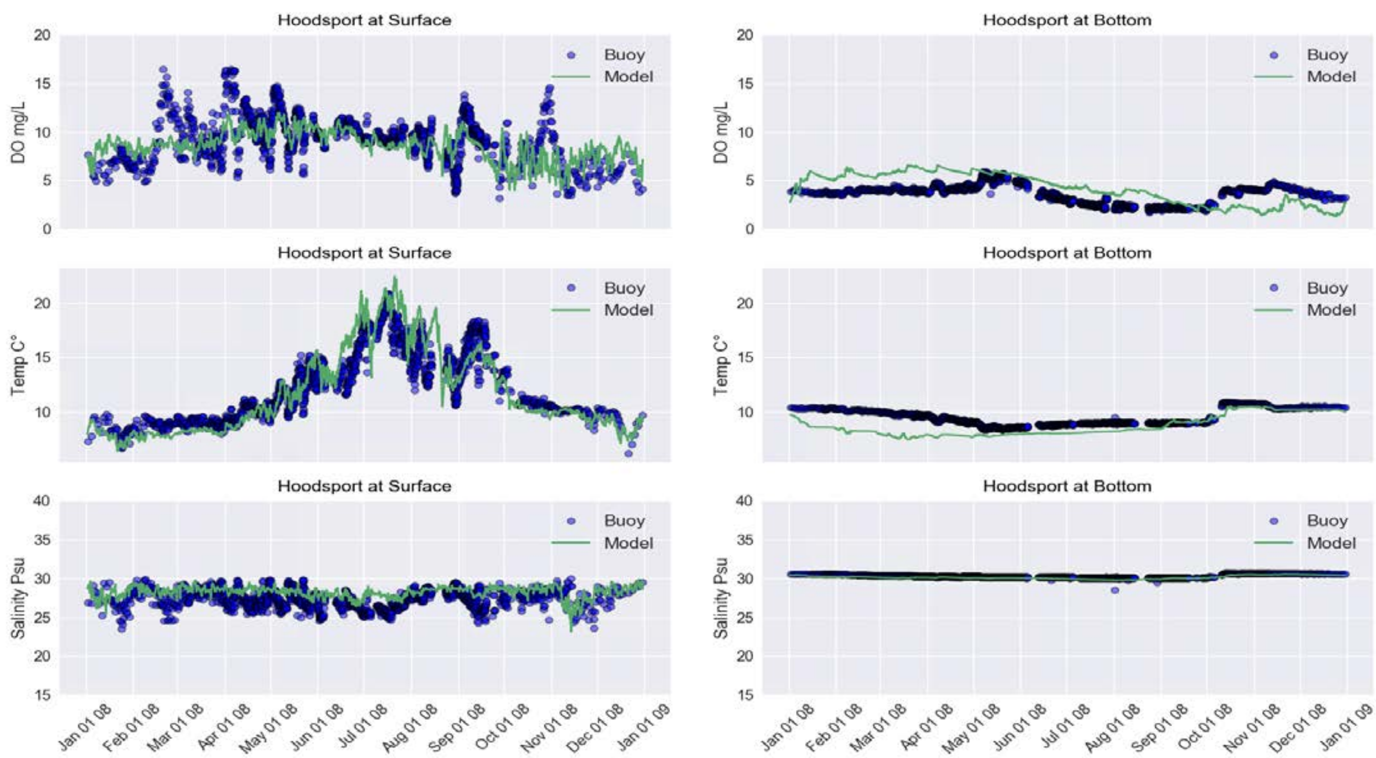

Figure J4: 2008 SSM vs. Twanoh buoy data for DO, temperature, and salinity at surface and bottom layers. Model results are captured at a 1 hour frequency while ORCA data collection frequency largely varies.

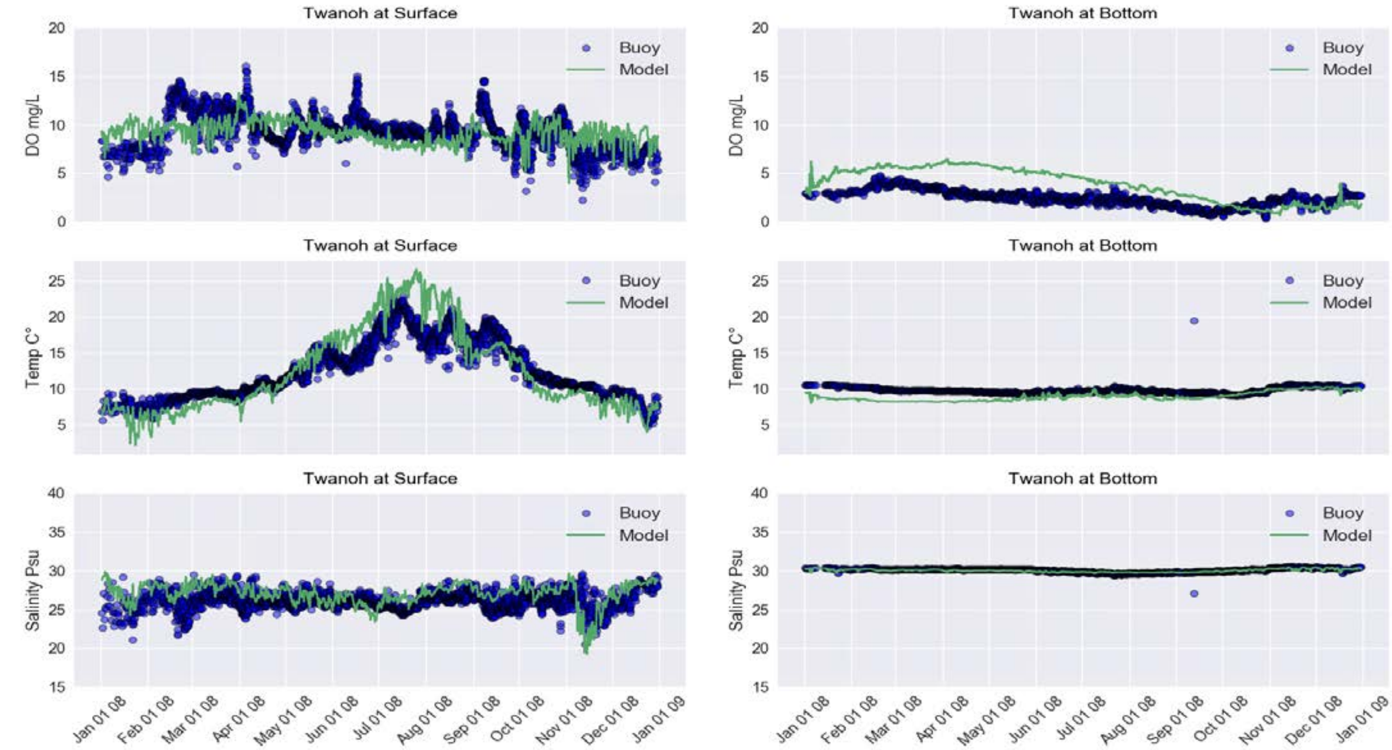

Figure J5: 2008 SSM vs. Hoodsport buoy data for DO, temperature, and salinity at surface and bottom layers. Model results are captured at a 1 hour frequency while ORCA data collection frequency largely varies.

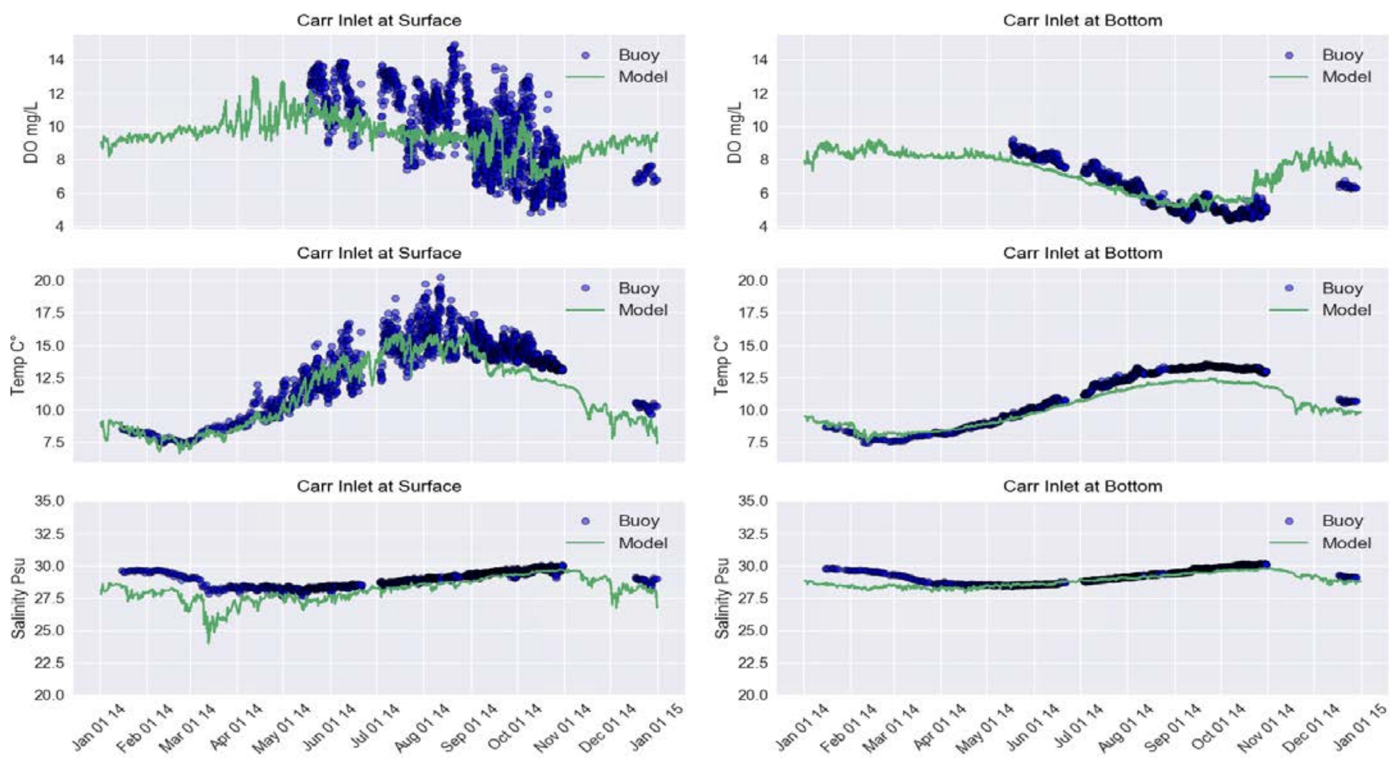

Figure J6: 2014 SSM vs. Carr Inlet buoy data for DO, temperature, and salinity at surface and bottom layers. Model results are captured at a 1 hour frequency while ORCA data collection frequency largely varies.

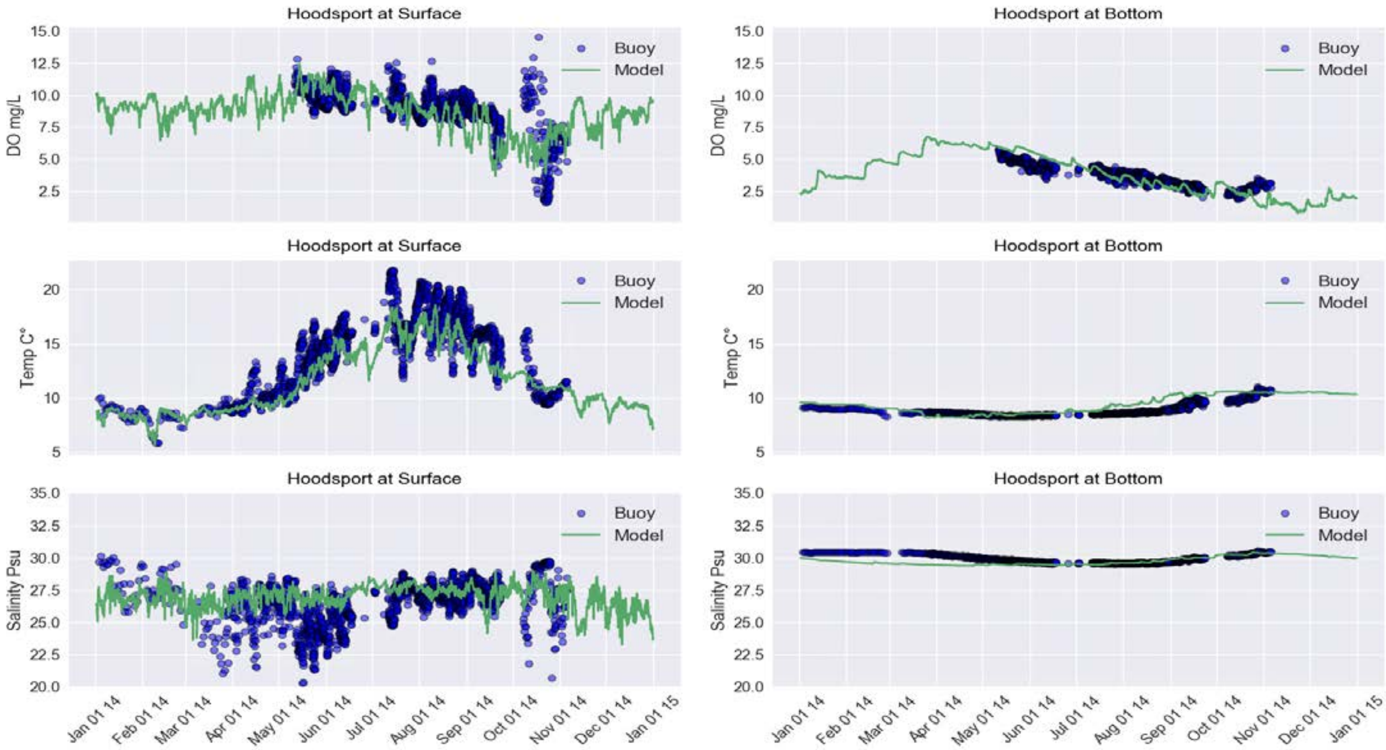

Figure J7: 2014 Model vs. Hoodsport buoy data for DO, temperature, and salinity at surface and bottom layers. Model results are captured at a 1 hour frequency while ORCA data collection frequency largely varies.

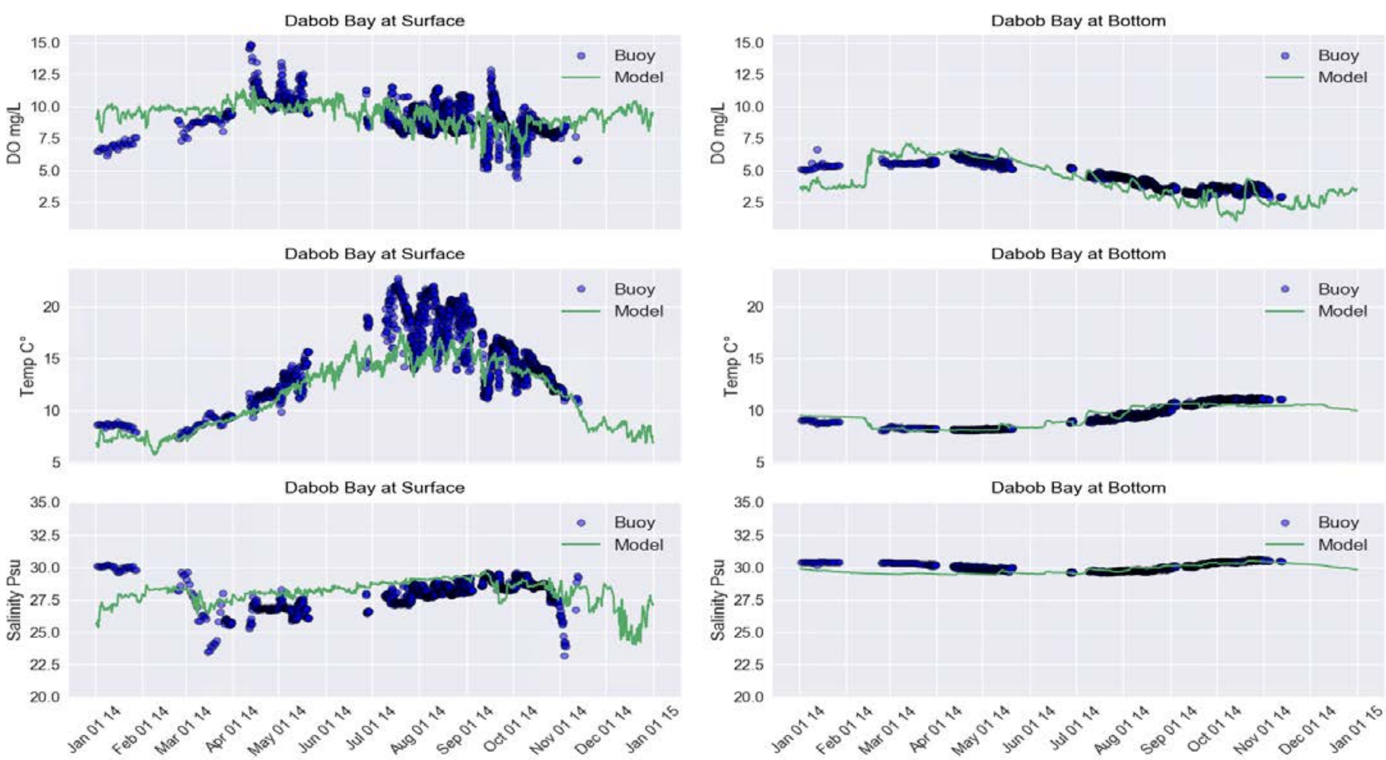

Figure J8: 2014 Model vs. Dabob Bay buoy data for DO, temperature, and salinity at surface and bottom layers. Model results are captured at a 1 hour frequency while ORCA data collection frequency largely varies.

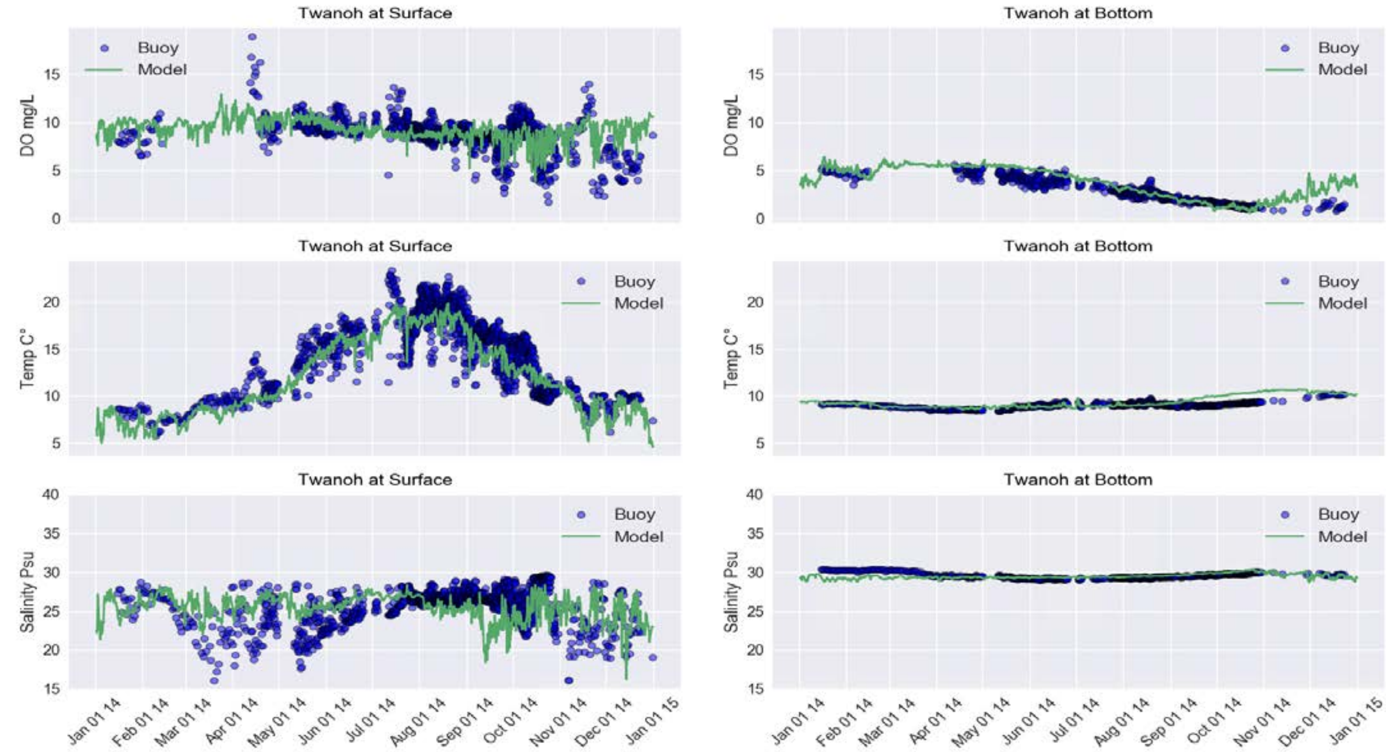

Figure J9: 2014 Model vs. Twanoh buoy data for DO, temperature, and salinity at surface and bottom layers. Model results are captured at a 1 hour frequency while ORCA data collection frequency largely varies.

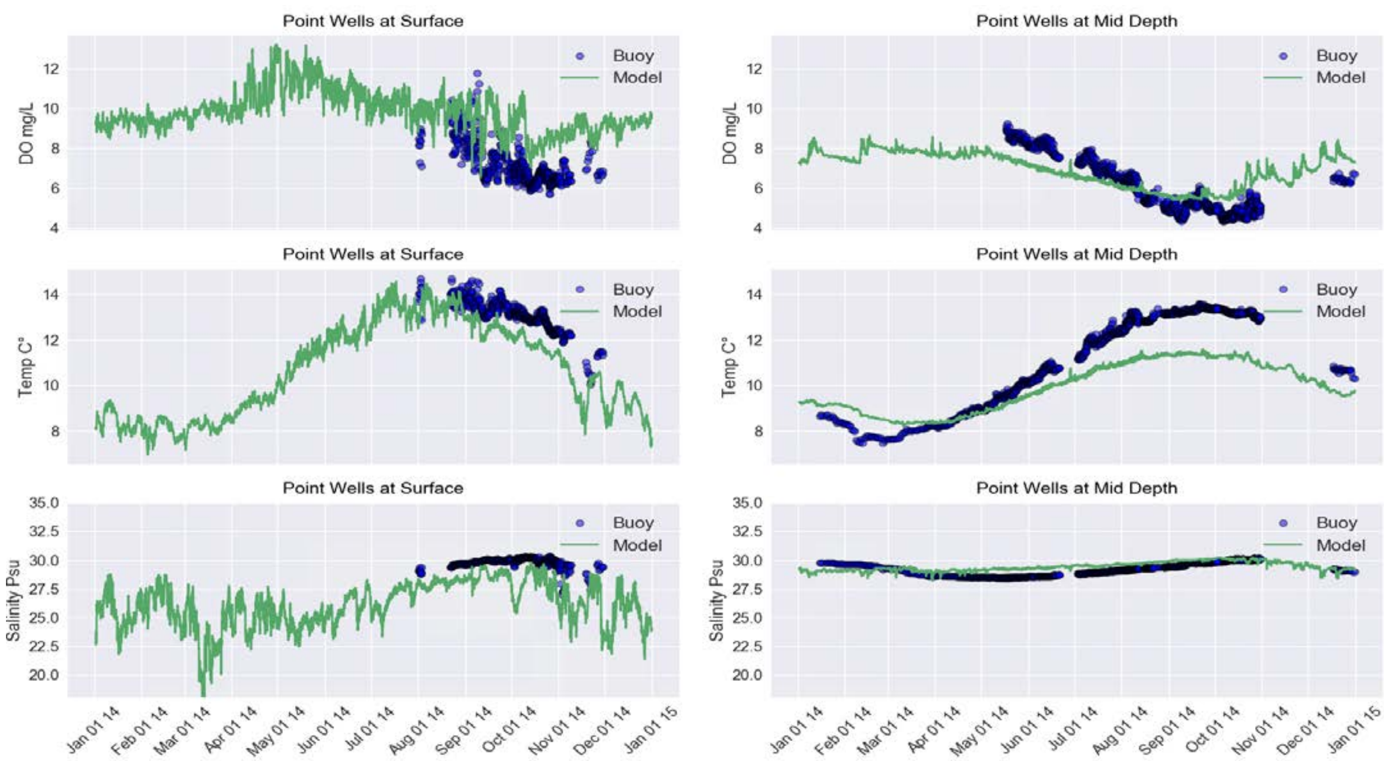

Figure J10: 2014 Model vs. Point Wells buoy data for DO, temperature, and salinity at surface and bottom layers. Model results are captured at a 1 hour frequency while ORCA data collection frequency largely varies.

A qualitative assessment of ORCA buoy and SSM output revealed an impressive amount of congruence in patterns and overall magnitudes between modeled and observed data. With the exception of Point Wells, temperature data, in particular, was very well represented by the model at both surface and bottom layers for all stations and years. Model predictions at Point Wells displayed an approximately 2 degree Celsius deviation from observations from August to November in Layer 4, which was the deepest layer with available data (Figure J10). Although temperature predictions were relatively close to observations during all years, SSM showed an apparent more pronounced tendency to under-predict surface layer temperature during summer months in 2014 when compared to previous years. Surface layer temperature, salinity, and DO model predictions have slightly greater deviation from observed data in the fall of 2014 at Hoodsport and Twanoh (Figures J3, J4, J7 and Figures J2, J5, J9). This deviation may, in part, be due to missing Department of Fisheries and Oceans Canada (DFO) data at the model open boundary used to force the model. Fourth quarter DFO data for temperature and salinity were missing in 2014 and were interpolated using 2014 3rd quarter data and 2015 1st quarter data.

In general, the model tended to capture variations in observed data for bottom layers well. As shown in Figures (J2-J9), the model had a near perfect fit with all parameters in the bottom layers.

DO variability at the surface is higher, and corresponding deviation between model predictions and observations is larger than for other parameters. This finding is not unexpected, as DO measurements in surface layers are highly variable in response to localized biological and physical drivers. DO model predictions at Carr Inlet at the surface followed the same patterns as the buoy data, with the model staying close to observed averages, but not following the observations' peaks and minimums. At Point Wells not enough buoy data is available to evaluate the annual cycle. The model under-predicted both bottom and surface temperatures for the periods for which buoy data are available at Point Wells. In terms of DO, the model over-predicted the minimum recorded at the near bottom layer at Point Wells. Overall, the model is capturing larger scale DO fluctuations reasonably well (Figures J2-J9), while not resolving fluctuations at the very fine temporal scale of the observations. It should be noted that the model predicts an average DO concentration for an entire grid area. Finer resolution events such as the presence of floating algal masses during surface readings for example, would lead to spikes in DO concentrations not represented in the model nor reflected in an area-averaged DO concentration.

In terms of salinity, as shown in Figures (J3, J4, J7) for Hoodsport and Figures (J2, J5, J9) for Twanoh, the model shows excellent visual fit with observed data for 2006 and 2008 both at the surface and the bottom layers, with some more deviation in 2014. Unlike DO, salinity model patterns appeared to be more influenced by year than by location. Generally, surface layer salinity in 2014 showed similar patterns to observations with a tendency for apparent under-prediction during specific time periods.

Moorings

Model predictions close to, but not co-located with, mooring station observations, were qualitatively compared with each other. Mooring observations for the period of interest were only available at Quartermaster Harbor /Tacoma Yacht Club (QMH) and Seattle Aquarium, both of which are maintained by King County (http://green2.kingcounty.gov/marine-buoy/). Sondes were deployed at depths of approximately 1 and 10 meters for Seattle Aquarium, and approximately 1 meter for the Quartermaster Harbor/ Tacoma Yacht Club. These depths vary with tidal fluctuation. Water quality observations in 2008 and 2014 for both moorings were compared with SSM model outputs. Parameters compared includes: chlorophyll a (Chl a), temperature, salinity, and dissolved oxygen (DO).

Data Limitations

Data from both of the moorings were considered to be preliminary as a complete QA/QC process for the data has not yet been undertaken. The data comes with the following disclaimer:

> *"Marine Mooring data provided by King County are preliminary and have not received final approval. Most data are relayed by satellite or other telemetry and may have received little or no review. Inaccuracies in the data may be present because of instrument malfunctions or physical changes at the measurement site. Subsequent review may result in significant revisions to the data"*.

As a result of the preliminary status of the data, no error statistics were computed to determine model performance. Instead, model output was compared qualitatively with the data. Qualitative comparison refers to assessing congruence of patterns and trends between model and observations.

Model Limitations

Both moorings were located just outside the edge of model grid shoreline, so model grid cells were not available at the exact locations of the Quartermaster Harbor/Tacoma Yacht Club or Seattle Aquarium moorings. To address this, both stations were compared to the nearest model grid (Figure J11).

SSM model grid cells are too coarse to accurately portray steep changes in bathymetry particularly in very shallow subtidal and intertidal regions of the nearshore. Model bathymetry near both the Quartermaster Harbor Yacht Club and Seattle Aquarium moorings is considerably deeper relative to actual bathymetry (Table J2). This tends to skew observations towards being matched with model predictions closer to surface layers, rather than being dispersed throughout several deeper layers.

Table J2: Actual and model bathymetry for mooring stations

Station	Actual Bathymetry[1]	Nearest Model Node Bathymetry
QMH	3.8 m	16 m
Seattle Aquarium	12 m	66 m

1. Bathymetry from 10m resolution NOAA DEM files: https://www.ngdc.noaa.gov/mgg/coastal/coastal.html

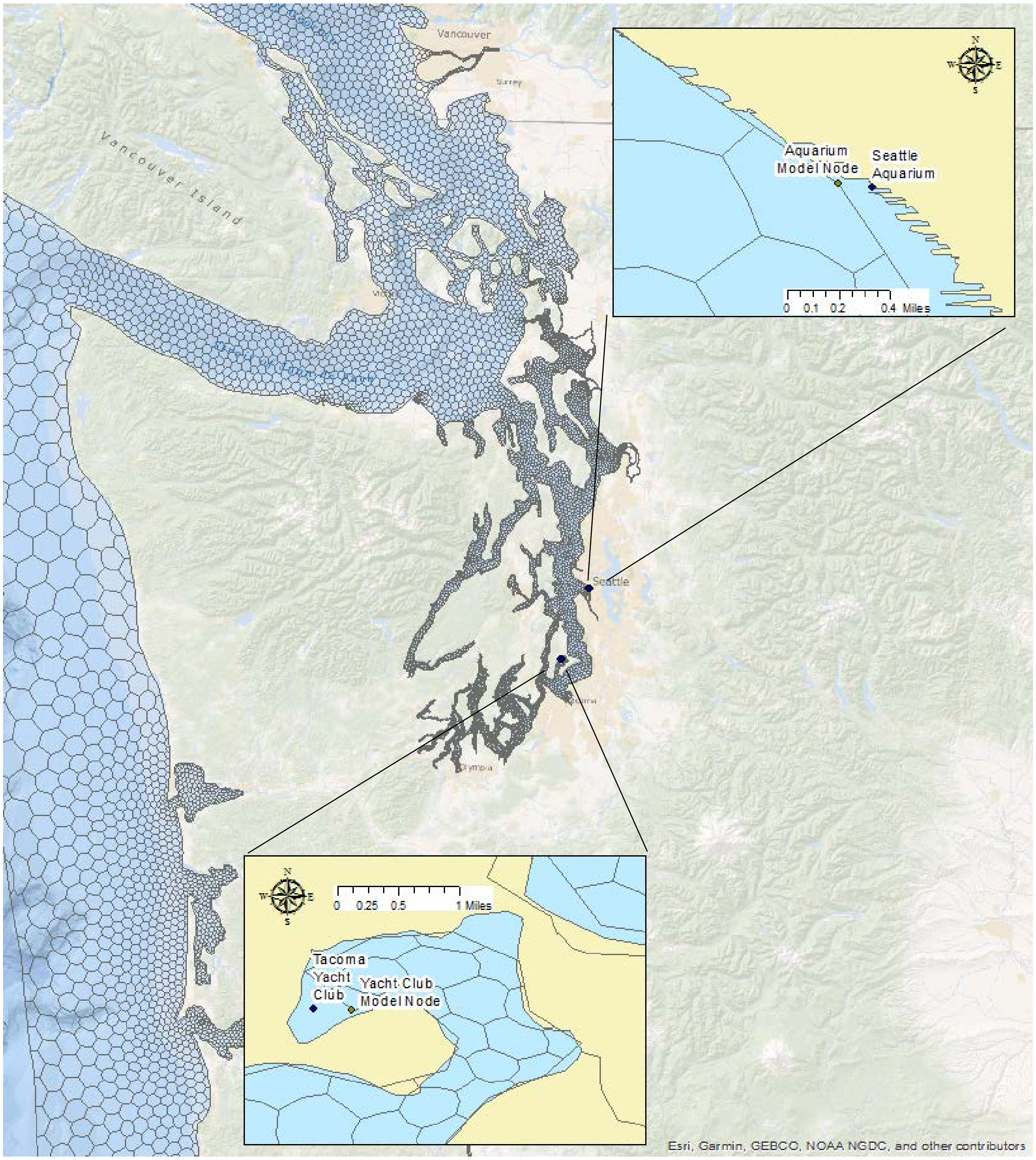

Figure J11: Map of mooring stations and nearest model grid nodes to be assigned. Seattle Aquarium and Quartermaster Harbor Yacht Club were 486 and 1135 feet away respectively, from the nearest model node

Results and Discussion

Temperature and salinity predictions and observations are shown in Figure J12 for 2008. The model phase and amplitude for temperature, in particular, displayed a high level of congruence with observed data at both stations. Model predictions for salinity captured the cyclical phase, with apparent under-prediction at both stations. At the Seattle Aquarium station, observed and predicted salinity both exhibited an upward trend during late spring and summer, with a degree of fluctuations during the fall, likely due to dilution from high precipitation events.

Model predictions and observations in 2014 are shown in Figure J13. Similar patterns to 2008 at the Seattle Aquarium were found in 2014. Unfortunately, data collection at QMH for 2014 began in late May, so a review of the annual cycle is not possible. Despite inconsistent data availability in 2014 at the QMH station, the model appears to:

- Underpredict temperature to a greater extent in 2014 from June to September (Figure J12 and Figure J13).
- Display a similar offset from observations for salinity between 2008 and 2014 (Figure J12 and Figure J13).

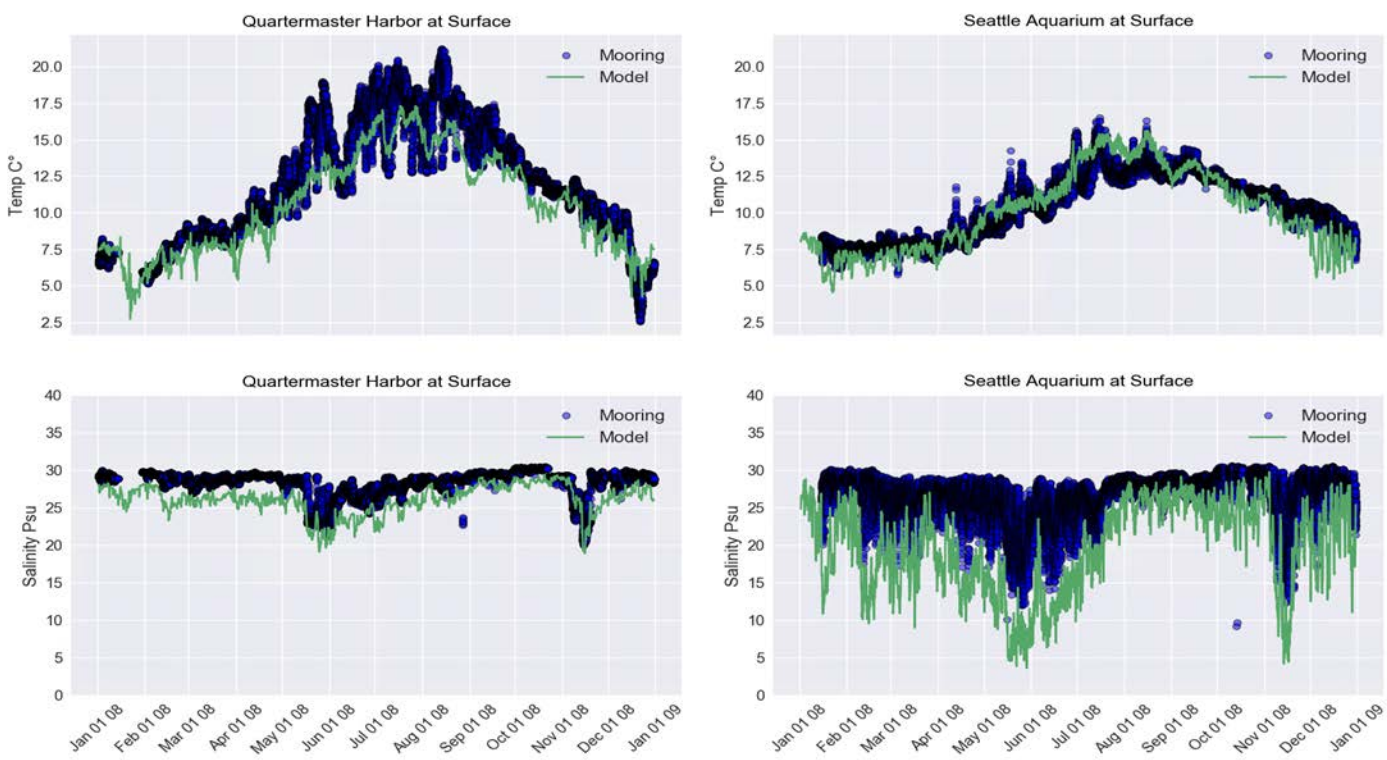

Figure J12: 2008 Model vs. mooring data for temperature and salinity. Model results are captured at a 1 hour frequency while mooring data are collected in 15 minute intervals. Data gaps are present for both temperature and salinity observations for the Quartermaster Harbor Yacht Club station.

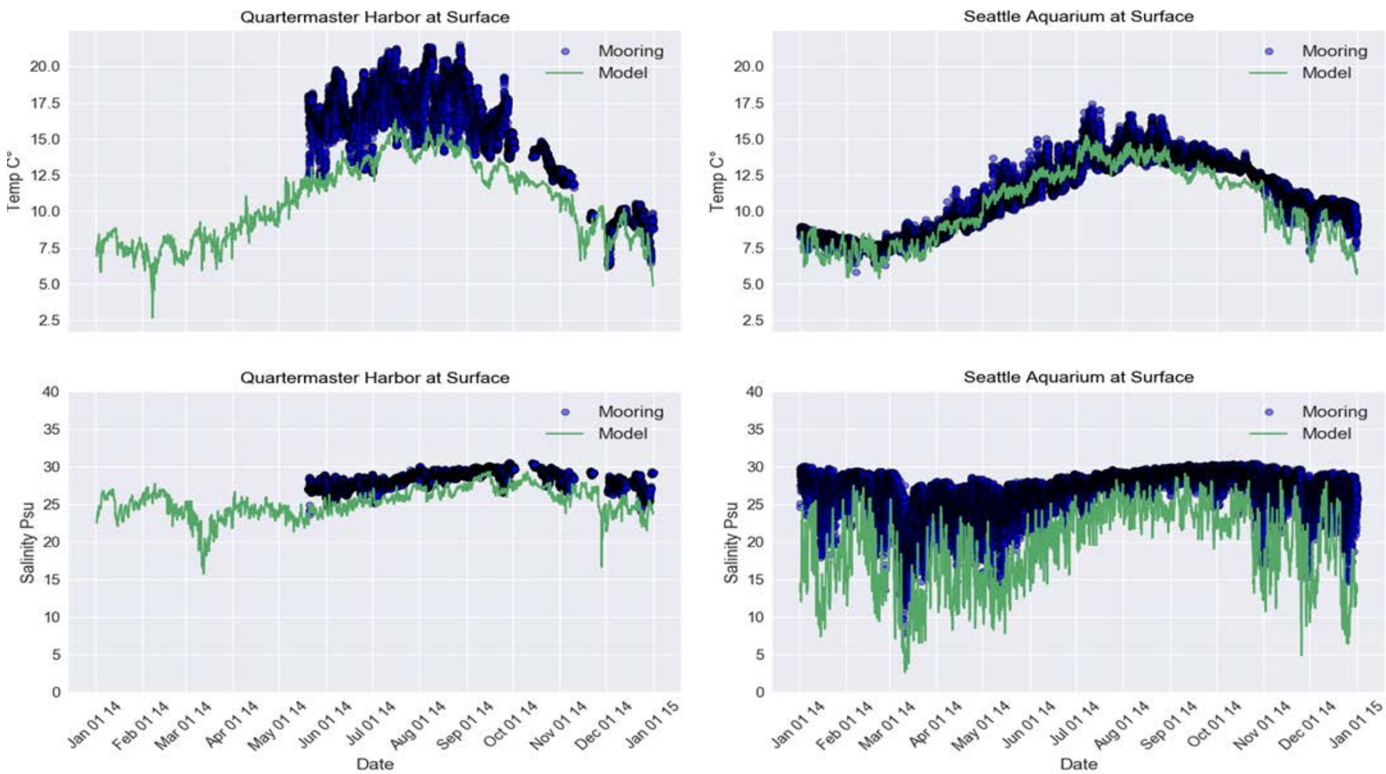

Figure J13: 2014 Model vs. mooring data for temperature and salinity. Model results are captured at a 1 hour frequency while mooring data are collected in 15 minute intervals. Despite continuous logging, data gaps are present for both temperature and salinity for the Quartermaster Harbor Yacht Club station.

Model predictions for chlorophyll, as shown in Figures J14 and J15, poorly reflected observations from both mooring stations in 2008 and 2014. The model reasonably captured the time period for the start and end of the algal bloom season. However, observations at both stations were nearly an order of magnitude greater than predictions during discrete peak events. It is important to note that the model does not use chlorophyll as a state variable, but rather it is computed at a fixed chlorophyll to carbon ratio from the algal group variables. While the model is expected to adequately predict means, it is unlikely to be able to predict peak chlorophyll events at specific locations.

Model predictions near the Seattle Aquarium mooring station show generally higher DO than observations in 2008 and 2014. The QMH station exhibited spikes during periods of high chlorophyll, and thus high photosynthetic activity, and low DO during die off periods from November to January (Figure J14 and J15). Model predictions for DO near the Seattle Aquarium were much less variable. Both model and observed values for DO were relatively high (10 mg/L) prior to the spring algal bloom season (Figure J14 and J15).

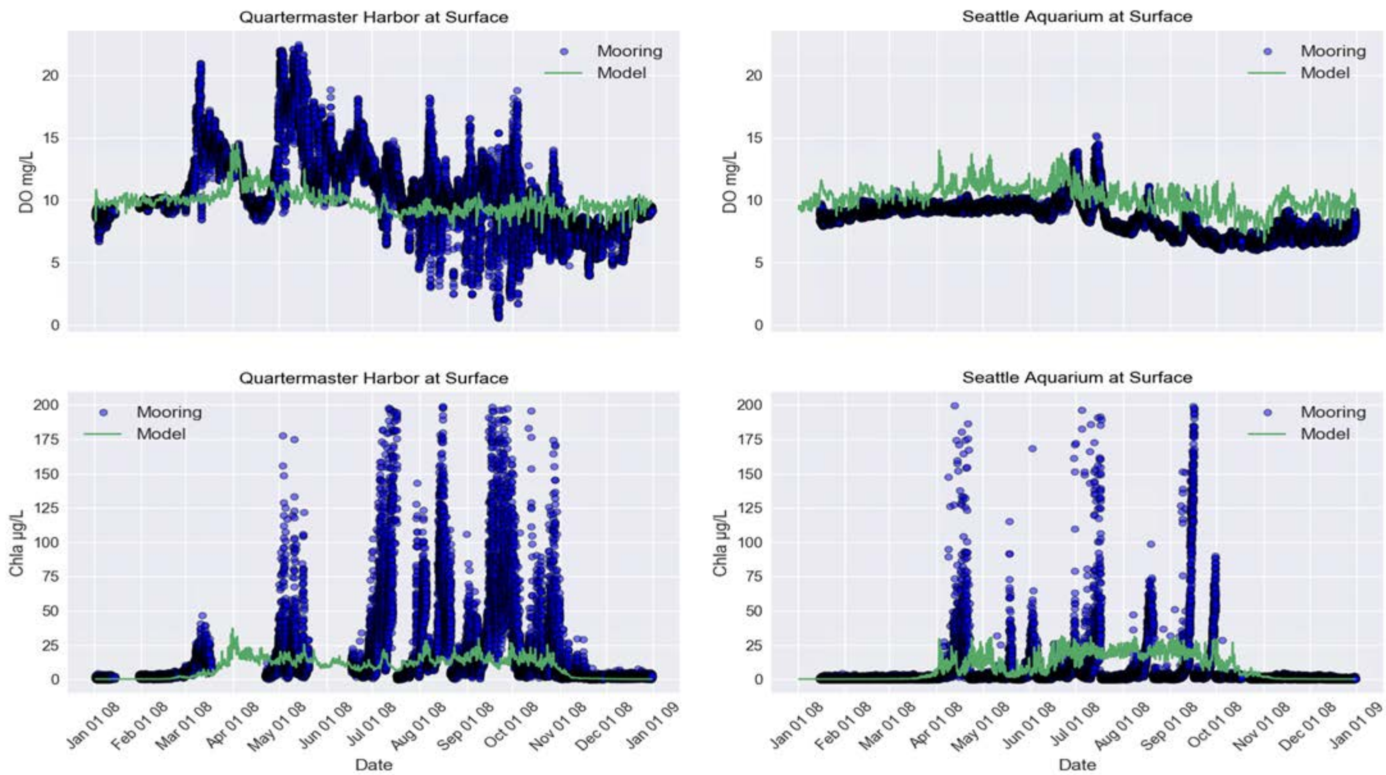

Figure J14: 2008 Model vs. mooring data for DO and chlorophyll. Model results are captured at a 1 hour frequency while mooring data are collected in 15 minute intervals. Data gaps are present for both DO and chlorophyll for the Quartermaster Harbor Yacht Club station.

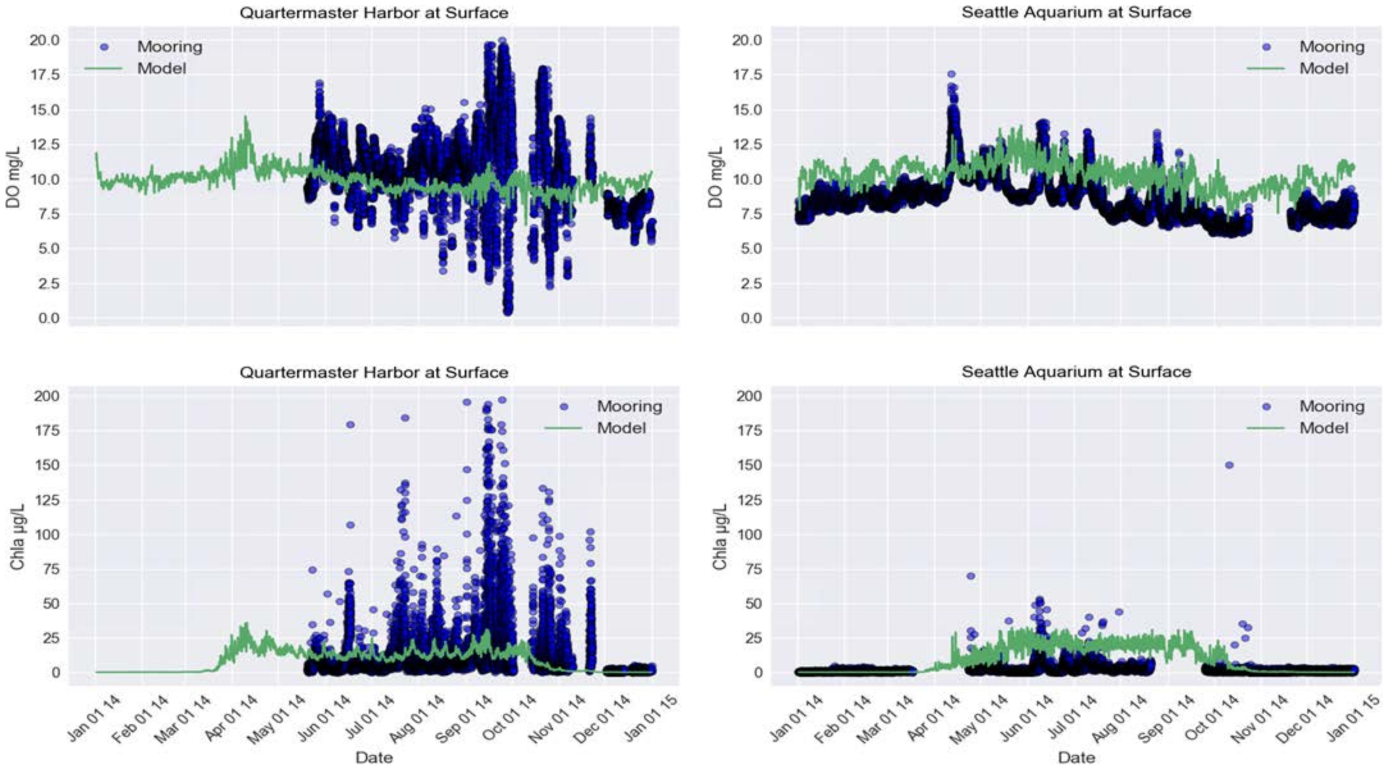

Figure J15: 2014 Model vs. mooring data for DO and chlorophyll. Model results are captured at a 1 hour frequency while mooring data are collected in 15 minute intervals. Data gaps are present for DO and chlorophyll at both stations.