Modeling the Columbia River Plume on the Oregon Shelf during Summer Upwelling

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Abstract

The effects of the Columbia River plume on circulation on the Oregon shelf are analyzed using outputs from a coastal circulation model and available observations for summer 2001. The extent of the river plume to the south, its depth, and cross-shore location in response to upwelling- and downwelling-favorable winds are modeled accurately as verified by comparison with surface salinity maps and SeaSoar hydrographic sections. Comparison of two model solutions, with and without the river discharge, suggests that the plume may affect alongshore and cross-shore momentum transports, as well as vertical turbulence fluxes underneath the plume.

1 Introduction

The Columbia River is the largest source of fresh water on the west coast of the United States, with average volume flux of about 4000 m³/s in summer. Under weak winds the river plume forms the density current that flows alongshore to the north, as a combined effect of buoyancy forcing and the Earth's rotation. During summer, the winds force the alongshore coastal current, southward on average, that advects the Columbia River water turning the plume to the south (Banas et al., 2007). Recent observations near Columbia River mouth suggest that the plume influences vertical material transports and zooplankton dynamics (McCabe et al. 2007, Peterson et al. 2007).

Our preliminary analysis of the real-time forecast model of flows on the Oregon shelf (http://www.orcoos.org) has suggested that differences in the SST between the model and GOES satellite imagery may possibly be attributed to the fact the Columbia river discharge was not included in the model. It is also not entirely known whether, and to what degree, the Columbia River plume affects the details of the shelf circulation. For instance, can the river water be considered as a passive tracer, or does it affect currents on the Oregon shelf? Does the change in stratification associated with the intrusion of the warm and fresh water influence cross-shore and vertical momentum and material transport in the ocean surface layer? And what is the latitudinal extent of this influence?

To answer these questions, and to provide the verification of the prototype forecast model that includes the Columbia River discharge, we analyze outputs of two retrospective model runs for the summer upwelling period of 2001. One run includes the Columbia river and tides, while the second does not account for the river or tidal effects. Before comparing the two cases, it is critical to confirm that the model can accurately reproduce the location and key features of the plume.

The sections of this paper are organized as described below. Section 2 includes a detailed description of the 2001 model, including previous model-data comparisons. Section 3 analyzes the model's reproduction of the location and quality of the river plume itself. Section 4 examines possible effects of the river plume at the surface on subsurface fields at 46N and 45N. Implications and summary are provided in section 5.

2 Model

This paper examines the outputs from a one way nested grid model of the Oregon Coastal Transition Zone (OCTZ). This model was developed and run by Scott Springer. The domain of the model extends from 40.5N to 47.5N in the vertical, from the Oregon coast to 129W in the horizontal, and can be seen in Fig. 1. The model, based on ROMS, has 1/36 degree resolution in the horizontal (approximately 3.1km) and 40 layers in the vertical. It is nested in the 9km resolution NCOM-CSS model. Boundary and initial conditions come directly from the NCOM-CSS model. Wind stress and heat flux are forced with input from a regional atmospheric model (COAMPS) which reproduces realistic atmospheric fluxes. Wind stress at 45N, in 80m deep water, is shown in Fig. 2 for the duration of the 2001 upwelling season. Winds are predominantly southward during summer, with occasional relaxations/reversals.

Two runs of the model are compared, one run including the Columbia River and tides (CR), and the sec-
Figure 1: Three dimensional view of the model grid. The Gray’s Harbor, COAST North Mid Shelf, and Rogue River moorings are represented by red circles.

ond run not including the river or tidal effects (NCR). Columbia river volume flux is shown in Fig. 3.

Previous model-data comparisons have been conducted for this model by Springer et al. (manuscript in preparation) involving mooring time series and alongtrack SSH altimetry.

3 Identification of the River Plume

In order to examine the plume’s possible influence on shelf dynamics, the plume must first be identified. Higher temperature, and lower salinity allow differentiation between river and ocean water. Normally, water with a salinity below 32 psu, fresh water, would be considered Columbia River water, however the NCR run includes water fresher than 32 psu in its surface contour. Fresher water in the NCR run can be attributed to variable ”nudging” resulting from data assimilative techniques in NCOM-CSS. Despite fresh water in NCR, the river plume is still clearly visible in case CR. See Fig. 4. In NCR, minimum surface salinity is 31 psu. In the CR run, blue water fresher than 30 psu can be extending almost as far south as 45N and a smaller distance north from the river’s mouth. Decrease in salinity, obviously separate from boundary effects, can be seen as far south as 43N. Additionally, the salinity contour maps reveal high-salinity upwelled water. During upwelling favorable winds, the river plume is pushed away from the shore. During wind relaxations and reversals, the plume will flow much closer to shore, and shift northwards, due to coriolis force.

4 Effect on Subsurface Fields

In order to evaluate the effect of the Columbia River plume on subsurface fields, salinity, temperature, and potential density transects were taken of both model runs at 45N and 46N (Figures 5, 6 and 7 respectively). The COAST SeaSoar data set provides a comparative base for the model runs. By visual comparison with SeaSoar data, it is apparent that the CR run accurately reproduces the location of the river plume within the first 20m of water from the surface. The NCR case lacks the plume and does not reproduce surface effects at all (not shown).

First, examining the Salinity comparisons in Fig. 5 qualitatively, the plume appears to be reproduced in the correct location. Dark blue water extends to about the same depth, extending for the same longitudinal range. Again, during periods of upwelling the plume is visbly pushed offshore in both model and data, and during periods of relaxation, the plume resides close to the coastline. See surface forcing in Fig. 2 for upwelling and relaxation periods.
Temperature contours suggest that the model may have slightly lower overall temperature, however the model appears uniformly cooler than the data, suggesting correct structures.

Last, the density transects reveal accurate reproduction of upwelling and relaxation period behaviour of the plume. Yeardays 158-159 and 163-164 occur right after periods of wind reversal (see Fig. 2). Density plots for these two periods show the plume immediately against the shore in both data and model. Yearday 144 is immediately after a period of upwelling favorable winds, and density transects for model and in data on that day show upwelling, and the river plume of lighter, blue water, being forced off shore.

To further examine subsurface fields comparative transects of density (again), stratification, and vertical momentum flux, all with overlaying v-component velocity contours reveal further differences between the NCR and CR model runs.

Notably, at 46N, near the river mouth, the CR run contains a subsurface maximum jet which is not visible in NCR. No correlating subsurface maximum is apparent in the transect area for 45N, however, as is expected, there is a significant change in the density with addition of the light, fresh river water. See Fig. 8 and Fig. 9.

The CR run shows a large increase in stratification (Fig. 10 and Fig. 11) from the NCR run. At both 45N and 46N this increase occurs against the shore, with a much stronger effect visible at 46N, near the river’s mouth. Similarly, transects of the vertical momentum flux (Fig. 12 and Fig. 13), reveal a small (possibly negligible) change at 45N but a much more notable change at 46N.

Additionally, by qualitative analysis, along shore velocity appears to be significantly changed in this sampling region between the two runs. It seems apparent that significant difference in vertical structure exists between the two model runs.

5 Implications

Model-data comparisons show that the model describes qualitatively the Columbia River plume. Additionally model-data comparisons support that the model accurately depicts the coastal dynamics during both upwelling and relaxation periods.

Many questions remain unanswered, and would be aided by further analysis. Examination of along shore and cross-shore momentum flux would help complete the picture of how subsurface dynamics are altered in three dimensions. Analyzing the differences between NCR and a run including tides but excluding the Columbia River would allow immediate differentiation between river and tidal effects.

Differences in the vertical turbulent momentum flux can be attributed to the Columbia River. This effect is pronounced at 46N, but not as obvious in three week averages at 45N. Further studies are planned to examine whether differences are larger during upwelling or downwelling events. This information will potentially help to understand the transport of nutrients and biota in the area between 45N and 46N.

References


Figure 2: Time series of the model’s forced surface stress from April through October.

Figure 3: Timeseries of Columbia River volume flux, with peak flow in May and June.
Figure 4: The model region without (left) and with (right) the Columbia River and tides. All water fresher than 31 psu is from the Columbia River. Contours made from time average over period from yearday 136 to 166.
Figure 5: Daily average salinity transects at 45N. On the left, model transects, on the right, SeaSoar transects.
Figure 6: Daily average temperature transects at 45N. On the left, model transects, on the right, SeaSoar transects.
Figure 7: Daily average potential density transects at 45N. On the left, model transects, on the right, SeaSoar transects.
Figure 8: Potential density transect at 45N. Mean from yearday 136 to 166.
Figure 9: Potential density transect at 46N. Mean from yearday 136 to 166.
Figure 10: Stratification at 45N.
Figure 11: Stratification at 46N.
Figure 12: Vertical Momentum Flux at 45N.
Figure 13: Vertical Momentum Flux at 46N.