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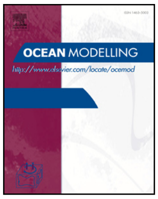

Evaluation of a long-term hindcast simulation for the Columbia River estuary

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ABSTRACT

In order to simulate the biogeochemical function of estuaries across the land-ocean continuum, circulation models must represent a cascade of complex physical processes spanning several spatial and temporal scales. Furthermore, governing physical processes tend to vary under different flow regimes, in response to external forcings. Model validation must therefore cover all relevant flow regimes and span sufficiently long time to represent transient and slowly-varying phenomena. We focus in a multi-year hindcast simulation of the Columbia River estuary – a mesotidal, river-dominated estuary that is also influenced by coastal upwelling in an Eastern Boundary Current system. Model skill is assessed against long-term observational time series, covering the lower estuary (for salinity) as well as most of the tidal river (for water temperature and elevation). In addition, high-resolution profiles of velocity and salinity are used to study salt transport mechanisms at a single station. Results indicate that the model captures the estuarine dynamics of the system, but the skill depends on the flow regime: In general the model performs far better during spring tides (i.e., under partially mixed or time-dependent salt wedge regimes) than under neap tides (i.e., salt wedge and strongly stratified regimes). While the model accurately represents tidal salt transport mechanisms, it tends to underestimate gravitational transport which becomes more important under neap tide conditions. Furthermore, the skill decreases during high river discharge periods, because the model has difficulty capturing the extremely strong stratification characteristic to those periods.

1. Introduction

Numerical modeling of estuarine flows is challenging because of complex bathymetric features, energetic flows and sharp gradients between water masses. In addition, estuarine dynamics tend to vary significantly due to the physical forcings, e.g., tidal variability, seasonal changes in freshwater flow, and synoptic or seasonal weather conditions. Depending on the forcings, estuaries may therefore exhibit multiple flow regimes, that may substantially differ in terms of the dominant physical processes. Calibrating and validating circulation models to all relevant flow regimes is thus of crucial importance.

Circulation models are typically validated for specific, relatively short time periods, whose length is limited by the availability of observational data and computational resources. Such a short-term validation, however, lacks proper representation of slowly-varying phenomena and may miss certain combinations of physical forcings. In this paper we present a skill assessment for a single long-term, multi-year simulation for the Columbia River estuary (Fig. 1). Long-term simulations are necessary to represent slow, history-dependent, seasonal, or interannual aspects of estuarine flows, such as biochemical processes, sediment transport, and response to weather anomalies (e.g., El Niño Southern Oscillation). Assessing the skill of such simulations, however, requires long-term observational record in order to obtain reliable error metrics across the flow regimes. In this work we rely on the rich observational data set of the SATURN network (Science And Technology University Research Network, Baptista et al., 2015) in the Columbia River estuary.

In terms of the flow regimes, we quantify the model skill versus regimes defined by the classification scheme introduced by Geyer and MacCready (2014) (henceforth G–MC classification). The G–MC classification is based on the two main forcings of estuarine systems: tidal currents and river discharge. River discharge affects the

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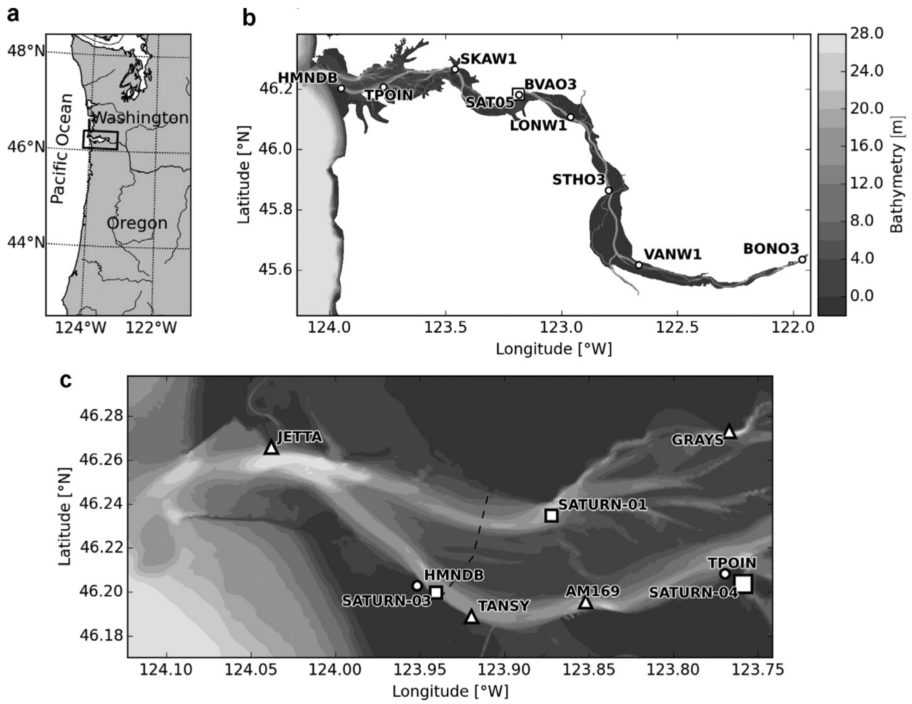

Fig. 1. Geographical location of the Columbia River estuary (a), bathymetry of the tidal river (b), and the lower estuary (c). The multi-disciplinary SATURN endurance stations are marked with squares. Triangles indicate stations that measure only physical quantities. Water level stations are marked with circles. Bathymetry color scale has been cropped at 28 m.

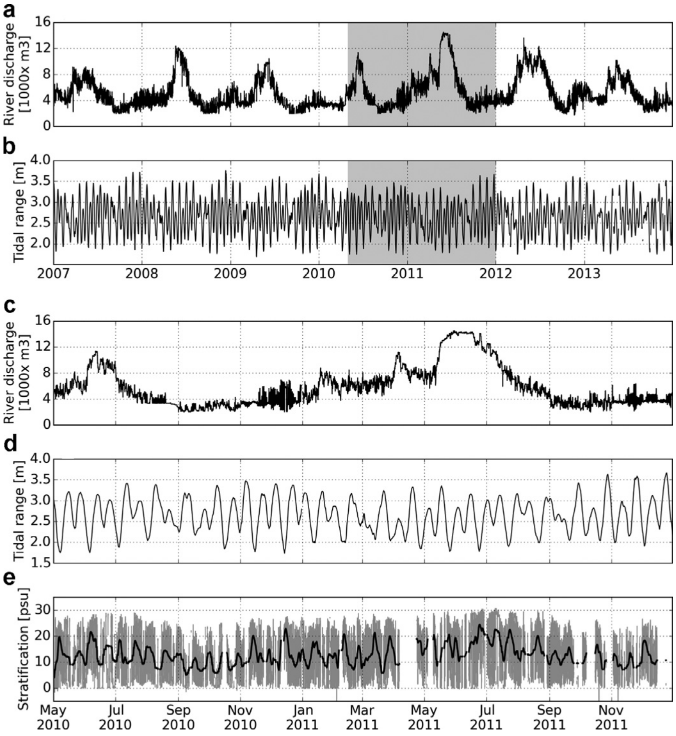

Fig. 2. Physical conditions for the simulation period; (a) river discharge at BONO3; (b) tidal range at TPOIN. Subsequent panels show correlation between river discharge (c), tidal range (d), and observed stratification at SATURN-03 (e) for a shorter time period. Stratification is computed as the salinity difference between the bottom (13.0 m) and surface (2.4 m) measurements. Instantaneous stratification is plotted in gray; the black line is the low-pass filtered signal.

freshwater Froude number Fr_f, that measures the hydraulic criticality of a stratified water column. The magnitude of tidal currents, on the other hand, affects the mixing parameter M, that is a proxy for mixing due to tidal currents and bottom friction. M is scaled to take into account the inhibitory effect of stratification on mixing: $M \approx 1$ indicates that tidal currents are strong enough to mix the entire water column in a half tidal cycle (Geyer and MacCready, 2014). In the context of the Columbia River estuary, the four relevant regimes in the G–MC parameter space are: strongly stratified (low flow, neap tides), partially mixed (low flow, spring tides), salt wedge (high flow, neap tides) and time-dependent salt wedge (high flow, spring tides) regimes.

In this work we analyze model skill for a multi-year hindcast simulation spanning years 2007–2013. River discharge and tidal range are presented in Fig. 2 for the analysis period. The river discharge is highest during the spring freshet period (typically May–June, Fig. 2a), its magnitude varying due to yearly snowmelt conditions and dam operations; for the study period the freshet flows range from 8000 to 15,000 m^3 s^{-1}. During the dry season (July–October) discharge may fall below 2000 m^3 s^{-1}. Tidal range varies from 1.7 m for the smallest neap tides to 3.8 m for the largest spring tides (Fig. 2b). The spring-neap progression is not stationary, however: There's a clear secondary modulation at roughly 190 day time scale, where spring-neap difference varies from the maximum 1.7–3.8 m to much smaller 2.1–3.0 m. This modulation is mostly due to tidal harmonics, namely the superposition of the five dominating tidal constituents (M2, 0.97 m amplitude; K1, 0.40 m; S2, 0.24 m; O1, 0.24 m; N2, 0.18 m). The magnitude of the tides is additionally affected by the river discharge, large discharge tending to decrease tidal range (e.g. during 2011 freshet, Fig. 2d). Both the annual variability of river discharge and the 190 day periodicity of tidal conditions further stress the importance of sufficiently long skill assessment studies.

River discharge and tidal range control stratification and circulation in the estuary (observed stratification is shown in Fig. 2e): stratification is anti-correlated with tidal range, being stronger during neaps; This is especially evident for the weakest neaps (less that 2.0 m tidal range). Stratification is further controlled by the river discharge, higher flows resulting in stronger stratification.

Model results for the analysis period are obtained from our most recent hindcast simulation database, called database 33