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Wastewater effluent dispersal in Southern California Bays

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ABSTRACT

The dispersal and dilution of urban wastewater effluents from offshore, subsurface outfalls is simulated with a comprehensive circulation model with downscaling in nested grid configurations for San Pedro and Santa Monica Bays in Southern California during Fall of 2006. The circulation is comprised of mean persistent currents, mesoscale and submesoscale eddies, and tides. Effluent volume inflow rates at Huntington Beach and Hyperion are specified, and both their present outfall locations and alternative nearshore diversion sites are assessed. The effluent tracer concentration fields are highly intermittent mainly due to eddy currents, and their probability distribution functions have long tails of high concentration. The dilution rate is controlled by submesoscale stirring and straining in tracer filaments. The dominant dispersal pattern is alongshore in both directions, approximately along isobaths, over distances of more than 10 km before dilution takes over. The current outfall locations mostly keep the effluent below the surface and away from the shore, as intended, but the nearshore diversions do not.

1. Introduction

Coastal oceans are discharge sites for agricultural, industrial, and urban pollution around the world; they are also places with dense human and wildlife populations and fisheries. Pollution management of offshore effluent is necessary and relies on treatment in reducing toxicity, and dispersal and dilution by ocean currents to reduce local concentration levels.

Urban treated wastewater (sewage) from greater Los Angeles has three major effluent discharge pipes, two of which are considered here. One is near Huntington Beach in San Pedro Bay (SPB, extending south from Palos Verdes Peninsula past Newport Beach) and is run by the Orange County Sanitation District (OCSD), while the other is near the Hyperion Treatment Plant (HTP) in Santa Monica Bay (SMB, extending between Point Dume and Palos Verdes Peninsula) and is run by the City of Los Angeles Bureau of Sanitation. Both have offshore outfalls below the surface within embayments and inshore of the strongest currents.

In this paper we simulate effluent dispersal and dilution using a circulation model that has multiply nested grids from a regional configuration for the U.S. West Coast with mesoscale horizontal grid resolution ($dx=5$ km) down to the SPB and SMB subdomains with submesoscale grid resolution ($dx=75$ m). The nesting approach is necessary to represent the influence of larger scale currents on the local ones by which the dispersal occurs. We choose the particular period of Fall 2006 to obtain a representative range of dispersal behaviors. Model forcing is by synoptic meteorological surface fields (themselves were generated in a nested meteorological model) and by lateral open boundary conditions constructed from the output of a global oceanic model with data assimilation and from an empirical tidal analysis. This configuration is intended as comprehensive for all relevant types of currents within this class of model formulation.

A regional coastal model with a nested-grid hierarchy can serve many purposes. We use the Regional Oceanic Modeling System (ROMS) whose principal algorithms are described in Shchepetkin and McWilliams (2005, 2008) and nesting techniques in Penven et al. (2006) and Mason et al. (2010). Using ROMS configurations similar to the one used here (Section 2.1), the simulation and empirical validation of the regional circulation and eddy characteristics are made for the U.S. West Coast in Marchesiello et al. (2003) and Capet et al. (2008a) and for the Southern California Bight (containing SPB and SMB) in Dong et al. (2009). Particular process studies are made for island wakes (Dong and McWilliams, 2007); upwelling events (Capet et al., 2004; Dong et al., 2011); mesoscale eddy distribution (Kurian et al., 2011) and buoyancy flux (Colas et al., 2013); California Undercurrent separation and its submesoscale instability (Molemaker et al., 2014); tidal currents (Wang et al., 2009; Buijsmann et al., 2012); sediment transport (Blaas et al., 2007); nearshore particle dispersion (Romero et al., 2013); plankton productivity (Gruber et al., 2006, 2012); and larval dispersal and connectivity (Carr et al., 2008; Mitarai et al., 2009).

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Besides including the effluent sources (Section 2.2), the present circulation and associated dispersal study is novel by incorporating smaller scale features and analyzing them closer to shore.[1] Compared to the persistent currents and mesoscale eddies that dominate the flow in deeper water offshore, the important local agents of wastewater effluent transport are the currents over the continental slope and shoaling shelf. They are comprised of mesoscale and submesoscale eddies (including poleward-propagating coastally trapped waves), and both barotropic and internal tides (Hickey, 1992; Kim et al., 2010). Some coastal waves are generated by wind fluctuations that are located equatorward of the model domain and have a smaller scale than is resolved in the open boundary condition fields; these are absent in our simulations, although regionally generated coastal waves are present. Submesoscale currents arise from frontogenesis and baroclinic instability processes in the surface layer (Capet et al., 2008b) and topographic and coastline shear wakes (Dong et al., 2009; Molemaker et al., 2014). Our configuration lacks surface gravity wave effects, so littoral currents in the surf zone are absent, hence this final step of effluent transport to the shoreline is missing. (We hope to address this later.) The focus here is not as much on these different types of currents and their dynamical processes but rather on the resulting effluent distributions they cause.

In Southern California discharge of wastewater effluent into the ocean was historically implemented as a way to safely dispose of minimally treated (*e.g.*, screening only) sewage with the understanding that dilution within the ocean would render the harmful constituents safe via biological and chemical reactions and physical transport. However, environmental concerns grew, and the municipalities began implementing increased treatment (*e.g.*, primary sedimentation, secondary biological treatment) on land as well as placing outfalls further offshore and at greater depth (SCCWRP, 1973; Anderson et al., 1993; Sklar, 2008). Outfall design also often included diffusers consisting of a pipe with discharge jets under pressure through multiple ports over a length approximately 10 times the discharge depth. This design enabled greater immediate mixing through the individual jets, followed by increased nearfield mixing and dilution of the turbulent buoyant plume, as compared to a single pipe outlet (Fischer et al., 1979). Both OCSD and HTP have primary outfalls that follow this design rationale, with outfalls that terminate approximately 5 miles offshore with multi-port, bottom-mounted diffusers at depths of $h=60$ m and 57 m, respectively (CRWQCB, 2010, 2012). Each currently discharged secondary-treated wastewater effluent, which typically has elevated levels of nitrogen (as ammonia and/or nitrate), organic matter, and pathogens relative to the receiving ocean waters. Both effluent and receiving waters are monitored for these conventional pollutants and for numerous other contaminants (inorganic, volatile and non-volatile organics, carcinogens, *etc.*) that might affect human and environmental health.

The effluent plumes of both the OCSD and HTP outfalls have been found to remain primarily subsurface below depths of 15–20 m during typical density-stratified conditions, as detected by a variety of parameters (salinity, colored dissolved organic matter, bacteria, ammonia) during routine monitoring (OCSD, 2012; City of Los Angeles, 2007). The routine monitoring stations used by the agencies extend about 10 km perpendicular from shore, and thus are not ideal for tracking the horizontal extents of the plumes. Jones et al. (2001) detected the OCSD effluent plume at least 12.5 km from the outfall in either alongshore direction during two sampling periods using salinity, ammonium, and fecal coliform bacteria as indicators. Boehm et al. (2002) investigated cross-shelf transport of the OCSD effluent plume towards the shore and found the plume within approximately 2 km of the shore (5 km from the outfall), as indicated by *E. coli*. Jones (2004) found consistent results in plume sampling for cross-shelf transport using salinity, fecal indicator bacteria, and ammonium as evidence of plume presence. In general, studies of the OCSD effluent plume have shown mainly alongshore transport either up or downcoast from the outfall, over subsurface depths ranging from 15 to 70 m, and with considerable heterogeneity in plume patterns (Jones et al., 2001; Boehm et al., 2002; Jones, 2004; Todd et al., 2009). Effluent plume surfacing appears rare, although evidence of the HTP effluent plume on the surface has been captured by synthetic aperture radar (SAR) imagery during one winter event in 1997, with the plume covering an area of approximately 16 km^2 above the diffuser location (Di Giacomo et al., 2004).

The current OCSD and HTP outfalls have been in continuous operation for 40–50 years. To perform any major repairs or internal inspection of the structures, the effluent needs to be diverted to another location. For both facilities, older, deactivated outfalls are permitted for use as temporary or emergency discharge locations; both discharge approximately 1 mile offshore, with the OCSD nearshore outfall at 20 m depth and the HTP outfall at 15 m depth (CRWQCB, 2010, 2012). Use of the nearshore outfalls for discharge diversion has been rare and recently limited to one event during 2006 when HTP performed an internal inspection of its standard pipe and one during 2012 when OCSD repaired its standard pipe. Additional diversions are possible in the future.

2. Model configuration

2.1. The ROMS model

The oceanic circulation model ROMS is used to simulate the circulation and tracer effluent dispersal in the coastal zone of Southern California. It includes K-Profile Parameterization (KPP; Large et al., 1994; Durski et al., 2004), a non-local turbulent closure model for vertical momentum and tracer mixing in the surface and bottom planetary boundary layers and in the interior of the fluid. In addition it has a numerical hyperdiffusion associated with horizontal advection with an effective diffusivity coefficient that decreases with the grid scale. The present ROMS configuration consists of quadruply nested model domains (Fig. 1) with an offline, one-way nesting technique that downscales from $dx=5$ km horizontal resolution of the U.S. West Coast (L0), to 1 km resolution for the Southern California Bight (L1), to 250 m resolution for the interior shallow area of the Bight with a multiple of large islands and deep basins (L2), and then to 75 m resolution for two separate subdomains encompassing Santa Monica Bay (L3a) and San Pedro Bay (L3b). Each domain has 40 (L0, L1, and L2) or 32 (L3a and L3b) topography-following levels vertically stretched such that grid cell refinement occurs most strongly near the surface and the bottom. The model topographies are from the 30 arcsec global bathymetry (SRTM30; Becker et al., 2009) overall, with refinement using the 3 s ($dx=90$ m) NOAA-NGDC coastal relief dataset[2] for the nearshore regions depending on data availability.

The outer L0 domain is forced by the monthly averaged data from SODA version 2.0.4, an assimilated global oceanic dataset (Carton and Giese, 2008) in the lateral boundary conditions; the monthly average AVHRR Pathfinder satellite sea surface temperature[3] (SST), and the COADS climatological dataset for sea surface salinity[4] (SSS). On the L0 grid the monthly climatology of runoff from major rivers (Dai and

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[1] Buijsmann et al. (2012) use these same simulations to analyze the internal tide in the Southern California Bight.

[2] http://www.ngdc.noaa.gov/mgg/coastal/crm.html

[3] http://podaac.jpl.nasa.gov/DATA_PRODUCT/SST/index.html

[4] http://www.ncdc.noaa.gov/oa/climate/coads/