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Hydrodynamic Numerical Ocean Models Support Environmental Studies and Conservation Efforts: From an Arctic Estuary to a Caribbean Coral Reef

Tal Ezer
Old Dominion University, tezer@odu.edu

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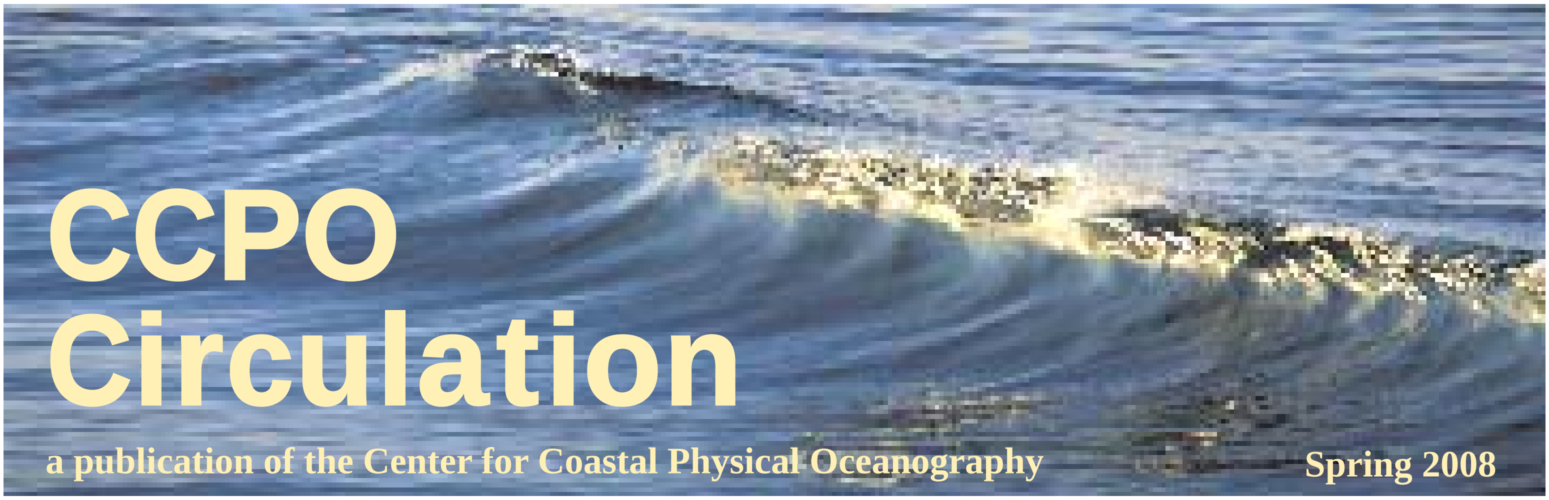

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Hydrodynamic Numerical Ocean Models Support Environmental Studies and Conservation Efforts: From an Arctic Estuary to a Caribbean Coral Reef

by Dr. Tal Ezer
Center for Coastal Physical Oceanography (CCPO) and
Virginia Modeling, Analysis & Simulation Center (VMASC)

Potential future climate changes, as highlighted recently by the Intergovernmental Panel on Climate Change (IPCC) report, are likely to have different local impacts in different regions of the globe. Oceanic ecosystems may be especially sensitive to large environmental variation, and they are closely connected to physical changes such as temperature, salinity, currents and sea level. Two examples, from very different environments – one in a cold climate and one in a tropical climate, will be discussed here to show how hydrodynamic numerical models are helping to understand physical-biological interactions and potentially help dealing with future climate changes.

Cook Inlet (CI) in Alaska (Fig. 1) is an Arctic estuary with a unique environment and one of the largesttidal ranges in North America (8-10m range).

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Figure 1. An aerial view of the upper Cook Inlet in Alaska, showing the exposed mud flats at low tide. The picture was taken by Tal Ezer as he flow over the Inlet on the way back from Anchorage (Anchorage is about 50 km north-west from that location).

About half of Alaska's population lives in Anchorage and around the Inlet. The inlet is also a home to a variety of wildlife, including a declining population of Beluga Whales (only about 300 are left out of the thousands counted there in the 1970s). NOAA's scientists have been studied the Belugas and tracking their movements with satellite telemetry (Hobbs et al., 2005). Whether environmental changes cause this decline is unclear, but a hydrodynamic model is used to relate the Belugas movements to the environment in the Inlet.

A three-dimensional ocean circulation model of CI has been implemented with a Wetting and Drying (WAD) algorithm (i.e., with a "movable" coastal boundary) in order to test its capability to simulate extremely large tides and evaluate inundation models and flood predictions (Oey et al., 2007). The model simulated unusual observed features such as fast moving (~5 m/s) tidal bores over shallow regions in the upper Inlet and strong "rip-tides" over deep channels in the central Inlet. The CI numerical ocean model is used to study the relation between the physical properties and the Belugas movements in shallow areas where no other observations are available. Preliminary results of a few weeks of data show that the daily movements of the Belugas in the upper CI seem to follow the propagation of the tides (and salinity fronts, not shown). The flooding of the shallow mudflats allow them to swim to areas that are not accessible during low tides and thus feed on fish in rivers farther up the Inlet (Fig. 2). More detailed analysis using several years of model simulations and whale tracking data are now underway; these will give us a better understanding of the impact that the daily and seasonal variations in the physical properties may have on the Belugas and their survival.

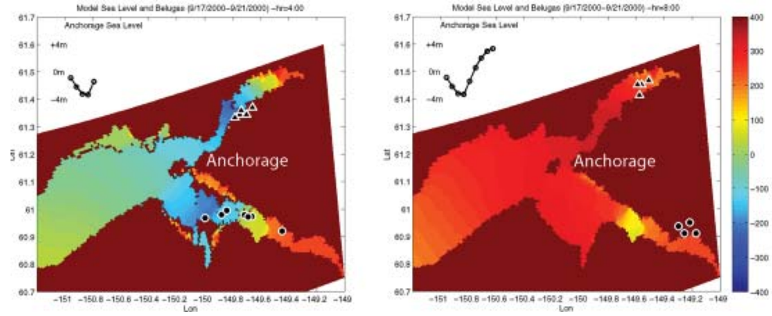

Figure 2. Model simulated sea level (in color) in upper Cook Inlet during low tide (left panel- note the exposed land) and high tide (right). Corresponding to each tide stage, the Beluga Whales spotted during 17-21 September, 2000, are indicated by circles (in Turnagain Arm) and by triangles (in Knik Arm).

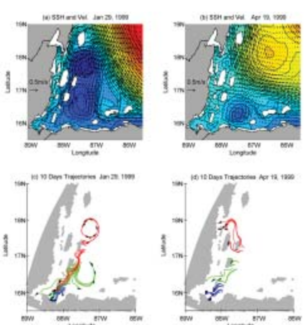

Figure 3. Model simulations (Ezer et al., 2005) of sea surface height (blue/red for low/high) and surface velocity for (a) January and (b) April, 1999, when a cyclonic and an anticyclonic anomalies, respectively, where observed near the MBRS. (c) and (d) show the trajectories of passive tracers released at the surface near reefs with known fish aggregations, and correspond to the velocity fields of (a) and (b). The model was initialized using observed altimeter data representing the

The Meso-American Barrier Reef System (MBRS) in the western Caribbean Sea, is another region of concern for the impact of climate change. In particular, rising ocean temperatures are causing coral bleaching in Caribbean reefs, and intense hurricanes such as Wilma in 2005 can also have considerable impact on the region (e.g., see the simulations of Oey et al., 2006, 2007). The MBRS is known to have a concentration of fish spawning aggregation sites. One of the outstanding issues in conservation efforts is the connectivity between reef and nursery areas (Heyman et al., 2008). Therefore, there are ongoing efforts to simulate the details of the flow along the reef, the impact of different forcing mechanisms and the implications for reef connectivity. The problem of predicting current variations near reefs is not simple since it involves the impact of unpredictable offshore Caribbean eddies (Ezer et al., 2005) and the interaction of currents with small-scale topographic features which are not well resolved in numerical models.

The dramatic impact of eddies on the flow near the MBRS is demonstrated by assimilating satellite altimeter data into a numerical model of the western Caribbean Sea (Ezer et al., 2005) as shown in Fig. 3a and 3b. The consequences for reef connectivity and the potential dispersal of eggs and larvae released near different reefs are shown in Fig. 3c and 3d. When a cyclonic eddy is found near the reef (Fig. 3a and 3c) the Caribbean Current moves farther offshore, creating two cyclonic gyres outside the reef that can trap some eggs, but also results in a strong southward flow along the Belizean coast. On the other hand, if an anticyclonic eddy is found near the reef (Fig. 3b and 3d), the flow is mostly westward across the reef toward the lagoon, so no eggs drift offshore. Note that simulated eggs released on two sides of the same reef may drift in opposite directions, similar to observations using drifter data (Fig. 4).

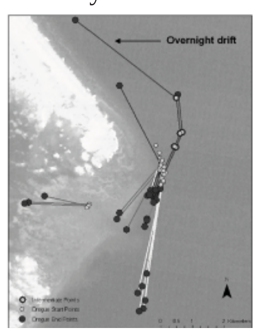

Figure 4. Drifters released at Gladden Spit, a popular point for spawning aggregations along the Belize Reef, show that simulated eggs may move in multiple directions (from Heyman et al., 2008).

Another area in the Caribbean Sea that is being studied extensively is the Cariaco Basin in the southeastern Caribbean, where intense upwelling is connected with high biological productivity. Long-term time series from this area is combined with models to study the impact of climatic changes. Recent studies indicate that upwelling there is more complex than previously thought and involves not only a classic coastal wind-driven upwelling, but other mechanisms, including offshore wind variations and Caribbean eddies (Rueda-Roa et al., 2008).

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dent) of USF. Support has been provided by grants from the Nature Conservancy, NOAA, NASA and MMS.

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Turbulent Shear Flow and Langmuir Turbulence in Shallow Water: Large-Eddy Simulation

by Ying Xu

Langmuir circulation (LC) gets its name from Irving Langmuir who first noticed, when crossing the Atlantic in 1927, patterns of floating seaweed in linear bands. He confirmed the existence of this circulation by simple but ingenious experiments performed in Lake George, NY and published the first scientific paper on LC in 1938. Dr. Ying Xu, in collaboration with Chet Grosch and Ann Gargett, has been studying the dynamics of these circulations for the last year or so.

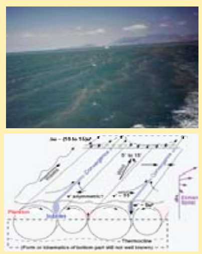

Figure 1. (a) Streaks of foams or other floating materials on the surface of the ocean and (b) Sketch showing the pattern of mean flow in idealized Langmuir cells. In practice the flow is turbulent, especially near the water surface, and the windrows amalgamate and meander in space and time. Bands of bubbles or buoyant algae may form within the downwelling flow.

LC in any water body produces streaks of floating material or bubbles on the surface (Figure 1(a)). Technically, LC is thought of as an array of horizontal vortices of alternating signs with the axes directed downwind (Figure 1(b)), though there is often a slight deviation (~ 15 degrees) to the right of the wind in the northern hemisphere. Flotsam and buoyant algae accumulate in bands, called windrows, where the surface flow converges. The separation of bands at sea ranges from 2 m to 1 km; their lengths are three to ten times the separation. LC rarely extends deeper than about 6 m below the surface.

LC was regarded as regular and steady, apparently constraining lateral dispersion by carrying material into narrow bands and inhibiting, rather than enhancing, dispersion. However, this perspective has now changed, partly because of developments in numerical simulation, particularly Large-Eddy Simulation (LES) models, but mainly as a result of new methods of observation, notably sidescan Doppler sonar, freely drifting instruments, and autonomous underwater vehicles (AUVs). LC is now known to produce bands that are generally orientated downwind. They are rarely steady, linear, or regularly spaced, but are more often twisted and subject to amalgamation one with another.

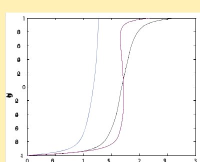

Figure 2. Mean downwind velocities of: pressure only driven flow at Re=180 (blue line), pressure and wind driven flow at Re=395 (black line) and pressure and wind driven flow with Langmuir circulation at Re=395, La_T=0.7 (purple line).

LC is now thought due to the interaction between the wind-driven shear current and the Stokes drift of surface gravity waves. Separation scales (twice the Langmuir cell widths), as well as band length, increase slowly with wind speed.

LC is one of the several turbulent processes in the upper part of oceans and lakes. It complements, interacts with, and often dominates other turbulent processes, such as wind- or tidal-driven shear flows, buoyancy-driven convection and wave breaking, that transport momentum, heat and mass, causing dispersion in the upper ocean. However, in spite of its evident importance, LC is not represented or parametrized in current global circulation and climate models, or even in smaller models used to predict dispersion of oil spills.

Model and Results

The first model for LC (by Craik & Leibovich) analyzed a vortex force (the Craik-Leibovich (C-L) force) arising from the interaction between the Stokes drift, driven by the surface waves, and the vertical shear of the current. This early model has been extended to permit density stratification which is shown to produce convective instability.

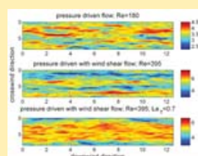

Figure 3. Color maps of instantaneous u on horizontal plan (x-y) and at mid depth (z=H/2) in different flows

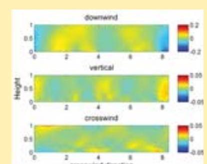

Figure 4. Color maps of time and downwind averaged fluctuating velocity of y-z plane for flow with pressure gradient only at Re=180.

In the last decade, LES calculations have shown that under typical oceanic conditions LC leads to: (i) homogenized mean velocity and momentum flux profiles; (ii) enhanced turbulent vertical velocity fluctuations; (iii) increased dissipation and entrainment buoyancy flux; (iv) wave forcing (creating LC) dominates near-surface turbulence, (v) dissipation rates were in good agreement with observations; (vi) the coherent downwind structures were more randomly distributed than those of prior simplified models; and (vii) LC played a bigger role than convection in generating mixing.

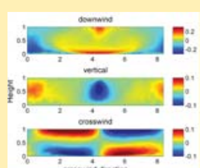

Figure 5. Color maps of time and downwind averaged fluctuating velocity of y-z plane for flow with pressure gradient and wind shear stress at Re=395.

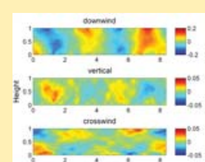

Figure 6. Color maps of time and downwind averaged fluctuating velocity of y-z plane for flow with pressure gradient and wind shear stress at Re=395, La_T=0.7.

The group at CCPO is exploring the dynamics of LC as it interacts strongly with the ocean bottom. We have conducted LES experiments with intermediate depth waves (wave lengths 6 times water depth) and an active bottom boundary layer. Three shallow water cases are considered: (1) tidally-driven flow; (2) initially tidally-driven flow with added wind stress but without LC processes; and (3) tidally-driven flow with winds as in (2) but including LC processes.

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