MODIFYING A THREE DIMENSIONAL NEARSHORE CIRCULATION MODEL FOR IRREGULAR SHORELINES

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ABSTRACT

As increased development and habitation of our shorelines continues unabated, and as science begins to provide us with the necessary tools to understand the dynamic nature of our shorelines, we find ourselves in the midst of debate. For as much as science tells us our shoreline is continuously evolving, we are forever trying to keep it from doing so. Advancements in the coastal sciences have allowed us only to prolong our claims on the shoreline. For example, computer models are capable of predicting where and when erosion or deposition is likely to occur. Accurate prediction of these phenomena is useful in shoreline development plans and is perhaps most important during storms, when devastating property damages are most likely to occur. Although various models exist, there is a need for a well agreed upon, versatile, and reliable model that is also computationally efficient, such that it produces results in a timely manner.

The aim of our study is to modify a model for bathymetric evolution under the combined effects of waves and currents in order to ascertain the rates and pathways by which a tidal inlet bypasses sediment. To this aim we have obtained SHORECIRC (version 1.3.6), developed recently at the University of Delaware (Van Dongeren, et al. 1994), which is a quasi-3D model for nearshore circulation under the combined effects of waves and currents. SHORECIRC first calculates 2D depth-averaged hydrodynamic quantities based on governing equations of motion which are integrated over depth and averaged over time periods on the order of wave periods (Putrevu & Svendsen, 1999; Svendsen & Putrevu, 1994). SHORECIRC then uses these 2D results to calculate the 1D vertical variation in fluid velocity. This results in a complete 3D determination of $u(i,j,z)$ and $v(i,j,z)$ where u and v are the x-directed and y-directed velocity components respectively, i and j denote location on a Cartesian grid, and z represents the vertical coordinate.

SHORECIRC solves a system of governing equations using a central finite difference scheme (Svendsen et al., 1999). Central finite difference schemes are the preferred method of calculating spatial derivatives, as they are accurate to (Δx^2). For example, $x'(i)$ is expressed as a central finite difference in (1) where i is the spatial coordinate in the x-direction, and dx is the grid spacing. All that is required to calculate this spatial derivative with a central finite difference scheme is information at two other spatial coordinates, such as $x(i-1)$ and $x(i+1)$ in (1).

$$x'(i) = \frac{x(i+1) - x(i-1)}{2\Delta x}$$ **EQ. 1**

Robust boundary conditions are necessary to calculate central differences at the edges of the model grid domain. SHORECIRC provides boundary conditions at the seaward boundary (x = 0), the shoreline boundary (x = L_x), and both lateral boundaries (y = 0 and y = L_y), where L_x and L_y denote length of the domain in the x and y direction on the Cartesian grid respectively. The following chart depicts the boundary conditions available in SHORECIRC:

Boundary Type	Boundary Condition				
	Flux Specified	Absorbing/generating	No Flux/wall	Periodic	Moving Shoreline
Seaward		*		*	
Shoreline			*		*
Lateral	*		*	*	

We have run SHORECIRC on numerous test cases utilizing both plane beach and equilibrium beach profiles. These test cases involve various bathymetric configurations, each of which increases in degree of shoreline irregularity. For example, the configuration consisting of a beach with a jettied channel oriented non-normal to the shoreline (test 4) is perhaps the most irregular. Additionally it is most representative of the bathymetric configuration found at our study site. Tests run to date are as follows:

1) Equilibrium beach
2) Equilibrium beach with a shore-normal channel
3) Equilibrium beach with a shore-normal jettied channel
4) Equilibrium beach with a non-normal jettied channel
5) Plane beach
6) Plane beach with a shore-normal channel
7) Plane beach with a shore-normal jettied channel

Preliminary tests ran for 0.45 hours with a 4 second, 2 m wave. We utilized the absorbing/generating boundary condition at the seaward edge of the domain, the no flux/wall boundary condition at the landward edge of the domain, and the periodic boundary condition at both lateral edges of the domain. It is important to note that the shoreline in tests 1, 2, 5, and 6 occupied the last grid row, and that these tests met with success. Subsequent tests with more irregular shorelines, such as those incorporating jetties, failed largely due to the simple no flux/wall boundary condition utilized at the landward boundary. SHORECIRC does not include a functioning moving shoreline boundary condition that allows for wetting and drying of the shoreline.

When modeling over irregular bathymetric configurations, the shoreline is hardly expressed as a straight line, as it changes orientation alongshore. Additionally, most realistic bathymetries contain some amount of dry land, which this original version of SHORECIRC is not capable of handling. Because this version is currently only capable of handling simple, straight shorelines which occupy the last grid row, we could not apply it to our study area without first modifying the no flux/wall boundary condition to allow for alongshore variation and dry land. Our work to date focuses on these modifications, which create a new shoreline boundary condition which we are calling the modified wall shoreline boundary condition.

To complete these modifications, we have taken clues from the embryonic moving shoreline boundary condition, where the contributions to the instantaneous momentum balance from points on land are zeroed. The original version of SHORECIRC performs these calculations in double do loops with variable limits determined by shoreline location. This formulation decreases code parallelization and significantly increases run time. We are able to improve code parallelization and reduce run time by replacing the double do loops with single do loops in which the limits are fixed to compute over the entire domain. This is achieved by creating pre-determined blanking arrays which account for the boundary by zeroing appropriate values. Additionally these arrays perform such tasks as zeroing flow on land, prohibiting flow into land but permitting flow away from and parallel to land, and applying appropriate differencing schemes near boundaries.

Five blanking arrays are created in a new subroutine at the start of each run. Sblank is the array that delineates wet from dry and is based on bathymetry. It has a value of 1 where a point is wet and indicates calculation of a value; it has a value of 0 where the point is dry and indicates zeroing of a value. Xdenom, xnumadd, ydenom, and ynumadd are the blanking arrays applied to the x-directed and y-directed gradients and fluxes respectively, and are created based on sblank values at and adjacent to each grid point. These values are included in velocity flux operations as in (2), for example.

$$qxnp1(i,j) = \left[\frac{\left(qxnp1(i,j) + \left(xnumadd(i,j) * |qxnp1(i,j)|\right)\right)}{xdenom(i,j)} \right] * sblank(i,j) \qquad \textbf{EQ. 2}$$

A similar scheme is used to apply appropriate derivative schemes near boundaries. With complicated bathymetries it is essential that the presence of land is properly included in derivatives, as derivatives generally represent the major forcing terms in the model. For example pressure gradients must account for the fact that water will pile up against the shoreline while velocity gradients should recognize that the shore-normal flow is zero at the shoreline. The original version of SHORECIRC properly accounts for these factors when the shoreline is a simple straight line but not when the shoreline is more irregular. In order to account for these factors, we create two additional arrays, xderivtype and yderivtype, at the start of each run. These arrays indicate where a point is located in relation to a boundary, which determines the values the x-directed and y-directed derivatives should utilize. The five possible types of locations are:

1) open water (interior points, located more than 3 points away from the boundary)
2) basic open water (located 2 points away from the boundary)
3) land to right (or in front) (located adjacent to the boundary)
4) dryland (located on shore)
5) land to left (or in back) (located adjacent to the boundary)

As an example, the x derivative, Fxdata, of the variable fdata may be expressed at any location in the domain by the following generic equation where xderivcoeff is a 5x5 array of weighting coefficients, and aux is a 5x1 array of normalization coefficients:

$$
\begin{aligned}
\text{Fxdata} = [&\text{xderivcoeff(xderivtype(i),1)} * \text{fdata(i + 2)} \\
&+ \text{xderivcoeff(xderivtype(i),2)} * \text{fdata(i + 1)} \\
&+ \text{xderivcoeff(xderivtype(i),3)} * \text{fdata(i)} \\
&+ \text{xderivcoeff(xderivtype(i),4)} * \text{fdata(i - 1)} \\
&+ \text{xderivcoeff(xderivtype(i),5)} * \text{fdata(i - 2)}] \\
&* \text{aux(dtype(i))}
\end{aligned}
$$

EQ. 3

To date we have run all previously discussed tests including the test that incorporates jetties oriented at some angle to the shoreline. These tests ran with an 8 sec, 1.5 m wave, and have met with success. We utilized the new modified wall boundary condition at the shoreline, and kept the seaward and lateral boundary conditions the same as in previous tests. Additionally these tests showed improvement in model run-time. For example, whereas previous tests took 45 minutes to simulate 30 minutes of time, these tests took only 15 minutes.

The use of this new modified wall shoreline boundary condition makes running SHORECIRC on more complex bathymetric configurations possible. As such, SHORECIRC's utility as a tool in nearshore circulation studies has been greatly improved. Our next step will be utilizing this modified wall shoreline boundary condition in simulations at our study site in order to accomplish the aforementioned goals of this project.

REFERENCES

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