Measurements and Three-Dimensional Modeling of Hydrodynamic Processes in the Inner Shelf and Surf Zone

by

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ABSTRACT

Surface gravity waves and winds play a dominant role in creating and modifying flows within the inner shelf and the surf zone. Understanding of these flow patterns is required to correctly identify the fate of sediment, pollutants, buoyant river discharge and anthropogenic material from the shoreline to deeper waters. This dissertation is focused on examining the inner shelf and surf zone circulation pattern through: (a) development and validation of techniques to incorporate the effect of surface gravity waves on mean flows using the modeling framework of Regional Ocean Modeling System (ROMS) and the wave propagation model Simulating Waves Nearshore; and (b) a combination of field observations from acoustic instruments, High Frequency radars and coupled wave-current interaction based modeling system.

In the first part of this dissertation, the circulation module is extended for surf zone applications through modification and implementation of depth dependent radiation stress formulations which is used to simulate three-dimensional flows due to depth-limited breaking of incoming waves and their interaction with non-uniform bathymetry. It is identified that radiation stress approach is satisfactory for surf zone flows, but creates incorrect flow patterns outside the surf zone for shoaling and non-breaking waves. In the second chapter, the modified modeling system and long term bathymetric records are used as the basis for the development of a preliminary framework of rip current forecasting system.

In the third chapter, short-comings of the radiation stress formulation is addressed by implementation of the Vortex Force (hereinafter VF) Formalism within the framework of the coupled ROMS-SWAN modeling system. This modification allows for incorporating the effect of surface waves and the updated modeling system works seamlessly from the inner shelf to surf zone. The VF formalism is evaluated against field data for wave breaking driven currents and also for non-breaking wave driven flows outside the surf zone.

The goal of the fourth chapter is to use in-situ measurement of waves and currents at various locations in the nearshore region of Cape Hatteras, North Carolina for investigating alongshore momentum balance around a cuspate foreland system. On the windward side of the cape, a balance between wind and bottom stress is revealed in deeper waters, while on the leeward side, the momentum balance is not closed by wind stress, and instead it is suggested that development of pressure gradient occurs as a response to the wind forcing. In shallower waters, wave breaking, VF, and nonlinear advective acceleration terms are found to be important as well.

The findings from chapter 4 are further corroborated by application of the Coupled Ocean-Atmosphere-Wave-Sediment transport modeling system in a nested framework to resolve wave variability and flows from inner shelf to surf zone. Alongshore momentum balance analysis from model simulation reveals contribution of pressure gradient term on both sides of Cape Hatteras. On the windward side, pressure gradient and wind stress balance the bottom stress, while on the leeward side the wind stress is balanced by the pressure gradient. The shallow shoal complex extending seaward from Cape Hatteras point acts like a coastline in regulating wave propagation and flow pattern for different synoptic wind and wave conditions.