CHAPTER 34

COMPUTATION OF 3-D WIND-DRIVEN CURRENTS BY RESPONSE FUNCTION METHOD

Shiao-Kung Liu and Jan J. Leendertse

1. INTRODUCTION

The paper describes the principle and the computational procedure for the calculation of coastal wind-driven circulation by means of the response function technique. Response functions for a specific coastal seas are derived by use of a three-dimensional model of the area. This method computes the dynamic features associated with the coastal circulation via numerical convolution. Consequently, it is several orders of magnitude more efficient than using the direct integration of the three-dimensional coastal model itself.

2. TECHNIQUES USED

For computing coastal wind-driven currents, the traditional, simple fixed drift-ratio method has many difficulties when applied in shallow coastal area with complicated boundaries. Strictly speaking, the fixed ratio method is applicable only for cases of steady wind with constant speed blows over water with infinite depth and with no boundaries. However the concept is rather good and simple. The proposed response function method is the extension of this basic idea except it includes the nonlinear dynamics associated with a specific coastal area.

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When used in conjunction with a verified model, the wind driven currents of different vertical levels can be calculated using numerical convolutional technique. When deriving the response function, local parameters such as the inertial period, tidal regime and tidal dissipation effect associated with the particular coastal area are all included. To generate a complete set of response functions, five computer simulation runs are needed. One computer run is without wind but with tide. The other four computer runs are with tides and with winds from each of four directions. The four response function sets are derived from the difference between them and the one with tide as the only forcing function. The magnitude of tidal currents at different coastal areas produces variable wind responses under the same wind, so the tide has to be included when deriving wind response functions, otherwise they will be overestimated. This is why in a coastal area with strong tidal currents the drift ratio would be lower than in the open ocean because of the quadratic nature of the bottom friction.

Wind driven currents over stratified waters vary with the degree of vertical stability associated with the stratification. Shore effect further complicates the three–dimensionality of the hydrodynamics of the coastal wind driven currents. To illustrate this point we use a simple case where the E–W and N–S components of the response function of water movement at two nearby locations in Norton Sound is plotted (Figs. 1 and 2). These response functions for the easterly wind are derived by appling east wind for a duration of 12 hours (close to the inertial period) over the water. The response of surface water at two nearby locations is not the same to satisfy the continuity principle of water within the bay. Response functions over the water column of the entire modeled area are calculated by the three–dimensional model.

When response functions are saved in discrete time intervals (usually 15 to 30 minutes) the drift velocity under a future wind scenario at a certain time is computed by numerical convolution.

$$U_{ijk}(n\Delta t)=\Delta t \sum_{m=0}^{n} (W^2)h_{ijk}(n\Delta t-m\Delta t)$$

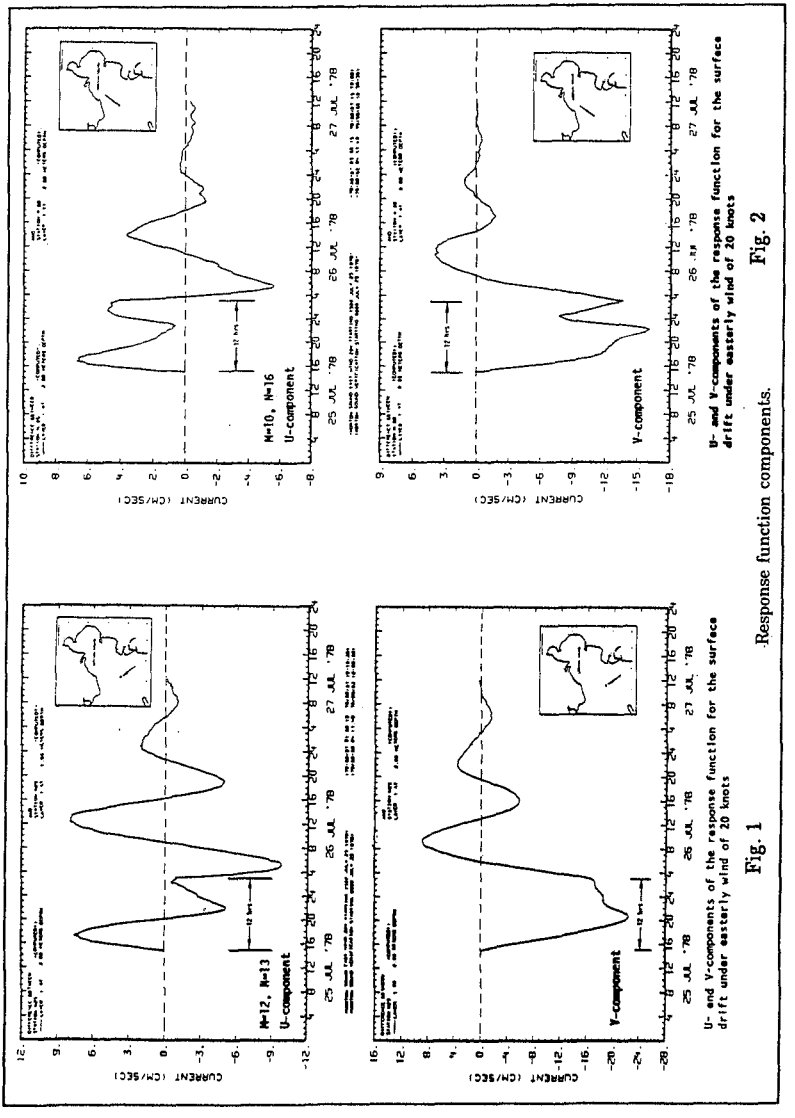

Fig. 1 Response function components.

Fig. 2

Two sets of wind response functions for the surface layer of two neighboring coastal locations showing the difference due to the effects of shore distance, depth, bottom friction, and vertical stratification.

where W = wind speed from a certain direction,

U_{ijk} = velocity at a particular point in space (i,j,k)

h_{ijk} = time domain response function between squared wind speed and velocity at point (i,j,k)

With this formula the velocity at point i,j,k can be determined if the wind speed from a specific direction is known, as well as the response function. The same principle applies for complex wind scenarios, then the vectorial decomposition is involved. Similarly, the principle has been extented to simulating movements and dispersion of pollutant, oil movements under ice, multivariant system analysis involving environmental impact due to multiple sources, etc. (Liu and Leendertse, 1987, 1989, 1978). Figure 3 shows a typical results of coastal drift as computed with numerical convolution. Computer time required by this method is approximately two orders of magnitude lower than the direct 3–D simulation method.

3. ACKNOWLEDGEMENTS

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4. REFERENCES

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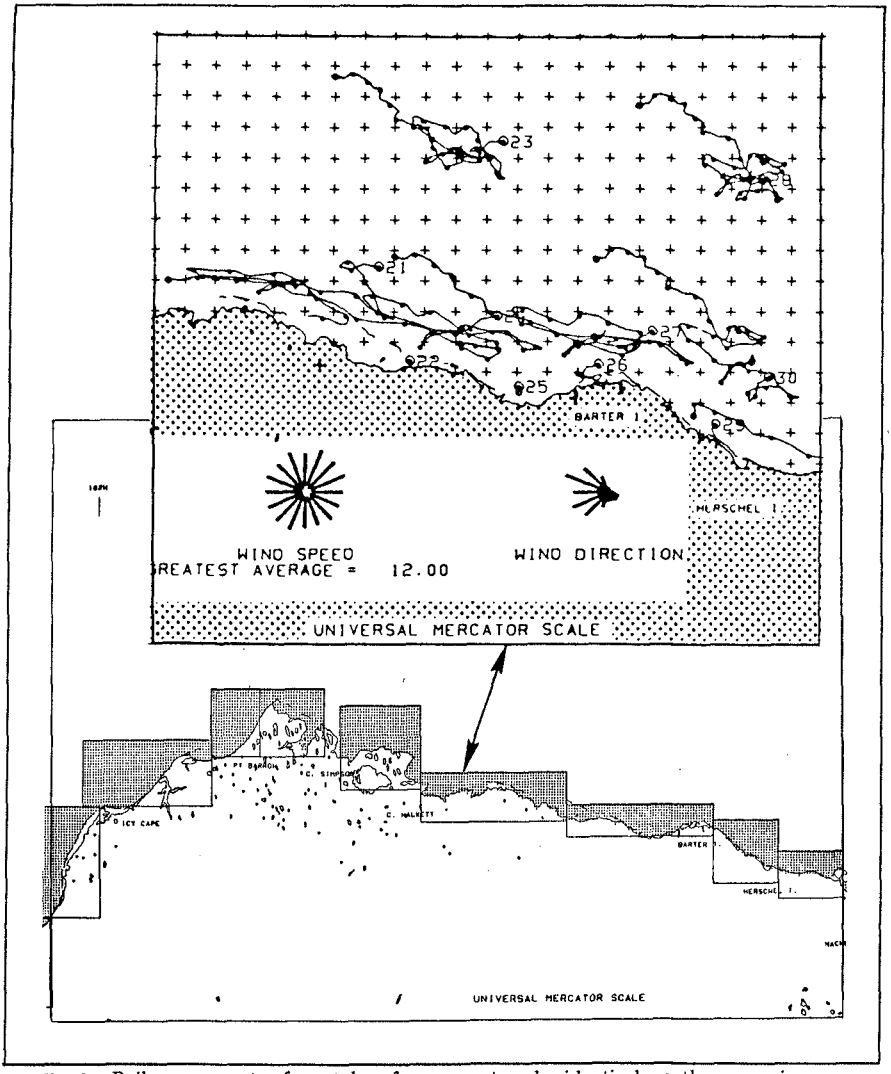

Fig. 3 Daily movements of coastal surface current under identical weather scenario as computed by the convolutional process using 3–D response functions. These trajectories shows the coastal wind drift as a function of shore configuration, , cal depth, vertical stratification, latitude, and the presence of ice.

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