Shallow Water Dynamics in the Arabian Gulf and Gulf of Oman

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LONG TERM GOALS

The development of a three-dimensional, high resolution nowcast/forecast system for the Arabian Gulf and Gulf of Oman which encompasses scales of 10 km or less when warranted, using the most advanced finite element coastal hydrodynamic models. The modeled dynamics are to include tidal and wind-driven flow, buoyancy forcing, surface heat flux, river inflow, and turbulent mixing processes.

OBJECTIVE

A nowcast/forecast system for the Arabian Gulf and connecting waters whose computational model reproduces the complex, 3-D circulation and mixing patterns in the region over seasonal, tidal, sub-tidal, and storm event time scales. Dynamical processes to consider include the three dominant external forcings in the region, a strong evaporative flux, seasonal wind forcing, and freshwater river discharge and their influence on the underlying thermohaline-driven current structure. Three-dimensional transport of mass, salt and heat through the Strait of Hormuz and the role of the Strait in the dynamic coupling of the Arabian Gulf and the Gulf of Oman basins are other important aspects of the circulation dynamics. Another aim of this study is to demonstrate the utility of the finite element approach using state-of-the-art, physically advanced, 3-D numerical models. Advantages of the unstructured grid discretization are evident in the placement of open ocean boundaries, localized resolution refinement, and representation of bathymetric and shoreline complexities. A study of this scope, encompassing the Arabian Gulf, Strait of Hormuz, and Gulf of Oman containing localized mesh refinements of less than 5 km, is unprecedented.

APPROACH

In working toward a nowcast/forecast predictive capability in the Arabian Gulf, two parallel modeling efforts are undertaken. The first effort involves application of the Dartmouth College model, QUODDY, a 3-D, fully nonlinear model that includes tidal, wind-driven, and baroclinic physics, and utilizes advanced turbulence closure is applied at seasonal and tidal time scales. The second thrust concentrates on developing a near-real-time predictive capability using the barotropic ADCIRC-2DDI model, a 2-D, nonlinear simulator of tidal and wind-driven physics. The ADCIRC-2DDI finite element model is noted for its ease of use and computational efficiency and thus presents significant potential for implementation as an operational model. Both of the finite element models implemented are designed with modular dynamics in which certain mechanisms, such as heat flux, wind forcing, stratification, tides, or river inflow can be independently included or excluded from model equations. This modularity is used to examine the contributions of each component to the overall circulation dynamics.

The domain selected for the model experiments includes the Arabian Gulf, Strait of Hormuz, Gulf of Oman, and extends into deep Indian Ocean waters. The finite element mesh constructed for this

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domain contains 8550 computational points whose spacing ranges from 0.5 km -1.0 km near the Shatt al Arab river inflow in the NW Gulf to 46 km in the Indian Ocean. Bathymetry in the Arabian Gulf, taken from the DBDB5, 5 minute data base (Naval Oceanographic Office, 1987), is markedly asymmetrical about the NW-SE axis of the basin. A deep channel off the Iranian coast contrasts the shallow broad shelf on the Arabian side giving an average basin depth of approximately 50 m. Tidal forcing is applied both at the open boundary and internal to the domain through the tidal potential. Values for tidal constituents prescribed at the open boundary are obtained from results of the Grenoble global tide model (LeProvost et al., 1994).

A diagnostic study of the 3-D seasonal circulation using the QUODDY model is undertaken to identify contributions to the circulation from forcing mechanisms associated with density stratification, tides and wind. Alongside this effort is the construction and subsequent validation of a prototype, real-time 2-D, barotropic forecast model (ADCIRC-2DDI) in the Arabian Gulf.

WORK COMPLETED

The 3-D QUODDY model is applied successfully at the seasonal extremes, January and July, in both diagnostic and prognostic computations. Forcing mechanisms include climatological hydrography, seasonal winds, and tides.

A real-time forecast capability in the Arabian Gulf and Gulf of Oman was developed using the finite element hydrodynamic model ADCIRC-2DDI. This prediction system was transitioned to the Naval Oceanographic Office (NAVOCEANO) and has been running operationally since May, 1998. Validation of the modeled sea surface heights computed by the ADCIRC-2DDI barotropic, finite element model as compared to tidal gauge data is also complete.

RESULTS

The QUODDY 3-D, baroclinic, finite element model is initialized with bi-monthly climatological temperature and salinity forcing derived from the MODAS-1 (Harding et al, 1998) static climatological database. The level of no motion is determined and applied as the offshore hydrography forcing. Additionally, five primary tidal constituents are included as boundary elevation forcing in the model. In the diagnostic mode, density stratification remains unchanged though temperature and salinity can respond to tidal mixing and advection. For prognostic computations initial temperature and salinity evolve as the model marches forward in time. The winter stratification (Figure 1) together with the tidal forcing drives the baroclinic tidal rectification shown as vertically-averaged currents in Figure 2. Freshwater inflow through the Strait of Hormuz results in highly stratified waters off the Iranian coast cause a strong coastal current along the northern boundary and eddy formations where denser bottom water meets fresh surface water on the Arabian Gulf side of the Strait.

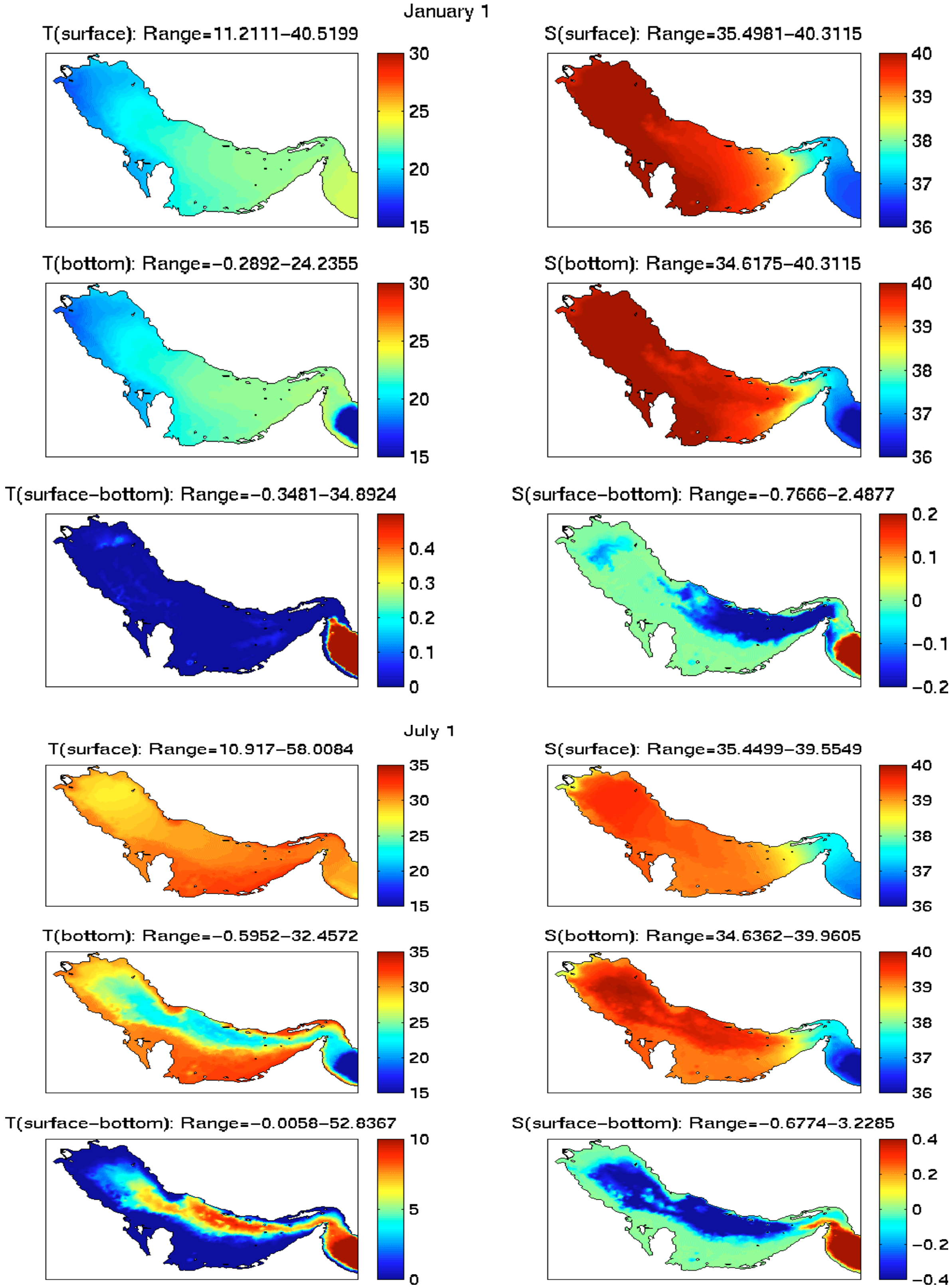

Figure 1. Winter and summer water mass properties in the Arabian Gulf used as forcing for diagnostic 3-D model simulations.

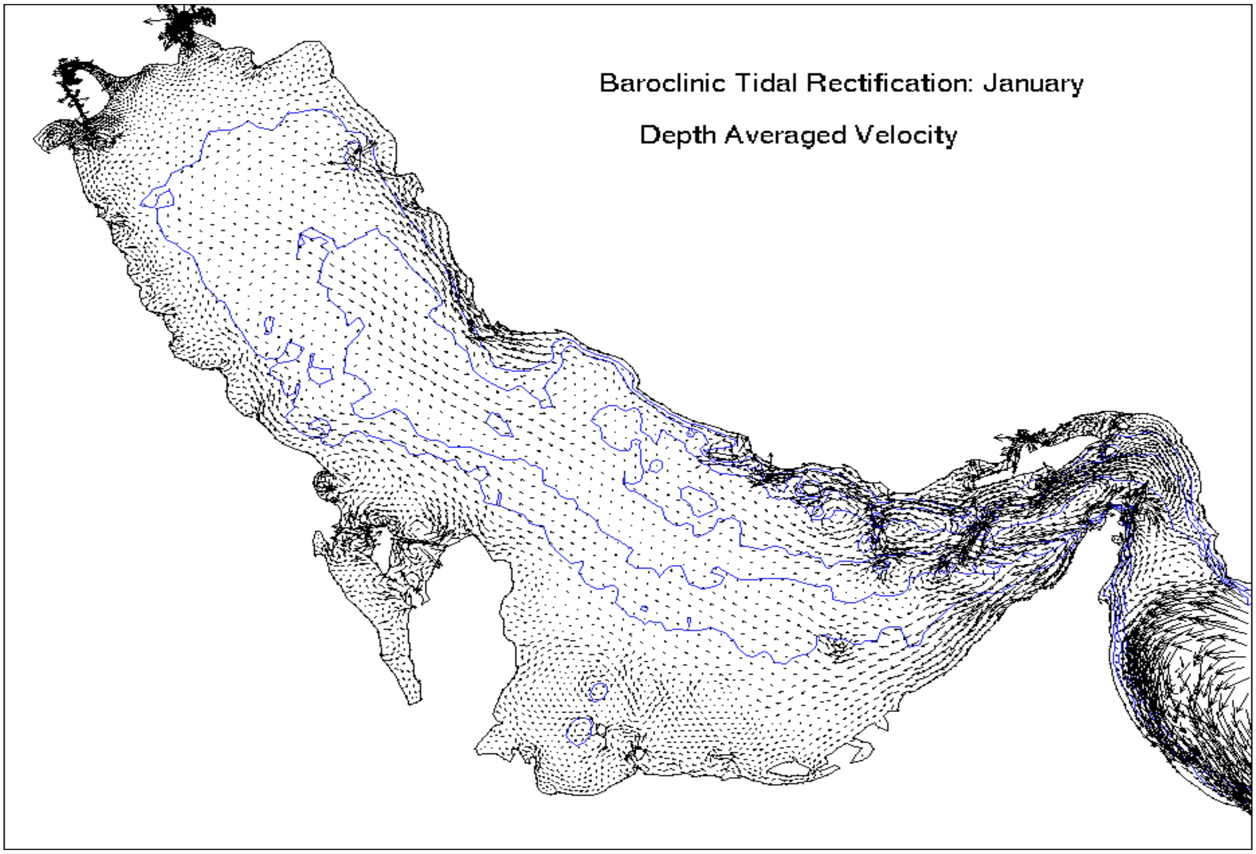

Figure 2. Baroclinic tidal rectification in the Arabian Gulf.

The operational forecast model developed for the Arabian Gulf provides automated, real-time forecasts of depth-integrated coastal barotropic currents and sea surface height forced by tides, wind, and surface pressure. The source of meteorological forcing are the NORAPS atmospheric pressure and wind velocity fields applied at the sea surface. Additional forcing comes from 10 global tidal constituents at the open ocean boundary derived from the Grenoble tidal database together with 6 constituents forced internally through the tidal potential. Data and model parameters are specified as appropriate to the Arabian Gulf region and the wind extraction software is designed to interface directly with the NAV-OCEANO OOC data formats. The software created for this real-time implementation of the ADCIRC-2DDI model includes automation of the input parameter file set-up, which among other things, updates tidal factors for the forecast date, reads and interpolates in space and time the surface wind and pressure forcing data, and automates graphical output of forecast fields using Matlab software. Operational programs and scripts are general in construction so as to accommodate other model domains, sources of forcing, and multiple computational platforms. Rapid transition of this real-time forecast to the NAVOCEANO Warfighting Support Center was made in response to a short time-scale request during the Arabian Gulf crisis, March, 1998. As of May, 1998 the transitioned model is running operationally at NAVOCEANO with a WWW interface displaying the model forecast current and elevation fields at and near 7 select locations (Figure 3).

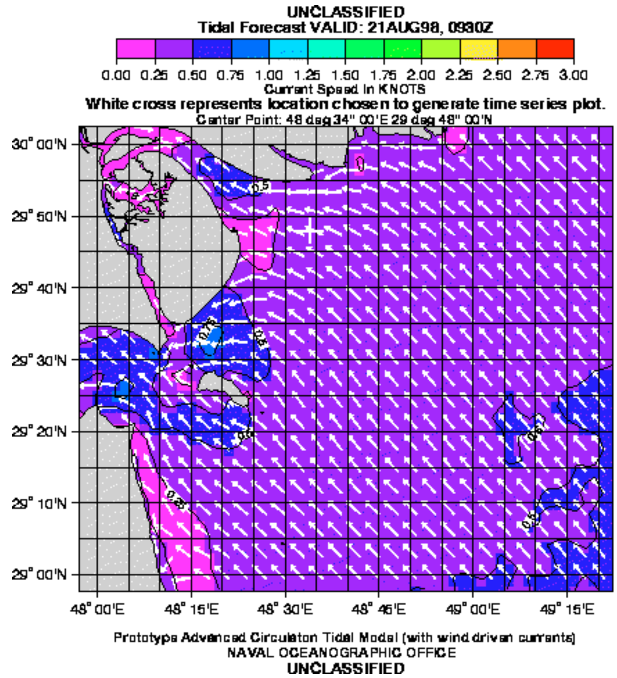

Figure 3. Operational forecast of tide and wind-driven currents in the northern Arabian Gulf derived from the 2-D ADCIRC finite element model transitioned May, 1998.

IMPACT/APPLICATION

Detailed knowledge and understanding of the processes governing shallow water dynamics in the Arabian Gulf, Strait of Hormuz, and the Gulf of Oman address Naval needs for anticipating variability in nearshore circulation and water properties over space and time scales relevant to mine-countermine, amphibious, or special operations in this priority area. High horizontal resolution of current fields assist in the planning of instrumentation and tactics associated with amphibious operations as well as search and rescue efforts.

The real-time run capability developed and demonstrated using the finite element hydrodynamic model ADCIRC-2DDI significantly advances the operational capability of NAVOCEANO to forecast barotropic currents and sea surface heights forced by surface pressure, winds and tides. Until this point NAVOCEANO relied on a regional tidal data base.

TRANSITIONS

A real-time forecast capability using the ADCIRC–2DDI model for wind and tidally-driven flow in the Arabian Gulf to NAVOCEANO Warfighting Support Center, March, 1998.

RELATED PROJECTS

Strong interactions exist with D. R. Lynch (Dartmouth College) through the ONR 6.2 "Finite Element Modeling of Coastal Circulation" which is developing a comparable modeling capability in the Yellow Sea. Communications are established with ONR funded W. B. Johns, (U. Miami) who has taken a yearly record of ADCP data in the St. of Hormuz. Collaboration with R. A. Luettich (U. North Carolina) are leading to advancement of the ADCIRC model to include baroclinic physics.

PUBLICATIONS

Blain, C. A., “Barotropic tidal and residual circulation in the Arabian Gulf”, in Estuarine and Coastal Modeling, Proceedings of the 5th International Conference, M. L. Spaulding and A. F. Blumberg, eds., American Society of Civil Engineers, 166-180, 1998, *reviewed*.