Numerical Modeling of the Responses of Salinity and Transport Processes to Potential Future Sea-level Rise in the Chesapeake Bay and Its Tributaries

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The relative rate of sea-level rise in the Chesapeake Bay region along the East Coast of the United States is greater than the worldwide rate. Concerns regarding sea-level rise include salinity intrusion into freshwaters that affects drinking water supplies, an increase of tidal range that affects freshwater habitat, and changes of estuary stratification and transport processes that will directly influence the regional ecosystem. The U.S. Geological Survey, in cooperation with the City of Newport News, Virginia and the Virginia Institute of Marine Science, conducted a comprehensive study during the last three years on the response of salinity and transport processes to potential sea-level rise in the Chesapeake Bay and its tributaries. This study focused on the changes of hydrodynamics and salinity based on 21st-century sea-level rise scenarios projected by the U.S. Climate Change Science Program. Three scenarios for the mid-Atlantic region were considered:

- *Scenario 1:* The 20th century rate, which is generally 3 to 4 mm/yr in the mid-Atlantic region (30 to 40 cm total by the year 2100).
- *Scenario 2:* The 20th century rate plus 2 mm/yr acceleration (up to 50 cm total by 2100).
- *Scenario 3:* The 20th century rate plus 7 mm/yr acceleration (up to 100 cm total by 2100).

A computational model known as HEM-3D (Three-Dimensional Hydrodynamic and Eutrophication Model) was used to perform the simulations. The challenge in this study is the requirement of long-term simulations performed over a decadal scale combined with the need for high resolution grids in the Bay and its tributaries. An approach with multiple nested grids was used to achieve this goal (Fig. 1). The model simulations are first conducted for the Chesapeake Bay. The results (tidal elevation, salinity, etc.) at the open boundaries of tributaries, such as the James and York Rivers, are then used to drive fine-resolution tributary models. The model outputs in the tributaries are in turn used to drive even smaller domains in tidal branches of the tributaries, such as the Chickahominy River. This strategy enabled us to address the influence of sea-level rise on drinking water supply for cities, such as Newport News, in very small reservoirs with a width of less than 100 m.

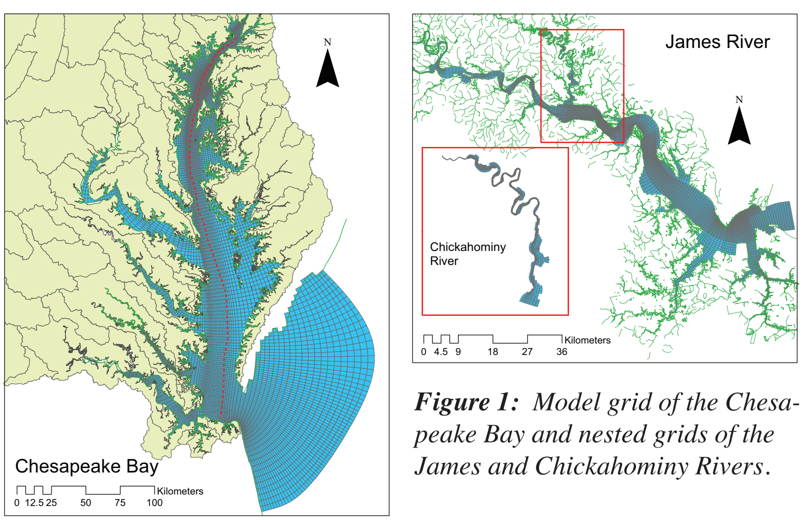

Figure 1: *Model grid of the Chesapeake Bay and nested grids of the James and Chickahominy Rivers.*

Model simulations were on time periods from 1998-2008 to establish current conditions and for the three sea-level rise scenarios (30, 50, and 100 cm by 2100). An extreme case of 150 cm was also investigated. The model results show that average salt content, salt intrusion length, and stratification will increase as sea level rises, with strong seasonal and inter-annual variations (Fig.2). Tidal range will increase as sea-level rises and the increase is more pronounced in the tributaries. The transport time scales, which were introduced to quantify the transport processes, indicate that (1) the exchange flow would be strengthened, and yet the downstream transport of freshwater would be slower; (2) the residence time in the Bay would increase due to the increased volume and change of circulation; and (3) the vertical transport time (referenced to the water surface) has a more pronounced increase. As a result, the retention time of dissolved substances in the Bay would increase. At the drinking-water intake of the Chickahominy River, for example, the number of days of salinity greater than 0.1 ppt increases with increasing sea-level rise. During a dry year, 0.1 ppt would be exceeded for more than 100 days with a sea level rise as small as 30 cm.

SciClone's *typhoon* subcluster was the main computing resource for model calibration and verification as well as sea-level rise simulations. Through the use of HPC capability, we were able to conduct these studies efficiently and successfully. The three years of research efforts have resulted in four conference presentations, one USGS Open-File Report, and two refereed journal articles. The model developed for this project is capable of conducting simulations for the Chesapeake Bay and its tributaries for a variety of urgent ecosystem-related studies.

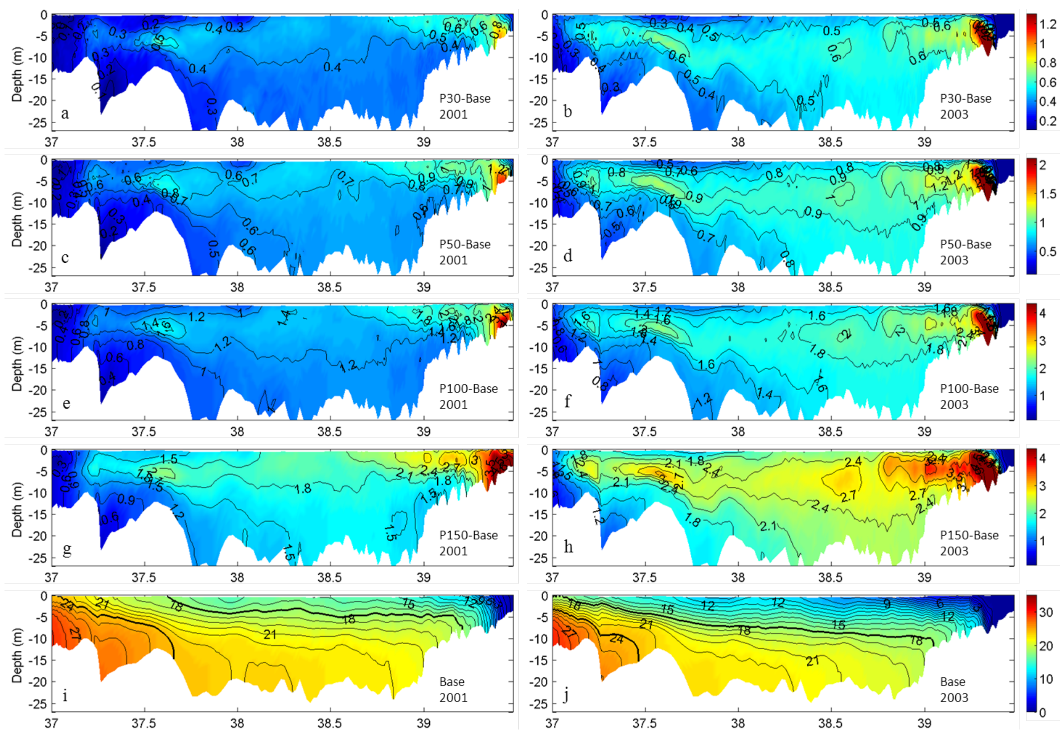

Figure 2: *Along-Bay transect (see Fig. 1) of salinity increase in each sea-level rise case relative to the Base Case (a-h); salinity in the Base Case (i and j). Results in the typical dry year, 2001, and the typical wet year, 2003, are shown in the left and right column, respectively. All the results are averaged in June in the corresponding year.*

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