

# FINAL REPORT

## High Resolution Modeling of the James River Estuary in Support of the USRS Project

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### **Distribution Statement**

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### **Major Goals**

The overall goal of this project is to develop a high-resolution numerical circulation model of the James River estuary in support of the USRS Project. The primary James River model was developed as a nested grid within an existing and extensively validated model of Chesapeake Bay. A second higher resolution nested grid was developed and successfully used to simulate the April 2019 USRS experiment. The new higher resolution model focuses on Newport News Point, with horizontal resolution of 17m. This horizontal resolution is roughly the same as the water depth, and realistically resolves the bathymetry of the region, including the complex variability associated with Monitor-Merrimack bridge-tunnel. Including this high-resolution bathymetry has improved the model's ability to simulate many of the easily observable surface fronts in the region and has increased model skill in simulating both in-situ and remotely sensed data.

### **Accomplishments**

Hindcast simulations using the high-resolution (17m × 17m) grid of Newport News Point, covering the period from April 1 to April 30, 2019, were conducted and validated through comparison with in-situ observations collected during the USRS field campaign in the James River (fig. 1). Model output has been made available to all USRS participants and utilized to support a wide range of research activity including : 1) 3-D acoustic propagation modeling (PI Reeder), 2) interpretation of acoustic backscatter due to bubbles (PI Bassett), 3) controls on surface convergence and radar backscatter (PI Honegger), 4) frontogenesis from in-situ hydrographic data (PI Geyer), 5) estimates of vertical mixing from microstructure profiling (PI Jurisa), and 5) inverse bathymetric modeling (PI Ozkan-Haller).

Results from the high-resolution (17m × 17m) grid of Newport News Point demonstrate that the model does an excellent job at capturing the major surface fronts observed during the flood tide in the James River. The modeled surface convergence agrees favorably with the X-band radar

backscatter anomaly (fig. 2). The key surface features that the model captures include: 1) the flow separation front that forms during late ebb originating at the tip of the northern bridge/tunnel island; 2) the initiation of the tidal intrusion front over Hampton Flats during early flood; 3) the “tunnel front” caused by the convergence associated with this the deceleration of the flood tide as it encounters the deep trough associated with the submerged tunnel; and 4) the pronounced v-shaped tidal intrusion front that forms west of the bridge/tunnel complex including the double convergence zone seen on the southern side of the “v.” There is considerable variability of precisely when and where these pronounced surface features appear that are associated with changes in tidal amplitude, river discharge and wind forcing, which the model captures at first order.

In addition to these surface features that result from the fully 3-dimensional flow, there are additional convergence features that result from the depth-averaged flow. These features, which are almost exclusively driven by the underlying bathymetry, also result in consistent convergence in the model that can be related to features that are observed in the X-band radar backscatter (fig. 3). The relationship between the bathymetry and depth-averaged flow convergence can be seen clearly in the depth-averaged continuity equation:

$$\frac{\partial \eta}{\partial t} + \frac{\partial}{\partial x} [(h + \eta)\bar{u}] + \frac{\partial}{\partial y} [(h + \eta)\bar{v}] = 0 \quad 1)$$

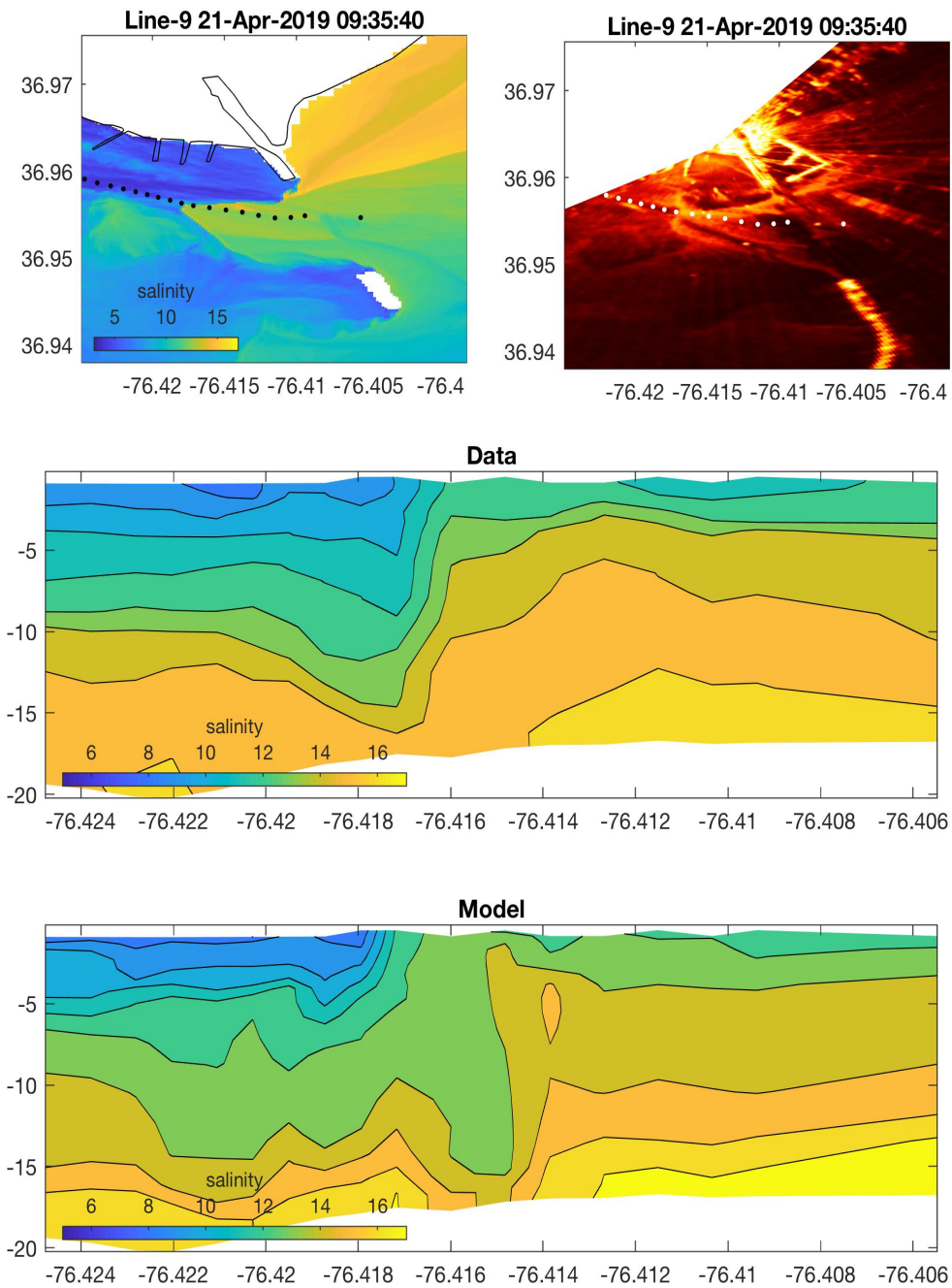
which can be approximated to first order as:

$$\frac{\partial \bar{u}}{\partial x} + \frac{\partial \bar{v}}{\partial y} \approx -\frac{1}{h} \left[ \bar{u} \frac{\partial h}{\partial x} + \bar{v} \frac{\partial h}{\partial y} \right] \quad 2)$$

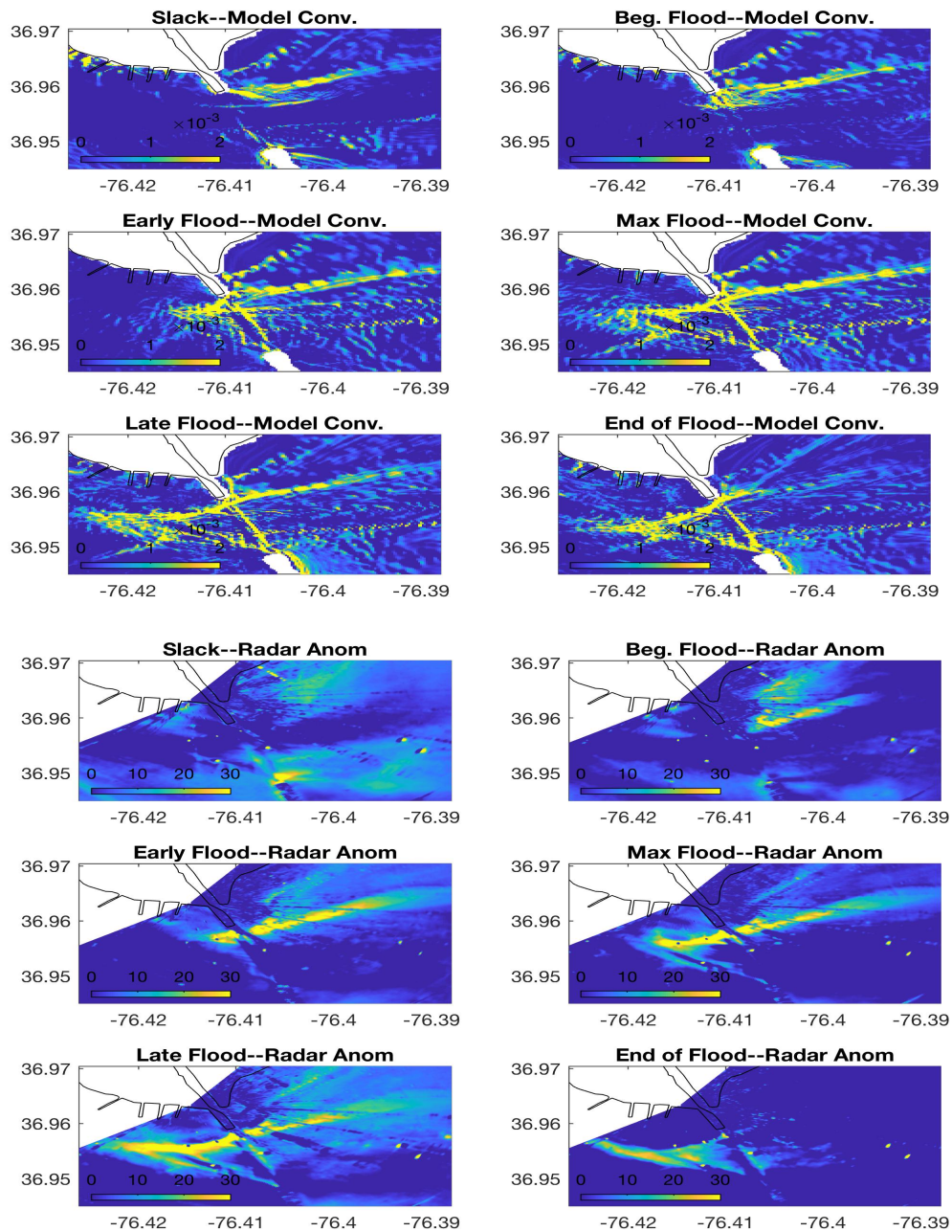
Equation (2) highlights the fundamental link between the bathymetry and depth-averaged convergence and provides insight into a number of features in the X-band radar. These features include: 1) alternating high/low backscatter over tunnel (region A), 2) alternating high/low backscatter where flood currents cross the deep channel (region B); 3) smaller v-shaped convergence off northern bridge terminus (region C); 4) convergence associated with Hampton flats (region D); and 5) convergence where flow enters deeper water south-west of main channel (region E).

In addition to providing key insight into remotely sensed features, the numerical simulations have helped to provide new understanding of frontogenesis mechanisms in the James River. Most notably, the model resolves the Hampton Flats region where strong frontogenesis occurs during the ebb tide (fig. 4). Flow separation that originates from the northern bridge/tunnel island is a source of vertical vorticity and strong lateral shear. This flow separation results in a very strong surface density gradient that drives surface convergence and the establishment of a strong surface front. This front, which is orientated mostly east-west and extends to the east of the bridge/tunnel, is the same front that is advected westward during the flood tide forming the pronounced V-shaped tidal intrusion front. During most of the flood tide, the strength of the surface density gradient remains relatively constant despite the intense surface convergence, highlighting that significant horizontal gradients are exported from the frontal zone, primarily by

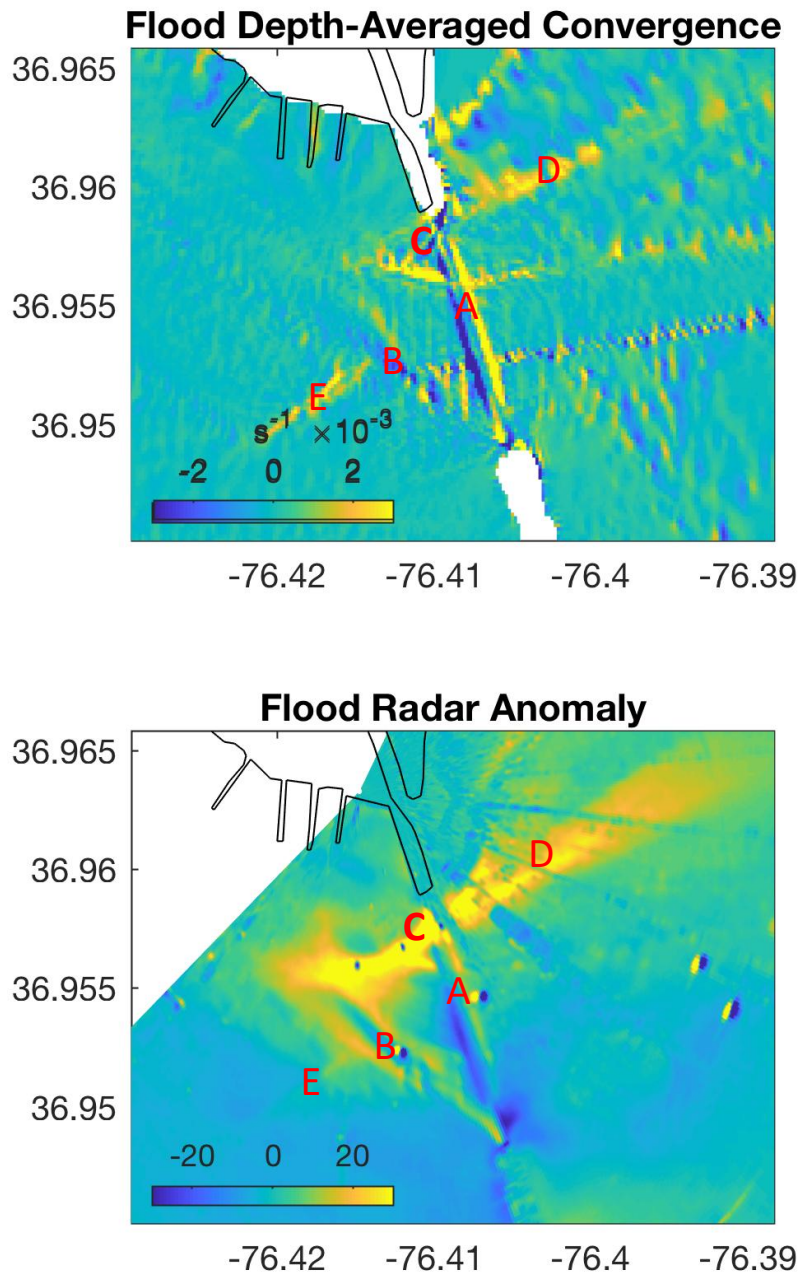
vertical advection and subsequent mixing. Thus, the frontal dynamics in the James play an essential role in controlling both vertical mixing and the creation of vertical density stratification.



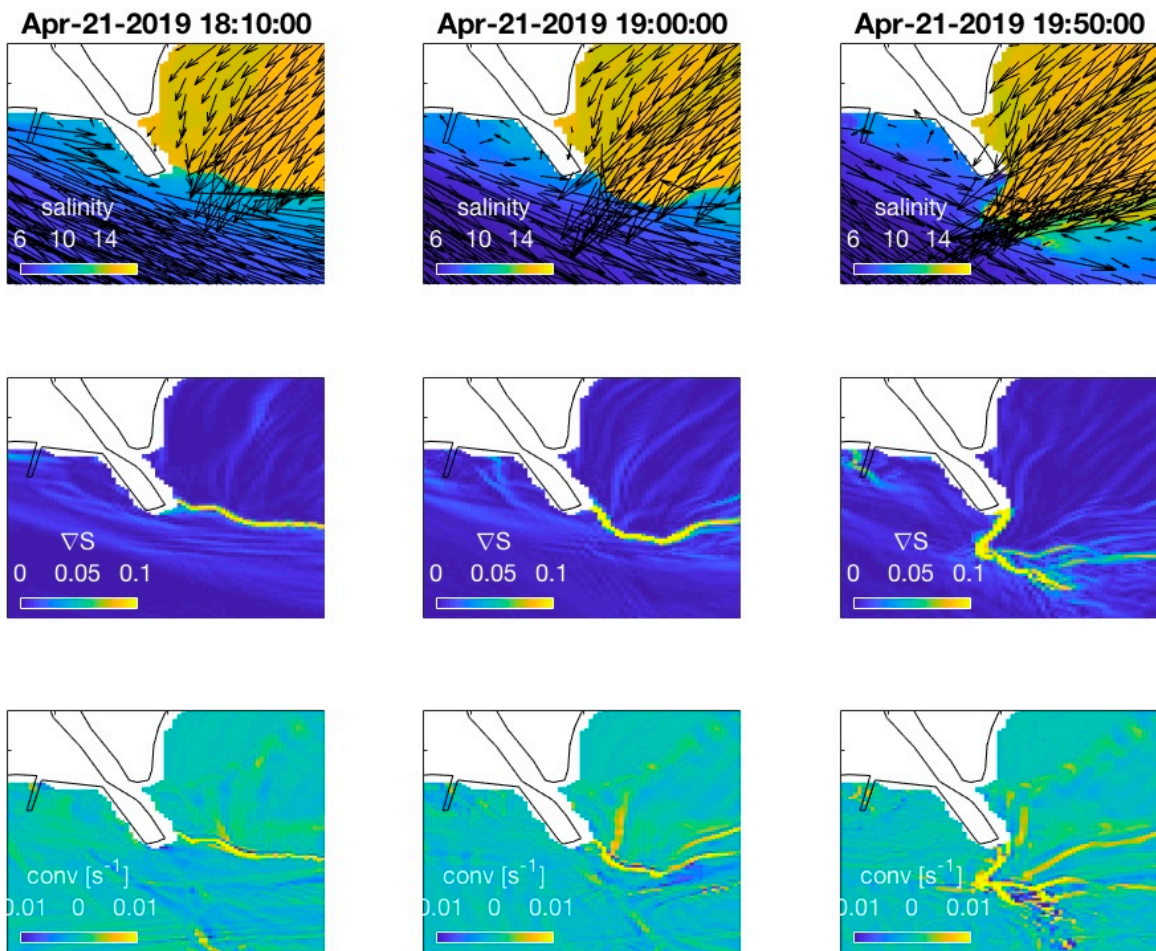
**Figure 1. Comparison of model to surface radar and in-situ salinity transects. The upper left panel shows the modeled surface salinity during flood tide when the tidal intrusion front is well established and clearly visible in the radar backscatter (upper right). Ship-based transects crossed the front (black and white dots in upper panels) multiple times measuring its density and velocity structure, which are simulated by the model with high skill.**



**Figure 2. Comparison of the model's predicted surface convergence (top 6 panel) with the radar backscatter anomaly (bottom 6 panels). Data have been averaged over the course of the experiment as a function of tidal phase. Modeled convergence agrees favorably with regions of high radar backscatter resolving the major frontal features.**



**Figure 3.** Comparison of the radar anomaly (top) with the convergence in the depth-averaged flow from the model (bottom) averaged over the flood tide. Several features associated with changes in bathymetry that are apparent in the depth-averaged convergence are also seen in the radar backscatter including the five regions labeled with red letters (see text for discussion). However, note that the main convergence associated with northern leg of the tidal intrusion front is not associated with the depth-averaged flow, but is strongly 3-dimensional.



**Figure 4.** Example of frontogenesis from the model during late ebb/early flood on April 21, 2019. Top row is surface salinity with surface velocity vectors, middle row is the surface salinity gradient and bottom row is the surface convergence. Note that there is an existing strong front that forms during late ebb associated with the flow separation at the northern bridge/tunnel island. This front does not change in strength appreciably as it advects over the tunnel transitioning to the tidal intrusion front, despite continued strong convergence.

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