Applying Gerris to Mixing and Sedimentation in Estuaries

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Research Project: Transport and Mixing of Terrigenous Material in the Coastal Ocean

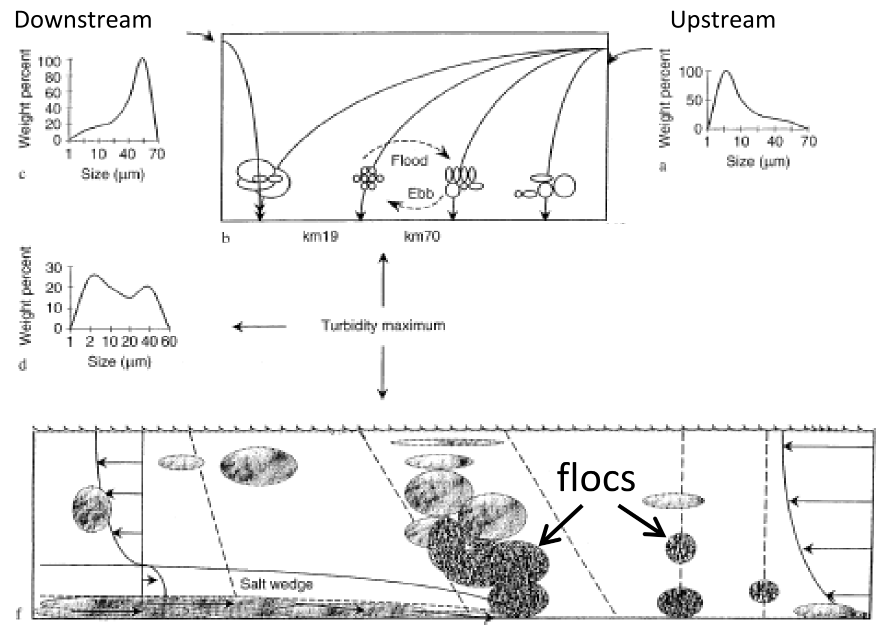
Project Objectives:

- Implement adaptive grid techniques for simulating hydrodynamics in coastal areas with high gradients of salinity and TSS (Total Suspended Solids)
- Test proposed conceptual models of fine-grained sediment dynamics as they relate to sediment trapping within estuaries and the formation of fluid mud on the continental shelf
- Implement object-oriented modular programming approaches into coastal ocean simulations

Focus Problem: The Estuary Turbidity Maximum (ETM)

ETM's (circled) in Danshuel R., Taiwan, and Tamar R., U.K.

Schematic of possible clay dynamics



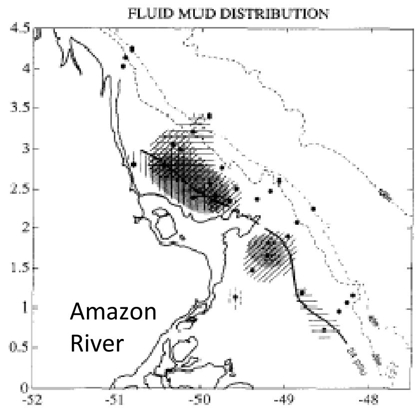
From Menon et al., *Env. Geol.*, 214-222, 1988

Summary

- Finer sizes enter ETM from upstream
- Alternating flood/ebb flow turbulence causes aggregation (flood) and disaggregation (ebb) of flocs
- Larger flocs form within brackish water downstream

Focus Problem: Fluid Mud* Formation on the Shelf

Fluid mud areas studied during the AMASEDS project (1990 – 1991).



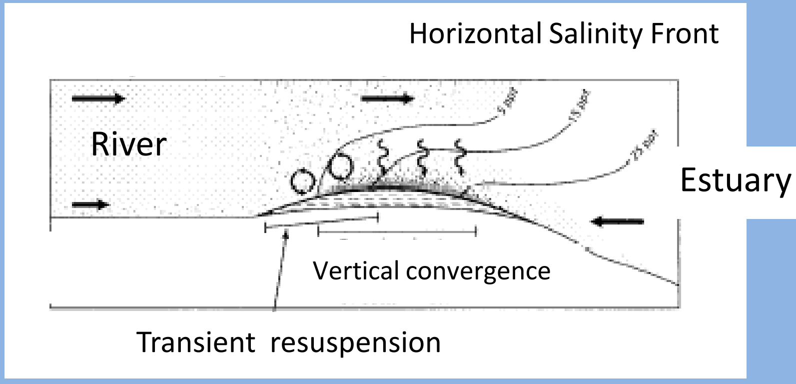
*Fluid mud is suspended sediment with a concentration > 10 g/l

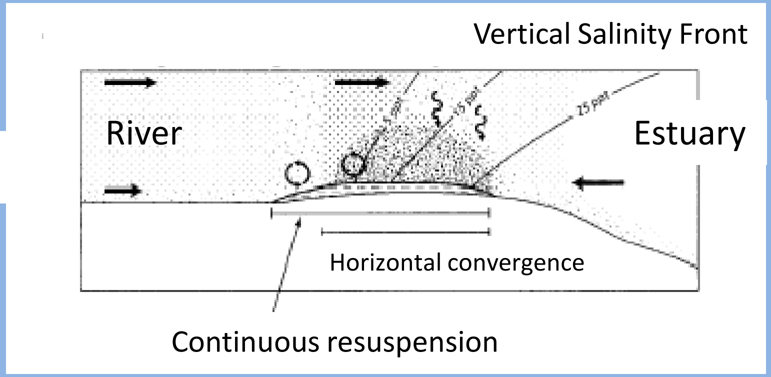
Fluid mud was observed under several different regimes:

- Near river mouth, inner and mid shelf
- Near the 24 PSU salinity front
- Most extensive during rising and high river discharge
- Commonly 1 – 2 m thick with a max of 7.25 m
- Areas appeared during individual cruises

(Kineke et al., *Cont. Shelf. Res.*, 667-696, 1996)

Proposed Fluid Mud Dynamics at Frontal Zone



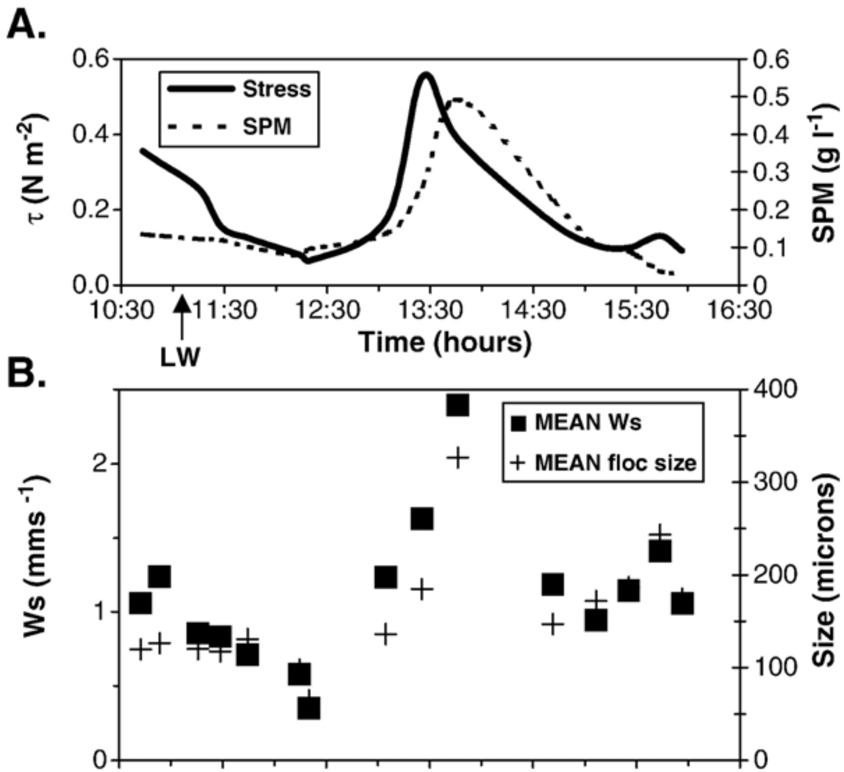


Neap Tide: Salt stratification causes sediment to settle out and become trapped in frontal zone.

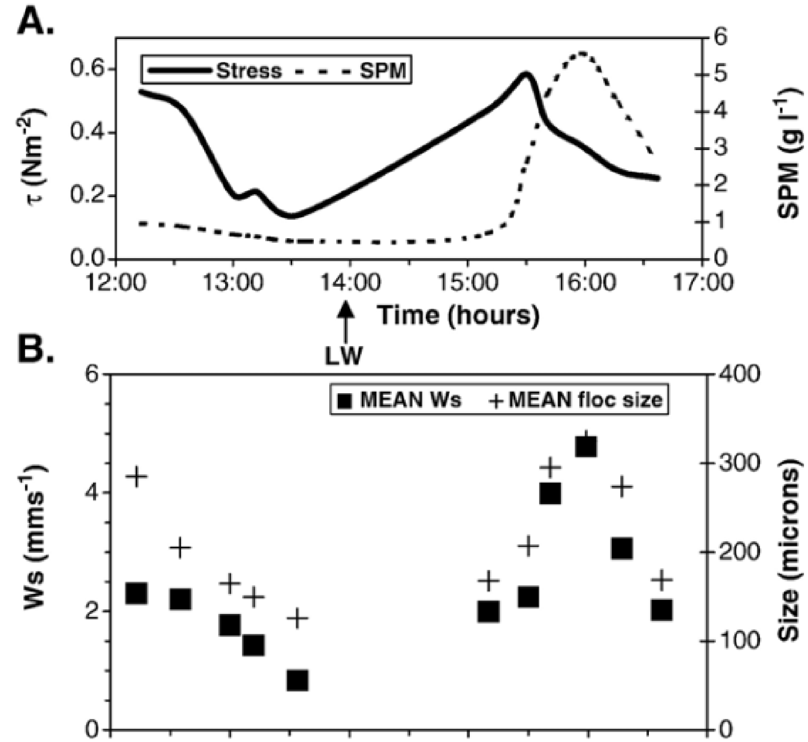
Spring Tide: Well-mixed water column allows resuspension and fluid mud formation.

Observations of the Relationships between Sediments and Turbulence in the Tamar Estuary ETM

Neap Tide



Spring Tide



(A) The shear stress is capped at ~0.6 N/m^2 even for the faster flow of the spring tide because the suspended particulate matter (SPM) is 10 times greater, which dampens turbulence and shear.

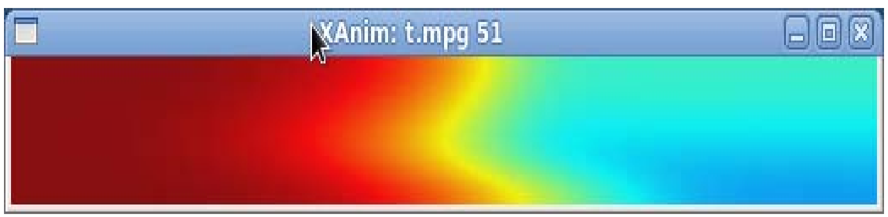
(B) The mean floc size is similar, but macroflocs with higher settling velocities (Ws) exist during spring tide due to increased turbulence.

(*Manning et al., Marine Geol., 193-211, 2006*)

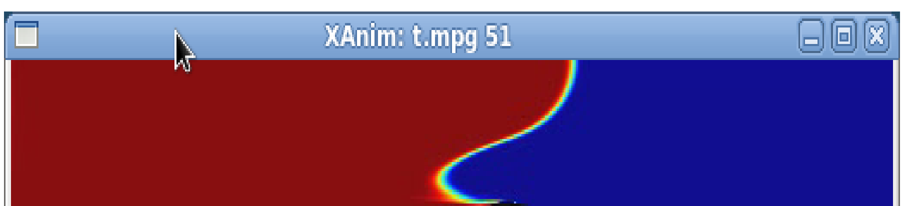
2D Vertical Simulations

- Rigid lid
- Density front
- Inflow
- Tidal forcing
- Bottom friction

Inviscid result after flow reversal

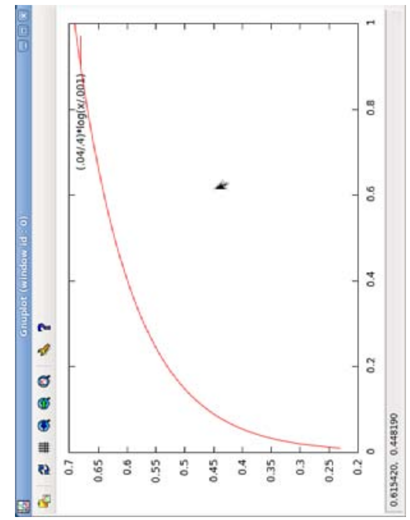


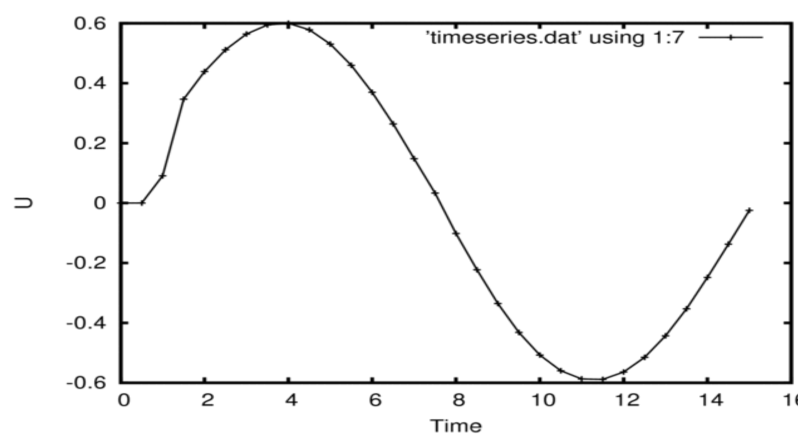
Result after flow reversal with diffusion: “SourceDiffusion {} T 0.0078125”



Result with bedform: “GfsSolid (ellipse (4,-.5, .2 ,.05))”

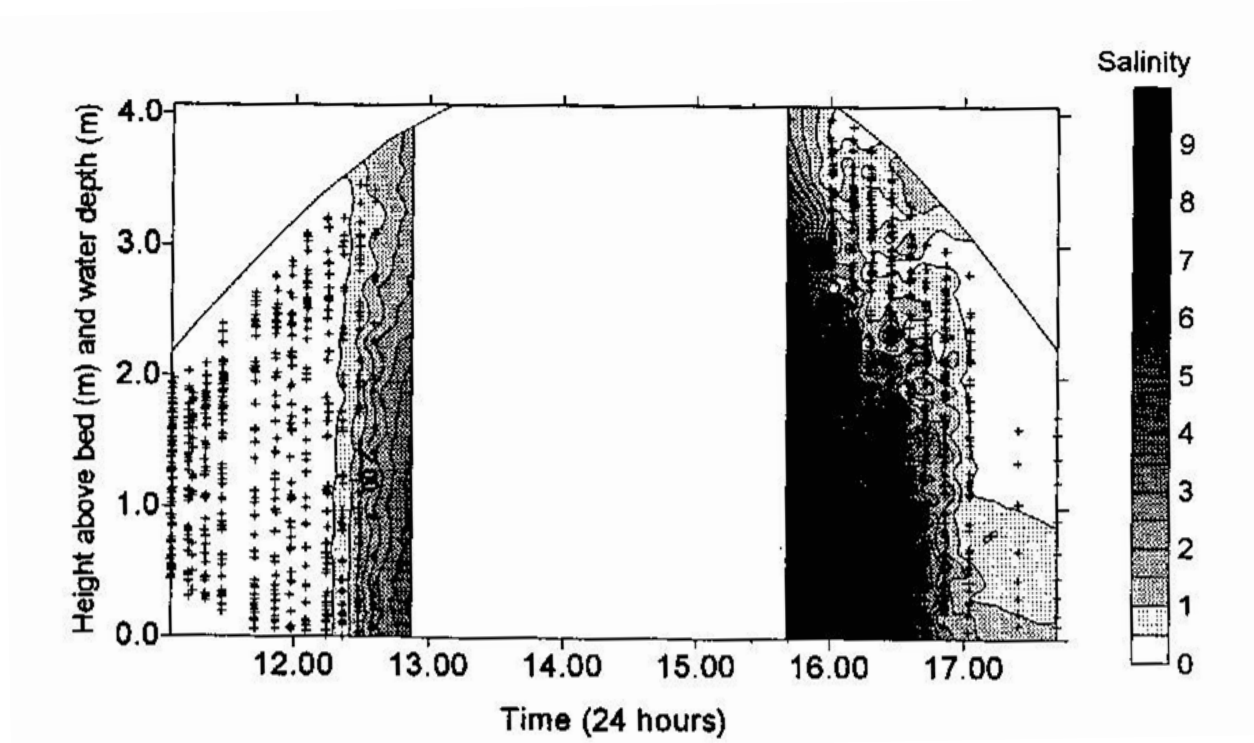
Logarithmic profile





Tidal forcing (output from Gerris)

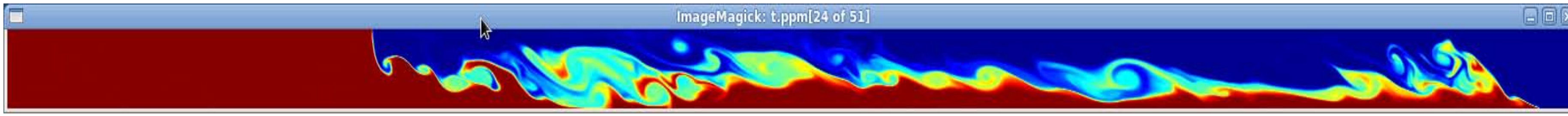
- Sections of salinity measured at Station A during neap tide on 15 September 1998.
- Note the vertical salinity front during the flood tide and the curved isopleths during the subsequent ebb tide.
- Also note how quickly the front can pass the station.
- The water depth is represented by the curved line bounding the top of the contours.



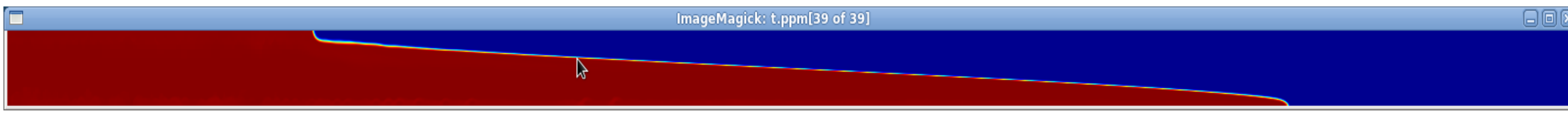
Density-Driven Mixing at the Salinity Front

- 25 GfsBoxes (e.g., 75 m channel 3 m deep)
- $\alpha = 1 /(1 + (T / 3.5) \times 0.025)$
- Max T = 10 psu
- $G' = -0.0907$

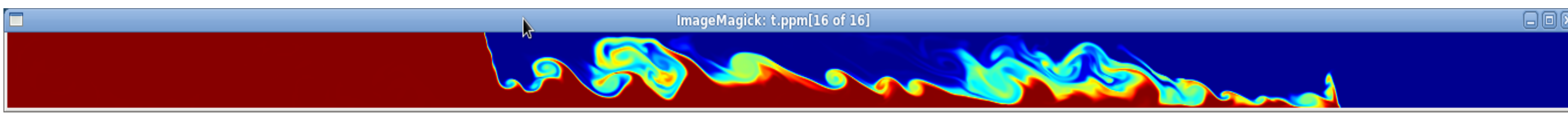
- Results for inviscid flow. The characteristic velocity is < 2 cm/s. Tracer distribution after 3 hours. The channel is 3 m deep and 75 m in length. Both ends are closed and it has a rigid top.



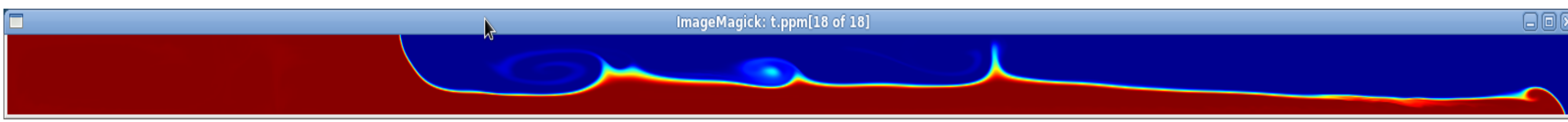
- Second Panel: Results for $\nu = 0.00078125$ and Re = 2560. The flow is quite slow (Uref = 0.0005 m/s) because of the viscosity.



- Results for Re = 1790189 after 1. 5 hr. The salinity front propagated much faster than expected.

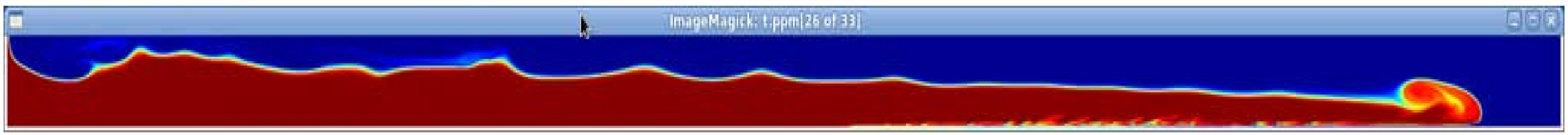


- Results for Re = 60000 after 1 hr 20 min. This is the most realistic case.



Bottom Friction and Bedform Drag

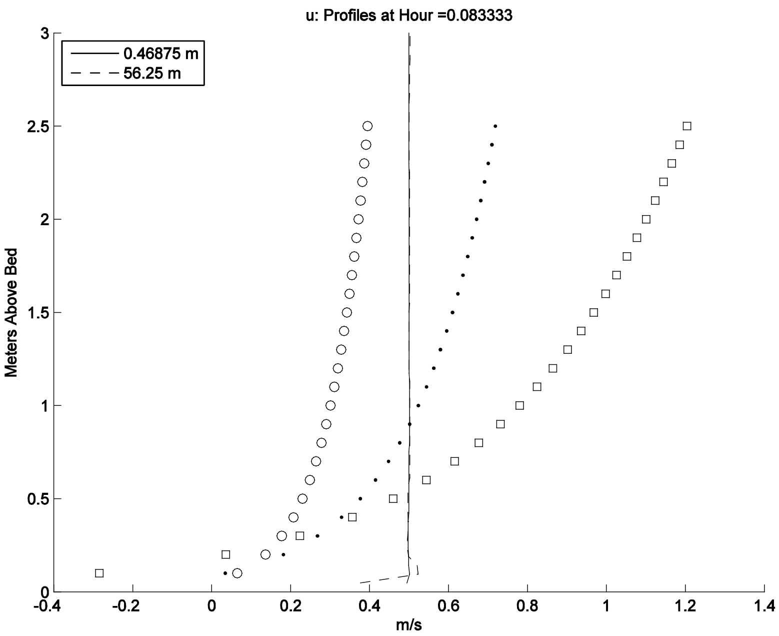
Salinity distribution after ~ 2 hr. The conditions are as for the last example above.

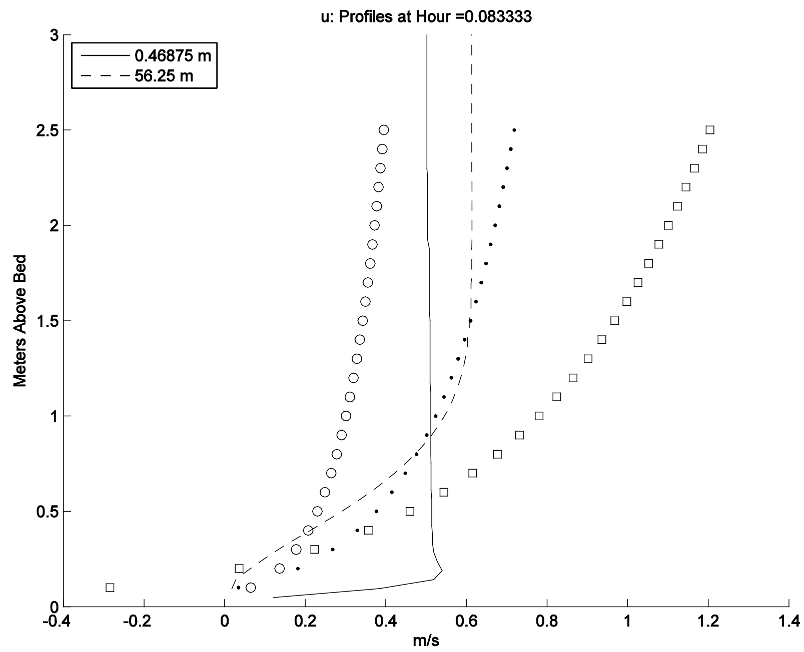


The first simulation uses a no-slip bottom to generate some additional vorticity. The solution (Figure 14) is somewhat smoother than the free-slip solution above. The salinity front has slowed its propagation as well.

The salinity distribution with a series of bed forms between 37.5 m and 54.5 m downstream. It isn't that different from the smooth bottom but the front propagation speed is less. These bed forms are 0.2·3m = 0.6 m in length and 0.05·3m = 0.15 m in height. Because of the very low speed, however, they generated very little vorticity.

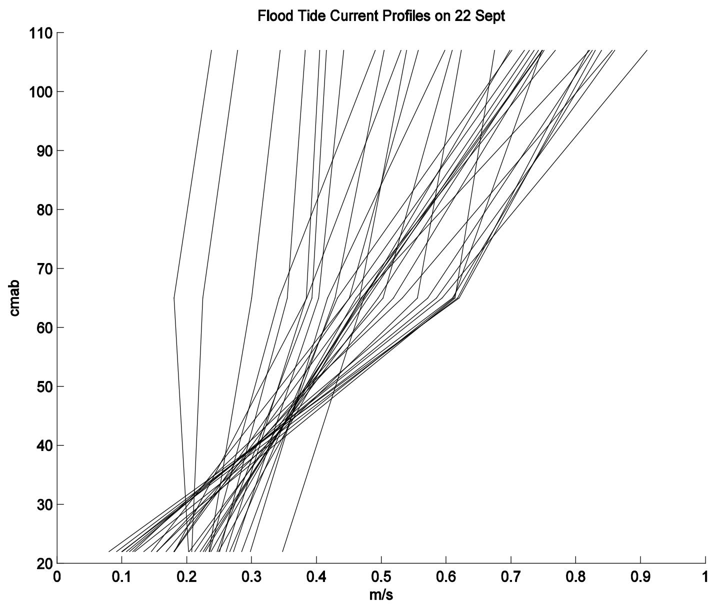
Profiles from simulations with a mean inflow of 1 and a density front at 12.5

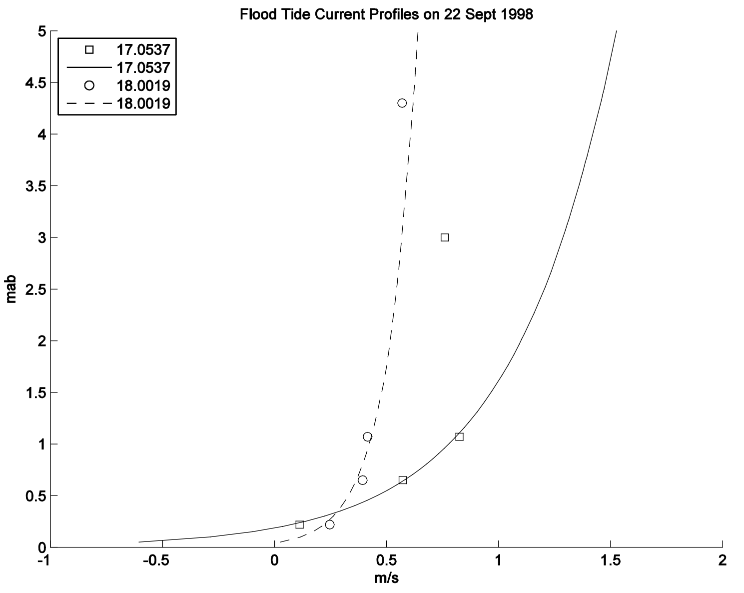




The left image is for $v_m = 6.7 \cdot 10^{-7}$ and the right image is for $v_m = 6.7 \cdot 10^{-4}$. It is apparent that the higher viscosity is necessary to produce a reasonable log profile. The inflow is a constant current of 50 cm/s (solid line). The profile at 56 m downstream (dash line) is represented by an analytical profile (dotted line computed using u_* / y_0 values of 0.085 m/s / 0.085 m, respectively.

Profiles in the ETM



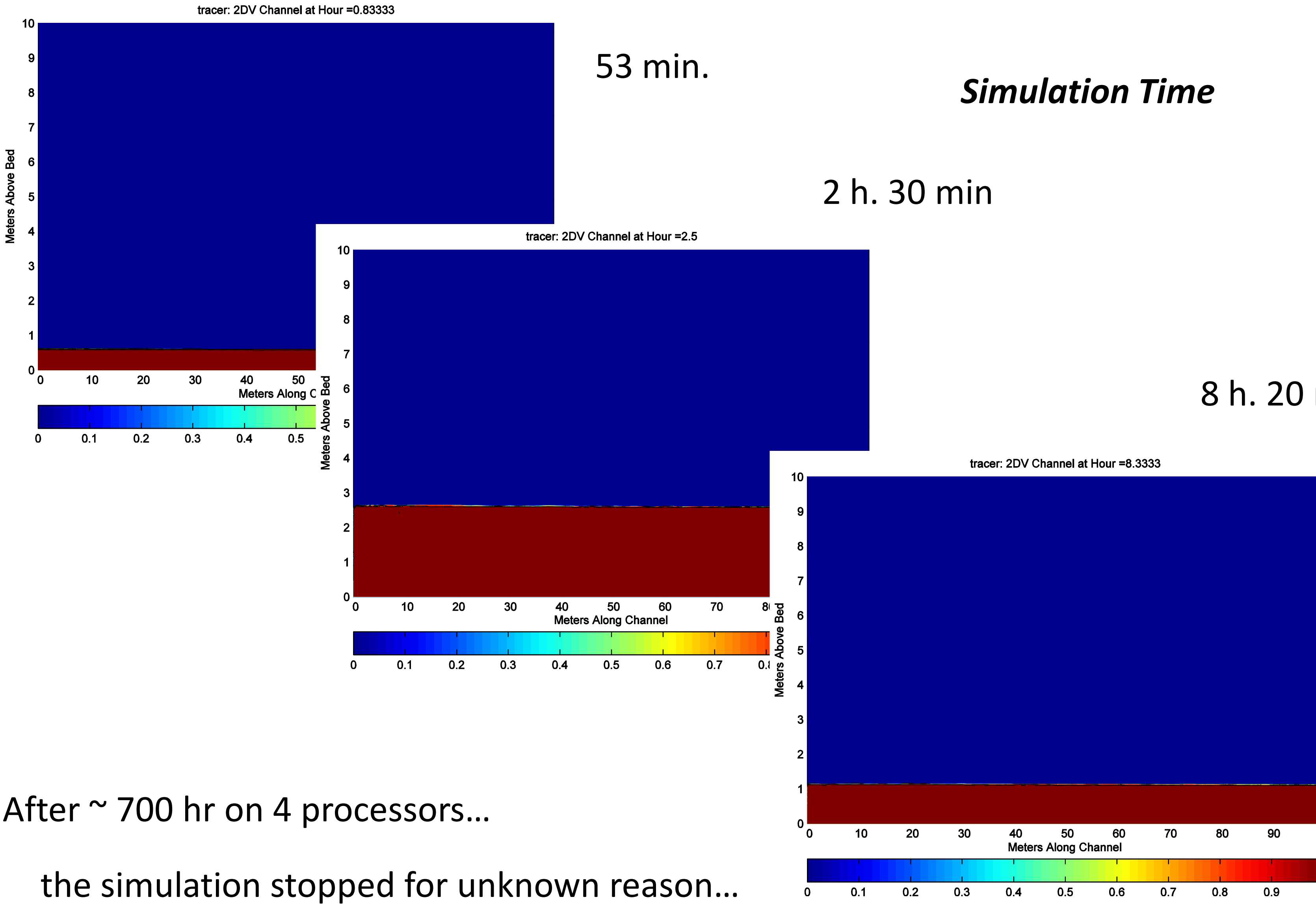


Left panel: All current data collected during the flood tide of 22 September 1998. Right Panel: Selected profiles at 17 h and 18 h (squares and circles) and model fits for a logarithmic profile using u_* / y_0 values of 0.185 m/s and 0.185 m and 0.053 m / 0.041 m for 17 h and 18 h, respectively, when the water depth was 3 m and 4.3 m.

VOF Simulation of a Free Surface

- The domain consists of 1 GfsBox (e.g., 100 m).
- Characteristic U = 0.5 m/s
- The ratio of upper:lower fluids is 1.2:1000 (air:water).
- The initial surface: “InitFraction {} T (-(y + 0.03))”
- Gravity is introduced as a source for V = -0.0245.
- The dynamic viscosity of the fluids are 0.001 and $1 \cdot 10^{-6}$.
- Tides: Amp. = 0.02 and Period T_T = 216 Δt (12 h).
- BC: “left = Boundary {BcDirichlet $U(U_T \sin(2\pi t)/T_T)$}”
- Maximum refinement = 12 levels

VOF simulations of Tamar at Calstock



53 min.

Simulation Time

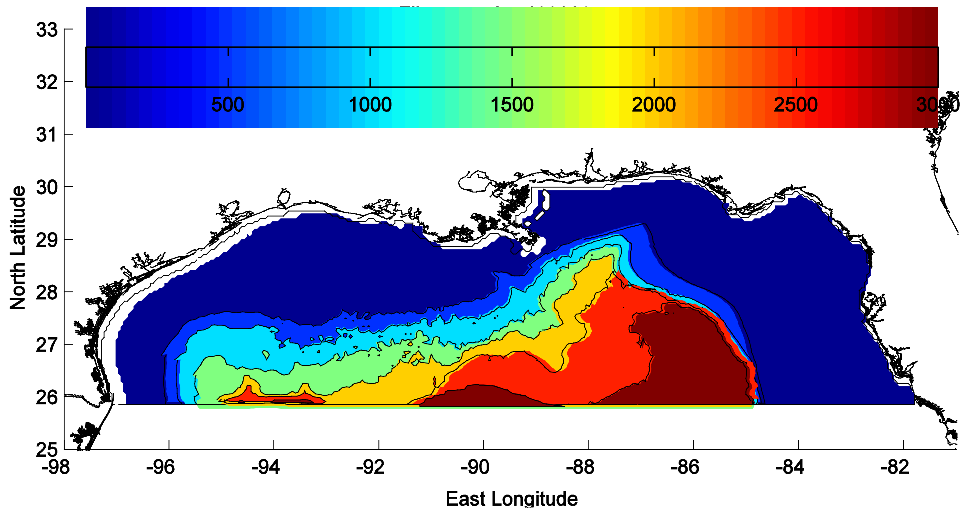
2 h. 30 min

8 h. 20 min

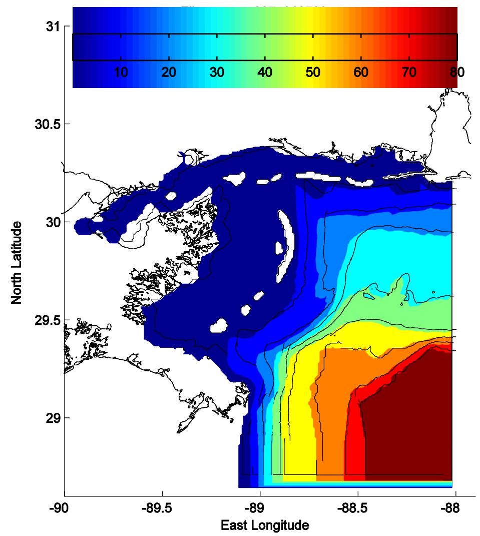
After ~ 700 hr on 4 processors…

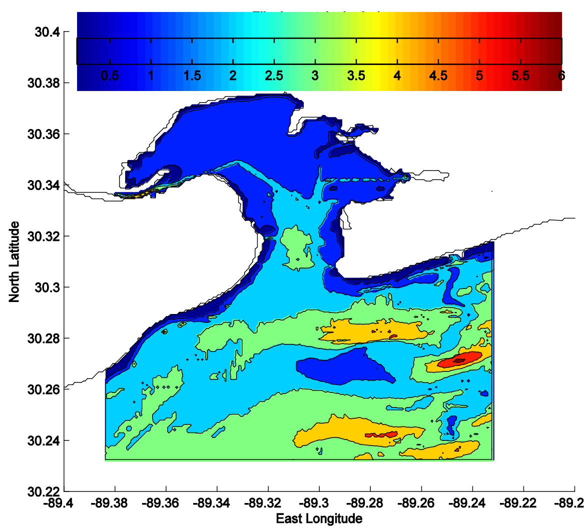
the simulation stopped for unknown reason…

Tidal Computations in the Gulf of Mexico



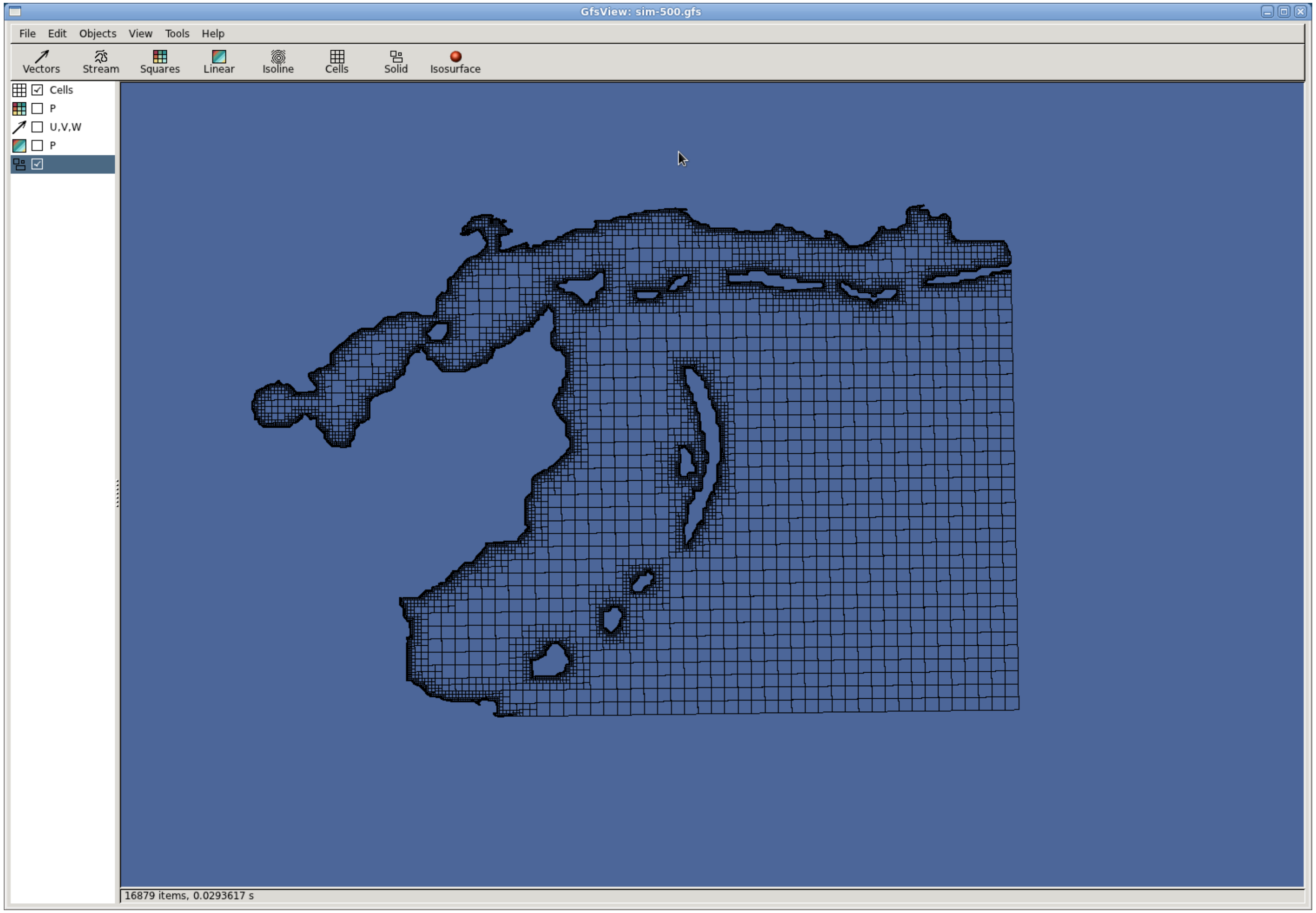
Previous work used these three nested grids plus a global model output.





- The St. Louis Bay grid has a cell size of ~80 m
- MSB cells are ~700 m
- N. GoM grid is ~5700 m
- The output data are not gridded and the highest resolution data are used in overlap areas for the Gerris grid…

The Gerris grid



This image is from gfsview. This is the initial refinement for the Mississippi Bight simulation.

Problems/Future Work

- Tidal constituents from GTS file not processed correctly
- Implement river inflow
- Apply open boundary from global NCOM
- Wind stress for surface
- Investigate 3D ocean module application
- Potential application of adaptive grid method to interpolation of observations for data assimilation