

# Modeling Tidal Circulation and Freshwater Mixing in Hood Canal, Washington

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## ABSTRACT

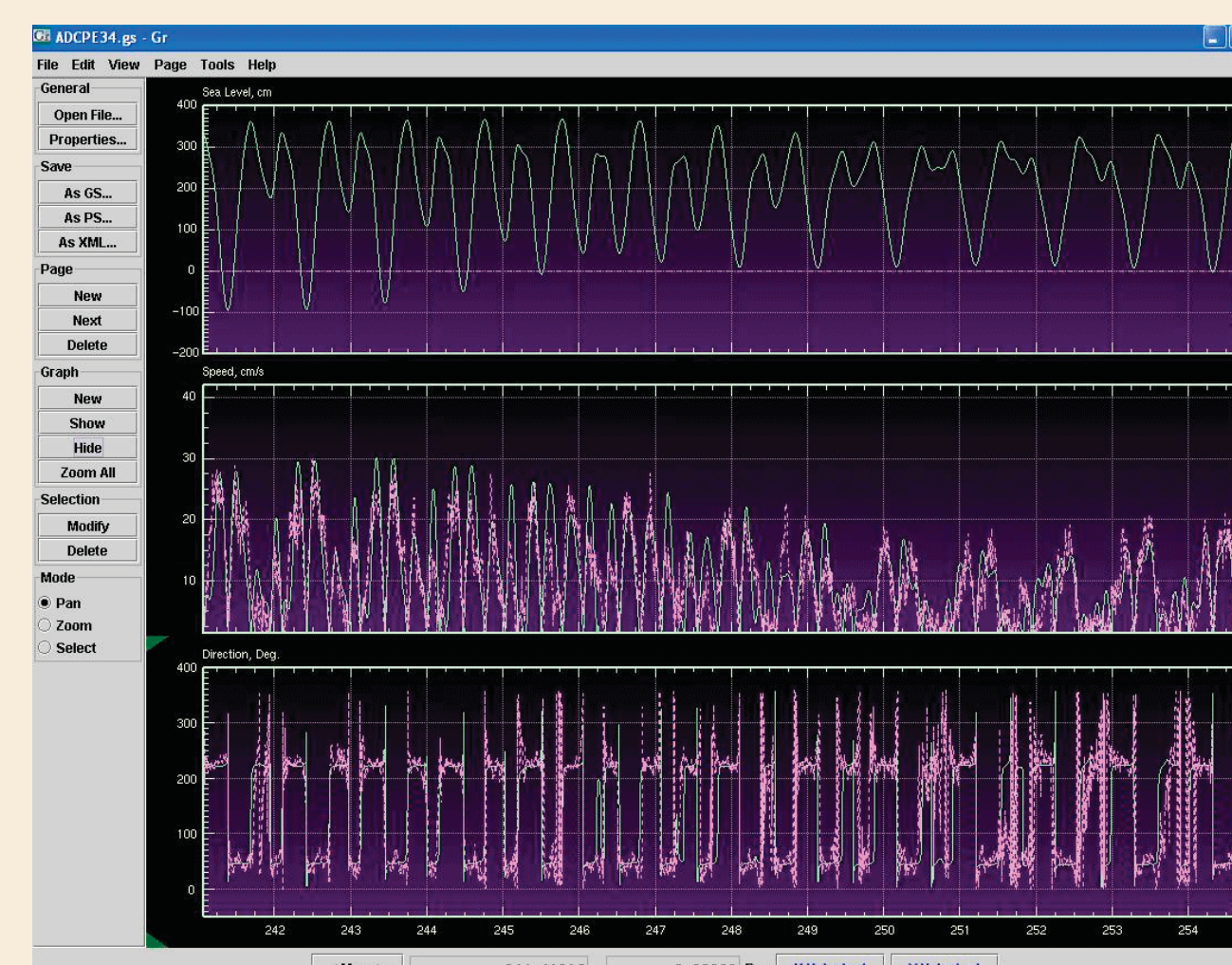
Hood Canal is a 110-km long narrow fjord in the Puget Sound estuary that is 175 deep in some areas and has a 55 m sill at the entrance. Low dissolved oxygen (DO) levels in the southern part of Hood Canal have been observed during late summer, causing widespread fish kills. The hypothesized cause for the low DO is the combination of increased nutrient inputs, naturally weak mixing, and sluggish circulation in Hood Canal. An unstructured grid, three-dimensional tidal circulation model known as UnTRIM has been implemented to simulate the circulation of Hood Canal and the cause and effects of low DO. Before embarking on modeling DO, the emphasis of numerical model development is focused on reproducing the tidal hydrodynamics, and on reproducing the mixing processes of fresh water introduced to the system from major rivers. There are eight historical tide stations in Hood Canal where tidal levels can be synthesized by harmonic constants for those sites. In the fall of 2004, the USGS deployed two bottom mounted upward looking Acoustic Doppler Current profilers, (ADCPs) in the "Great Bend" area for two month between late August and late October, 2004. This phase of the model application focuses on reproducing the available ADCP data and the synthesized tidal water levels at the eight stations distributed along the axis of Hood Canal, and the presence of vertical stratification due to river inflows. An unstructured model grid has been constructed which allows boundary fitting to the topography of Hood Canal and very fine resolutions in areas of interest. Thirty three vertical layers are placed strategically to resolve the vertical structure of salinity and velocity fields. For the two-month simulation of September and October 2004, the numerical model reproduces the tides and tidal currents very well. The modeled vertical salinity depends on the choice of for the vertical turbulence closure model, and several have been evaluated. While there is limited spatial data on the distribution of salinity, the model results are judged as "reasonable" and qualitatively correct. The success in implementing the numerical model to reproduce tidal time scale processes forms the basis to begin building the model for simulations of DO in Hood Canal.



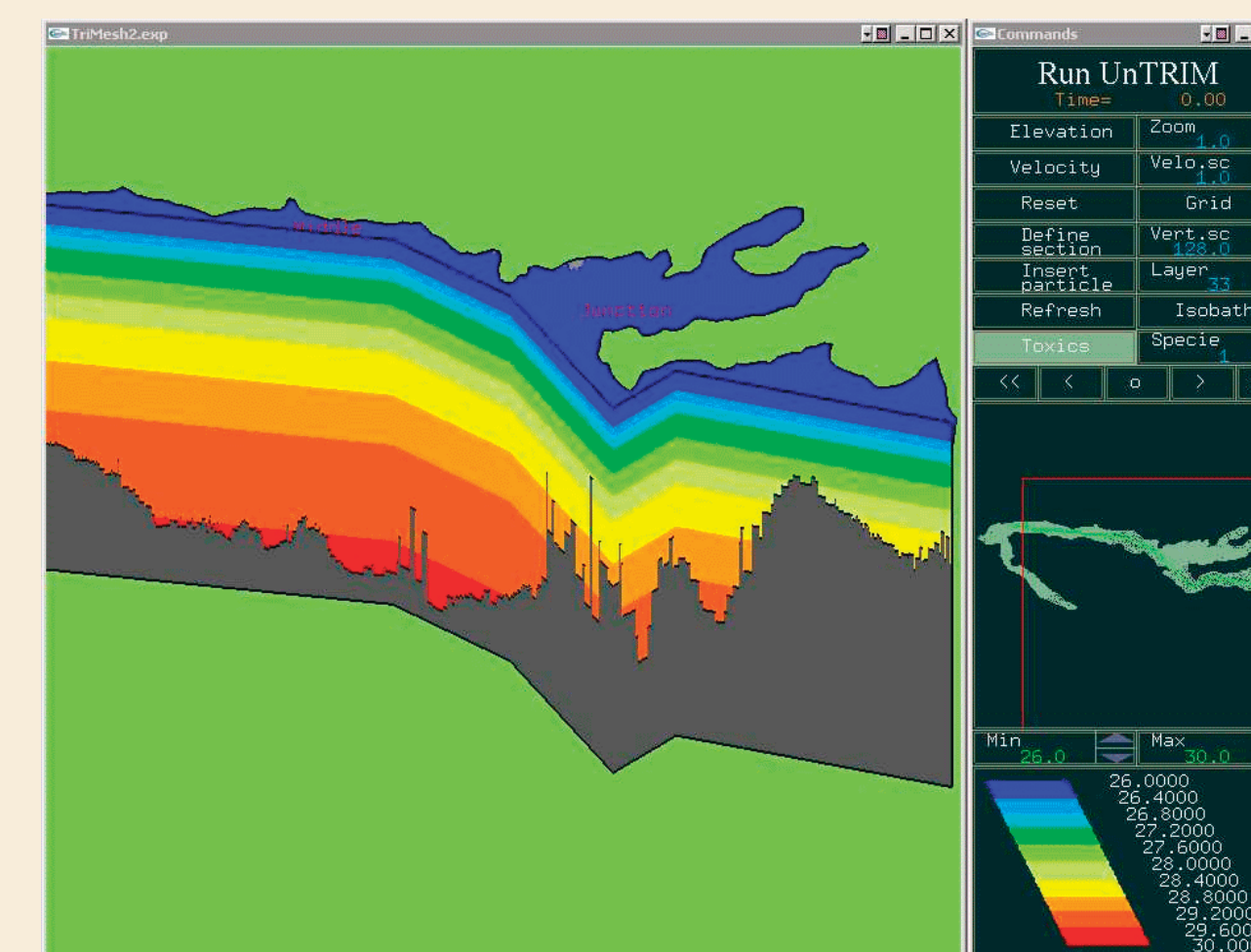
USGS and US Navy personnel recovering a tripod from Lynch Cove, October 24, 2004. Instrumentation on the tripod included an ADCP, and the resulting vertical profiles of tidal velocities have been used to validate the model.



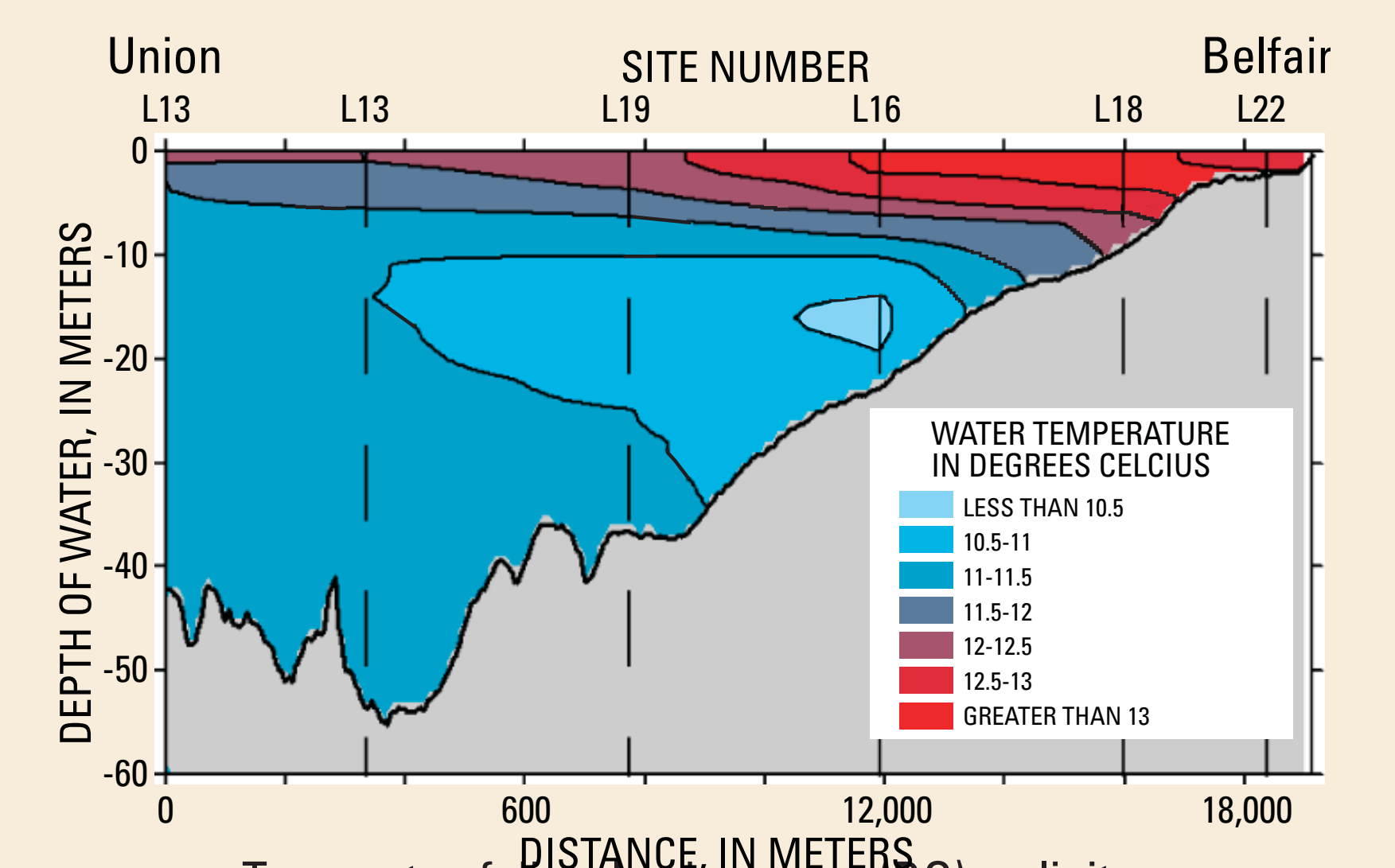
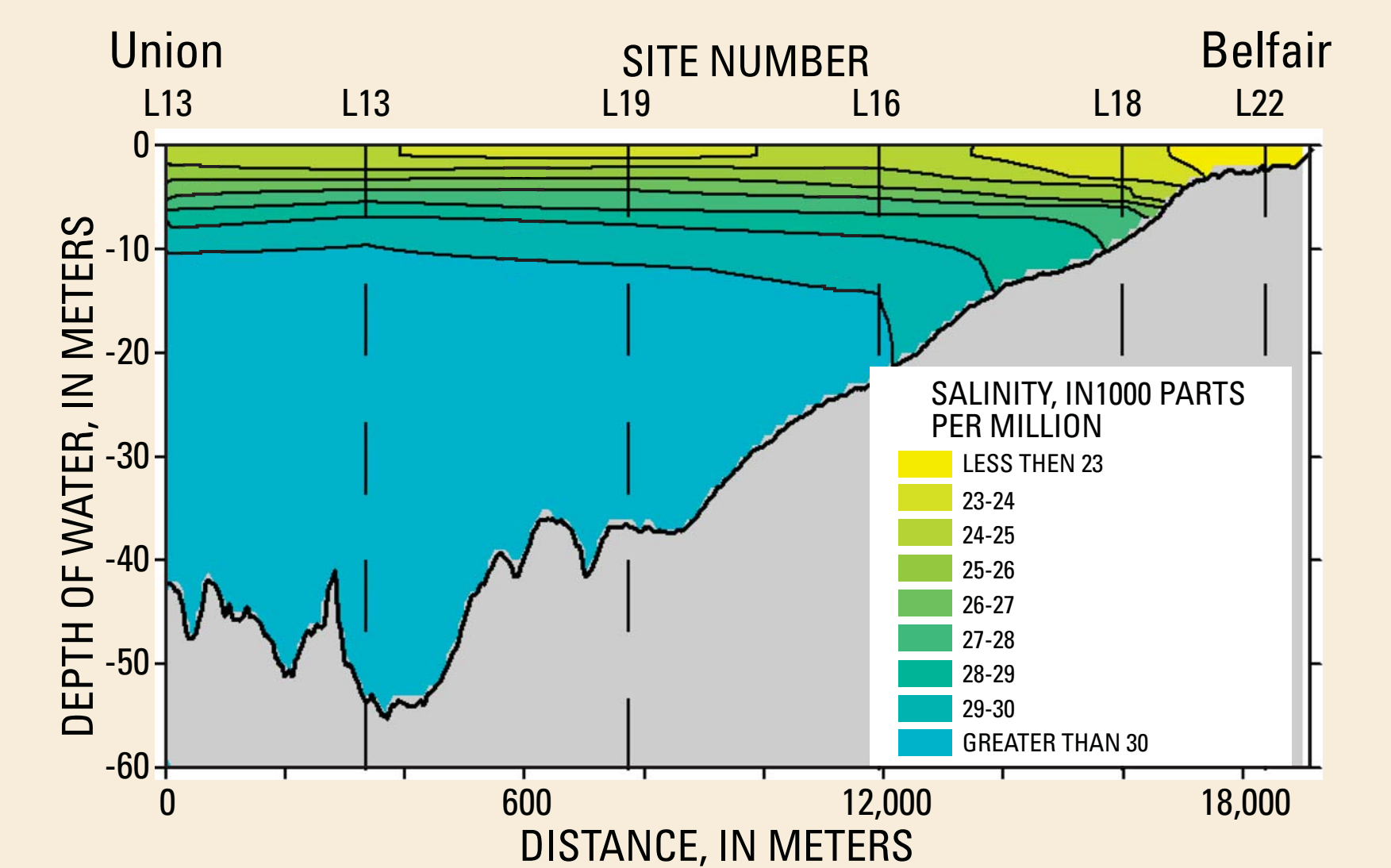
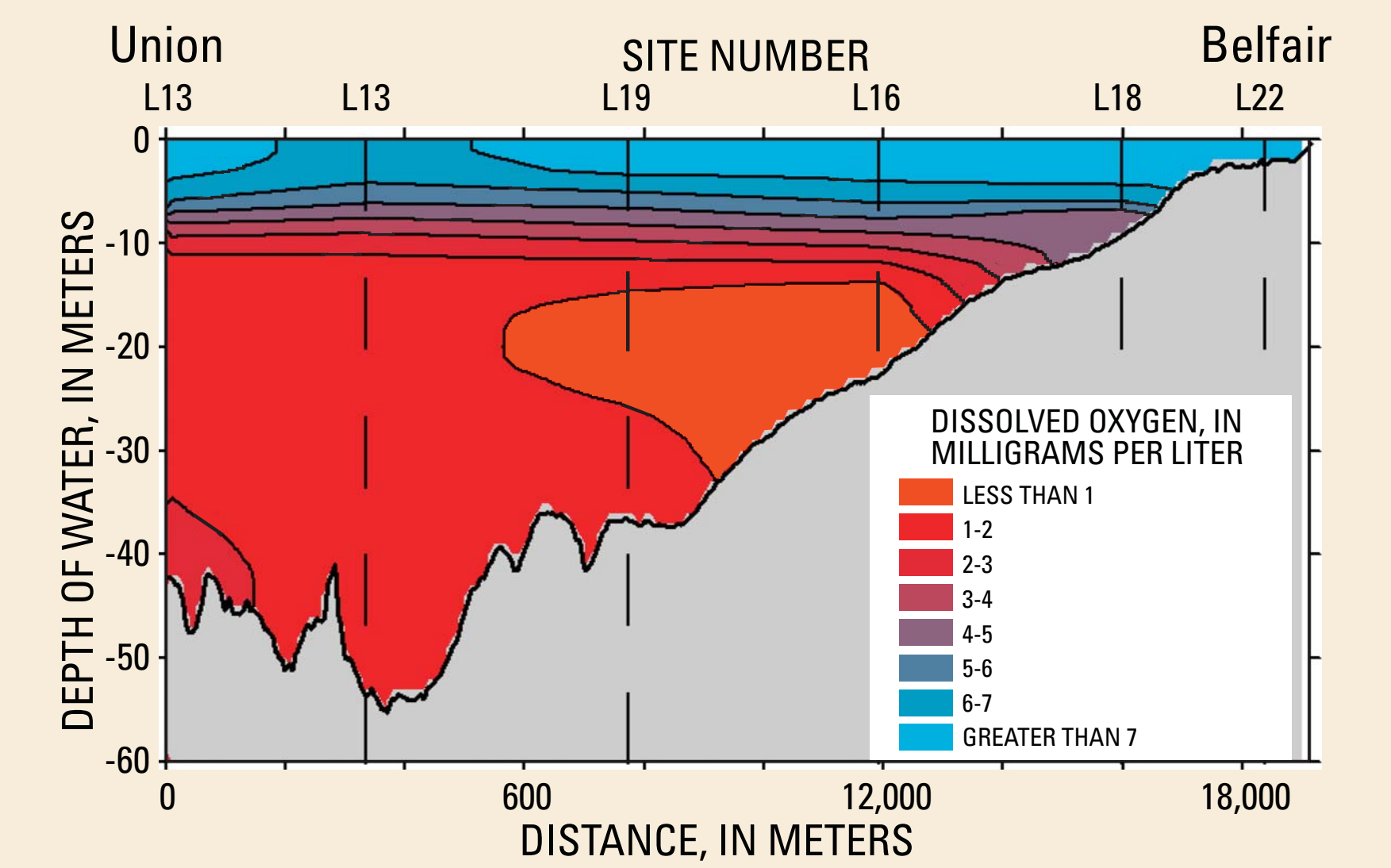
USGS scientist collecting DO, salinity, and temperature. Data from Lynch Cove, October 20, 2004. We also collected nitrate data for nutrient loading studies. The data were collected for July, August, September, and October of 2004.



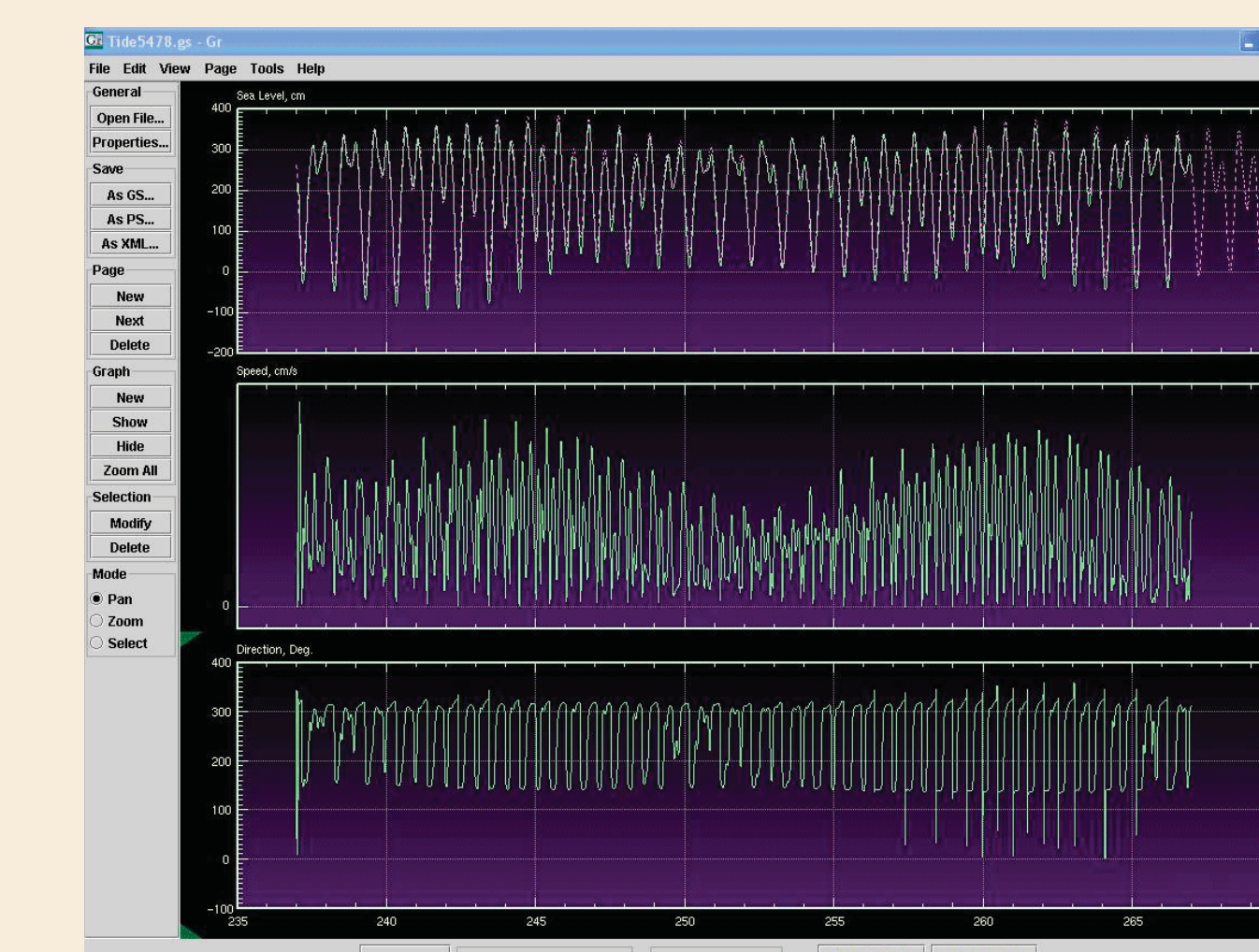
The modeled tidal currents and the measured velocities are in good agreement, in both speed and direction. This two week long portion of model output, the solid green line, and the observations, the dashed purple line, demonstrates the agreement that was observed for both ADCP deployments.



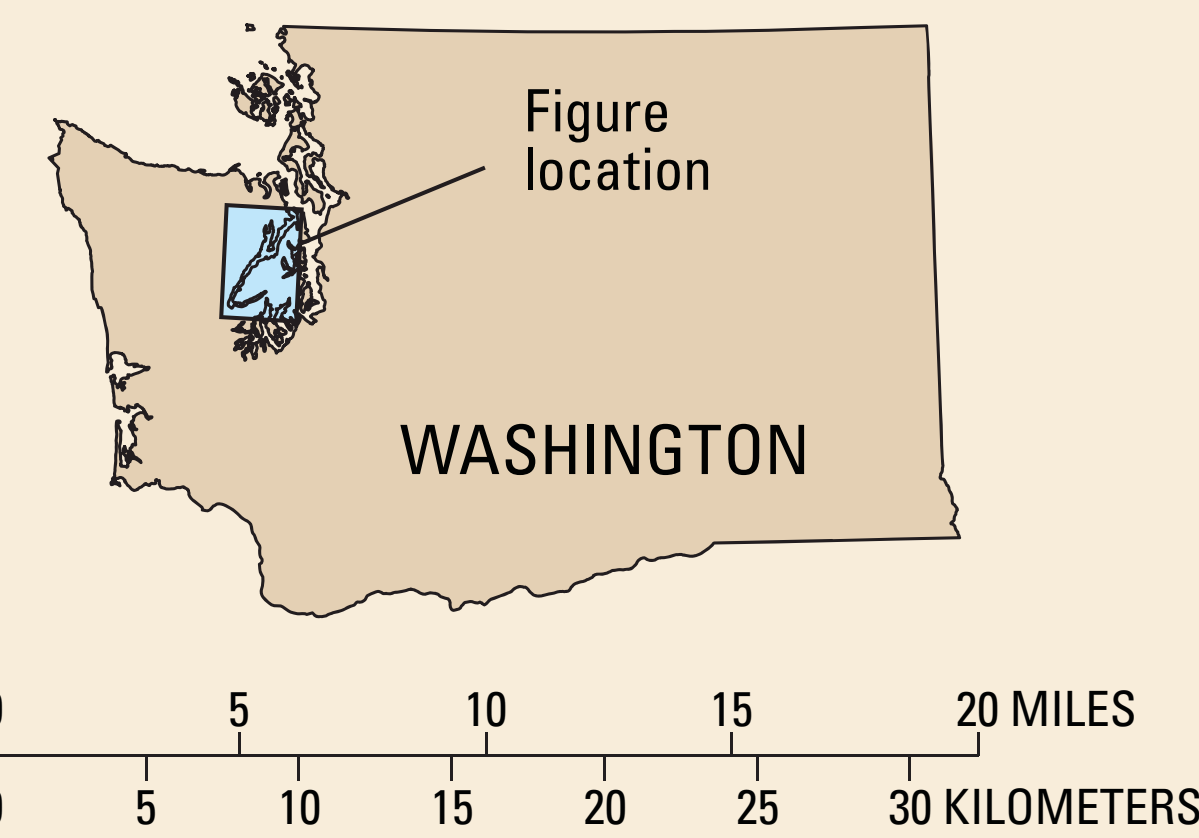
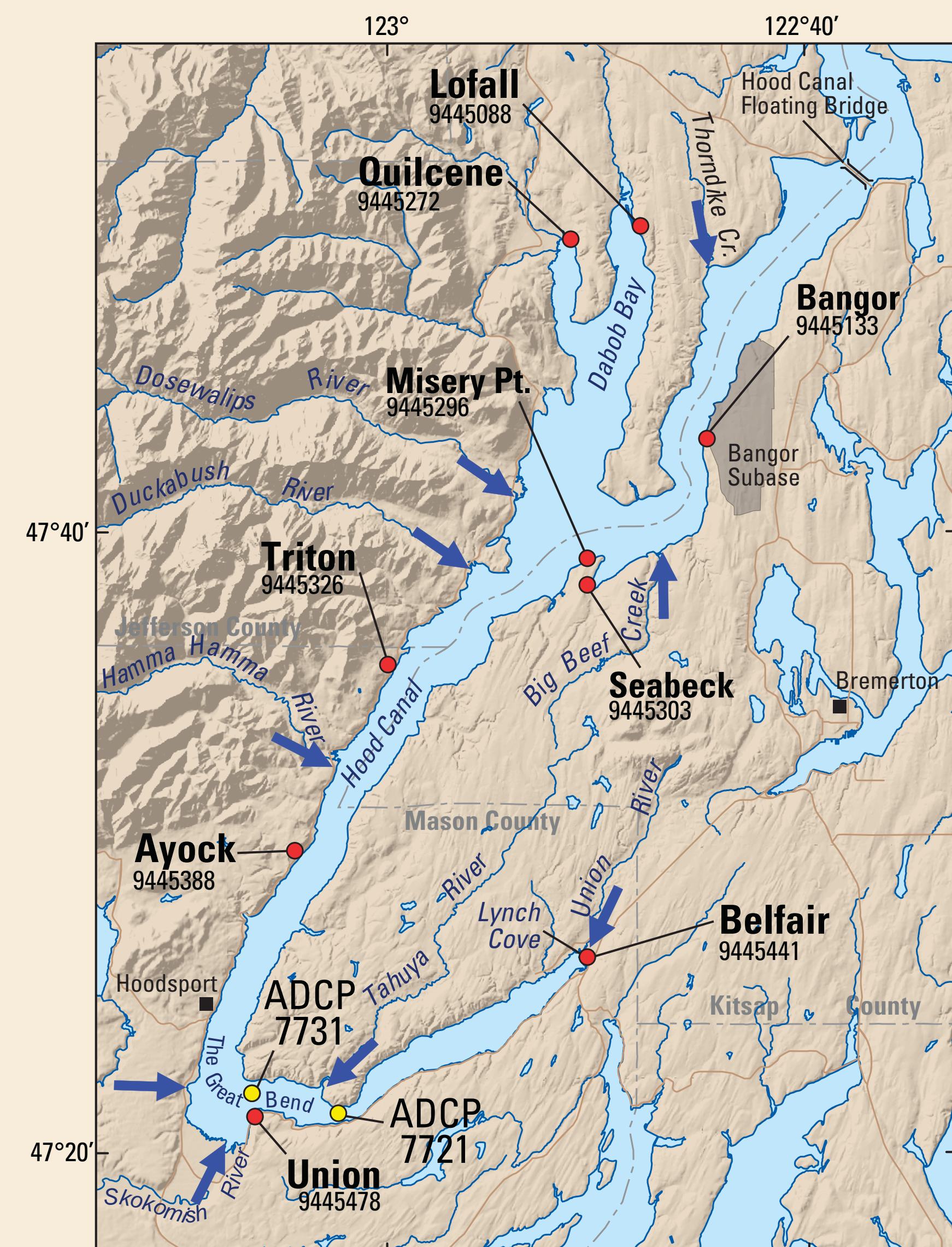
The UnTRIM user interface. This case shows a portion of Hood Canal, the layer structure, the bathymetry along the transect, and the initial condition for salinity.



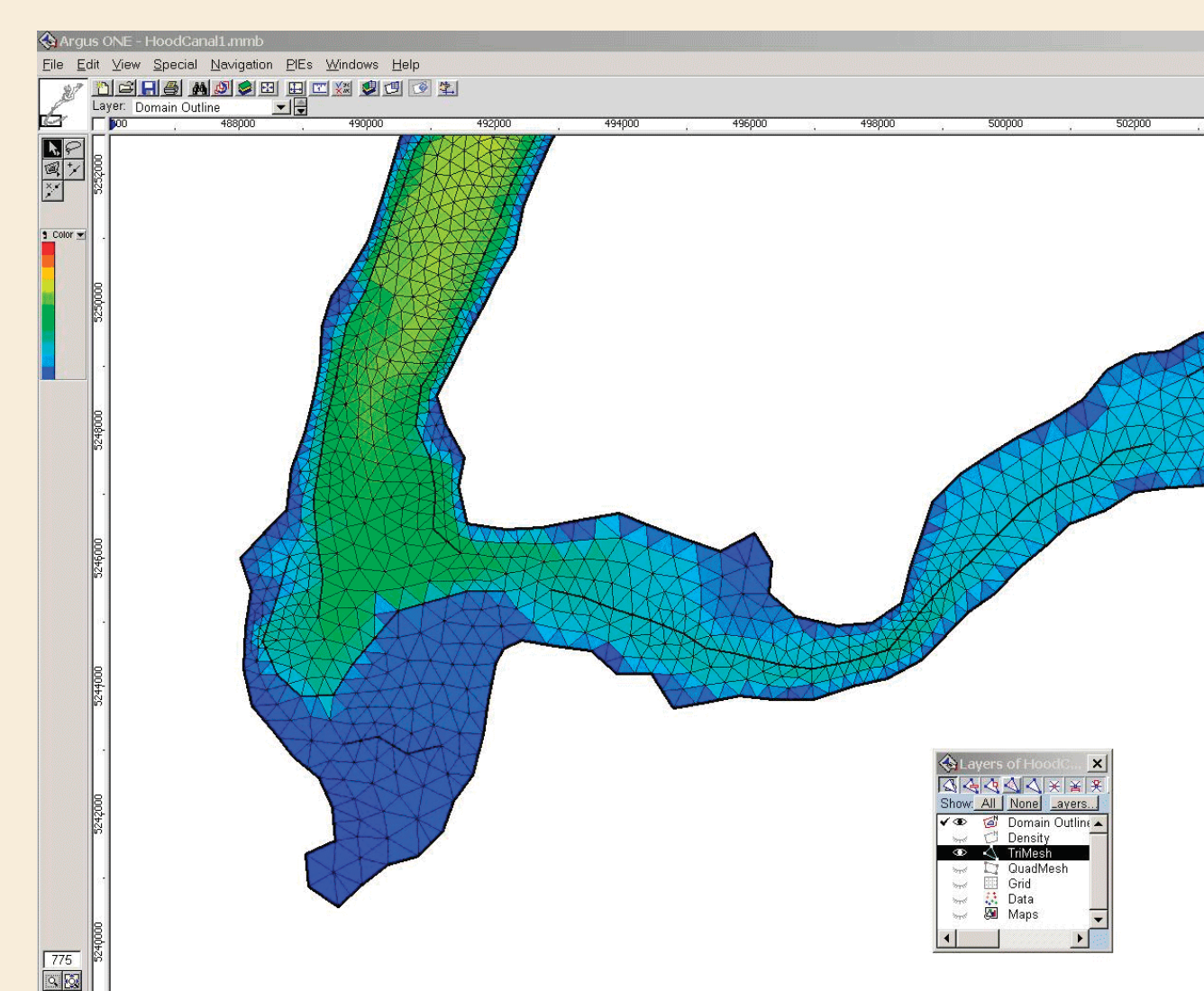
Transects of dissolved oxygen (DO), salinity, and temperature from Lynch Cove, from Union to Belfair, show the low oxygen conditions below 10 meters and the strong halocline in the surface layer for October 20, 2004. The halocline and the thermocline, to a lesser extent, combine to produce a strong stratification that inhibits the mixing of the oxygen rich upper layer with the oxygen deficient deep layer.



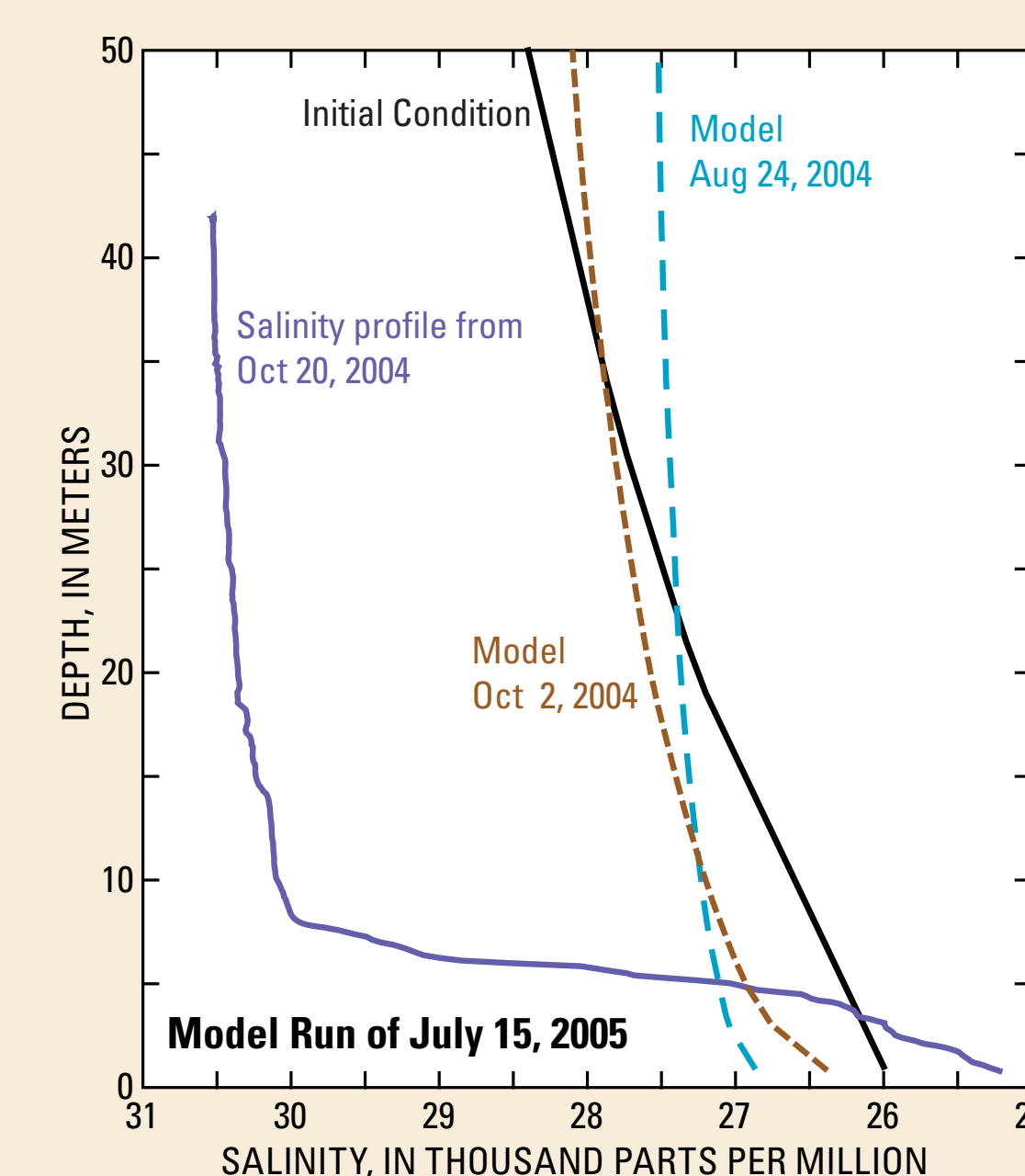
There are eight historical tide stations in Hood Canal where tidal levels were synthesized from harmonic constants for those sites. This figure shows a comparison between the model output and the synthesized tides for Union. For the other seven sites, the model and the synthesized tides were similarly nearly identical. The figure shows only part of the record as displayed by GR.



- EXPLANATION**
- RIVER INFLOW
  - WATER-LEVEL MEASUREMENT SITE
  - ACOUSTIC DOPPLER CURRENT PROFILER SITE



An unstructured grid, three-dimensional tidal circulation model known as UnTRIM has been implemented to simulate the circulation of Hood Canal and the cause and effects of low DO.



- UTRIM is a result of 25 years of collaboration with Vincenzo Casulli of Italy
- The UTRIM Family of Models includes:
- Unstructured Tidal, Residual, Inter-tidal Mudflat
  - Solution of Shallow Water Equations
  - Transient, Multi-Dimensional (3D, 2D, 1D)
  - Simultaneous Solution of Transport Variables
  - Semi-implicit Finite-Difference Method
  - Boundary Fitting Unstructured Grid Mesh

## CONCLUSIONS

- The UTRIM model accurately reproduces the tidal elevations throughout Hood Canal.
- Comparison with ADCP current meter data is very good.
- The model is computationally efficient, 2 month simulation takes ~ 14 hours on a PC.
- Reproducing the extreme stratification in southern Hood Canal is a challenge and ongoing.

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