Adaptive Sampling for Understanding Processes across the Shelf, Shelf Break, and Slope of the Mississippi Bight

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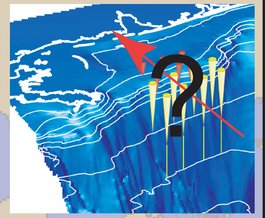
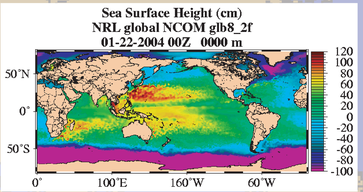
Motivation:

As part of the Slope to Shelf Energetics and Exchange Dyanmics (SEED) project, the Naval Research Laboratory is planning to deploy 14 Acoustic Doppler Current Profiler (ADCP) moorings with 6 on the shelf and shelf-break and 8 on the slope of the Mississippi Bight region in the spring of 2004. The placement of this mooring array is intended to resolve the dynamics of processes interacting across the shelf break. The purpose of this study is to use an advanced assimilation system to determine the positions of instruments that best observe the cross-shelf break flow. The adjoint of the Naval Coastal Ocean Model (NCOM) is used to compute representer functions. Representers show the influence that a measurement impulse of cross-shelf velocity has on the ocean dynamic variables in both 3D space and time. The reciprocal property of representers also indicates at which places and times that the ADCPs should be placed to determine the cross-shelf velocity.

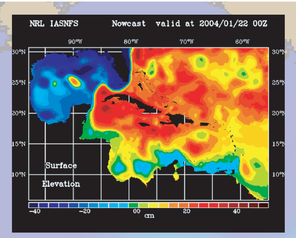


Nesting within the Advanced Data Assimilation System:

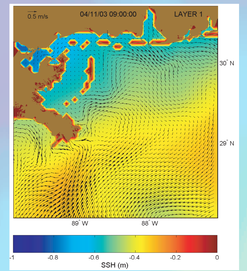
The tools used here are part of the relocatable nested advanced data assimilation system being researched at the Naval Research Laboratory. This system provides an optimal ocean dynamic solution using the Navy Coastal Ocean Model (NCOM) to represent the ocean equations of motion and available observations. The assimilation system is a nested model beginning with the global NLOM/NCOM system. The coupled NLOM/NCOM assimilates near real time altimeter and observed sea surface temperature in a daily analysis cycle. The global NCOM model is run at a 1/8 degree resolution and provides 3 day forecasts every day.



The Intra-Americas Seas (IAS) NCOM uses boundary conditions from the global NLOM/NCOM system and provides solutions with a horizontal resolution of 1/24 degree and 40 layers in the vertical (19 of these layers are sigma layers and 21 are Z layers). Similar to the global system, the IAS assimilates altimeter and sea surface temperature in a daily analysis cycle and provides 3 day forecasts.



The Mississippi Bight NCOM is a free-running (no assimilation) nest within the IAS domain and has the same horizontal and vertical structure as IAS NCOM. The Mississippi Bight NCOM could be run at a higher resolution, however its purpose is to conviennantly provide initial conditions, boundary conditions, and background values for the advanced data assimilation system. The background states are used within the tangent linearization that is with this assimilation system.



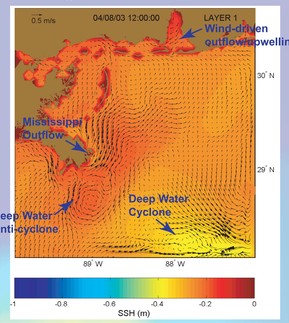
Relocatable Nested Advanced Data Assimilation System:

This assimilation system is a 4-D Var using dynamics of the Mississippi Bight NCOM with the same horizontal resolution, vertical structure, and parameterization. The Mississippi Bight NCOM (and hence its inverse) is a free surface model based on the primitive equations and the hydrostatic, Boussinesq and incompressible fluid approximations. The model is implemented on the Arakawa C grid with second-order centered spatial finite differences, and uses leapfrog time stepping (dt = 600s for this area) with an Asselin filter to suppress time splitting. The propagation of surface waves and vertical diffusion are treated implicitly. The Mellor-Yamada Level 2 turbulence closure scheme is used for the parameterization of vertical mixing, and the Smagorinsky scheme for horizontal mixing. The horizontal grid is curvilinear and the vertical grid uses sigma coordinates for the upper layers and z-level coordinates (constant depth) for the lower layers (the separation depth is 138 m for this area). This assimilation system uses atmospheric forcing (windstress, surface heat flux, solar radiation, and atmospheric pressure) provided by the Navy Global Ocean and Atmospheric Prediction System (NOGAPS), and a source term in the model equations allows river inflow. The inverse NCOM is comprised of two main components: the tangent linearization of the forward NCOM model and the adjoint.

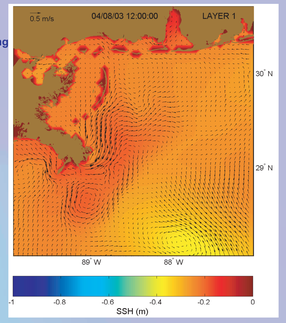
Linearization:

The tangent linearization is the first-order Taylor's expansion of the model equations around a given trajectory or background. A tangent linear model computes the linear propagation and growth of small perturbations about the background. The assimilation system is tangent-linearized about the output of the Mississippi Bight NCOM in order for computation of the inverse solution. The tangent linearization is carried out on all nonlinear dynamical terms in the model equations, except for the computation of the horizontal and vertical mixing coefficients and bottom stress. These are set to the background fields provided by the Mississippi Bight NCOM. Since NCOM uses total depth within the equations of motion and total depth is a function of the time varying SSH, most dynamical equations are nonlinear.

Tangent Linearized Solution



Mississippi Bight NCOM Solution

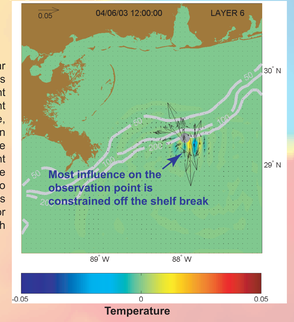


Some differences along the open boundary area result from not implemementing the Orlansky BC in the inverse model. This is presently being updated in the tangent linear and adjoint models.

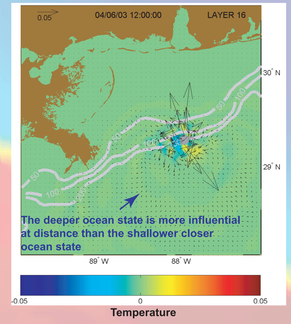
Adjoint:

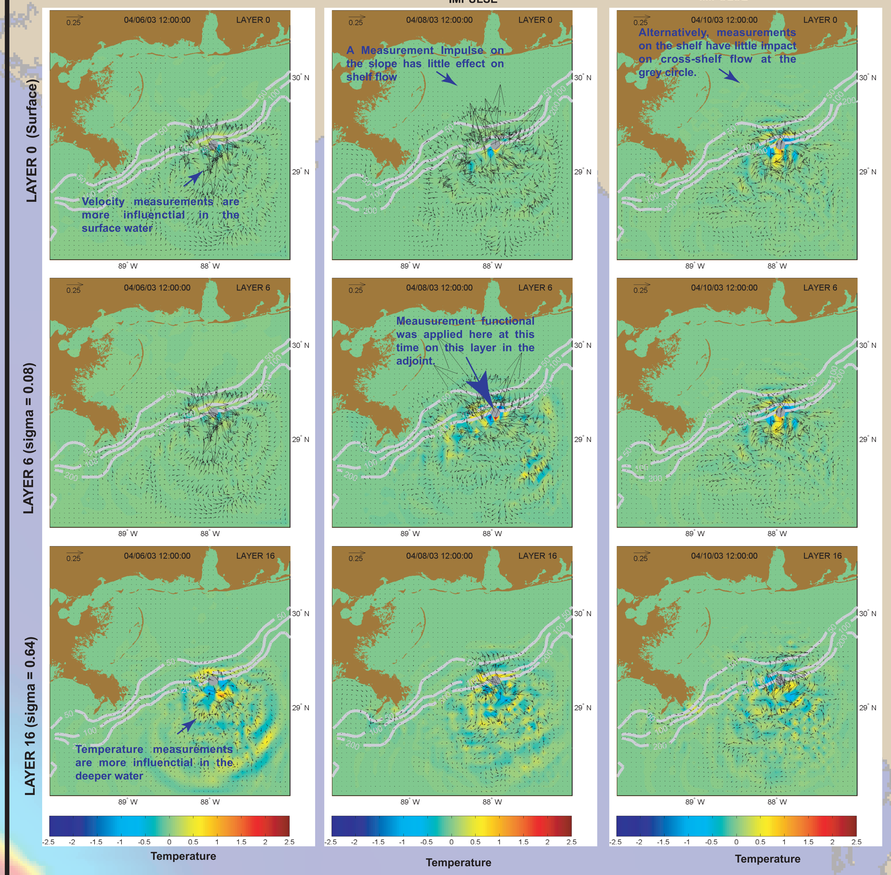
The adjoint model is the transpose of the tangent linear model. In a representer calculation, the adjoint model is first integrated backward in time forced by a measurement functional. The solution is a Green's function of the adjoint model. The adjoint model marches backward in time, propagating the observation information from its location through the model dynamics to all variables. For the results shown here, a cross-shelf velocity measurement impulse is applied at 11 m depth (in the 6th layer) at the horizontal position marked by a gray circle in the figures to the right. Snapshots of the adjoint solutions or Green's function are displayed at two days prior to the impulse for the same sigma layer as the measurement and a much deeper sigma layer (layer 16, sigma depth = 0.64).

2 Days Prior to Impulse on sigma layer 6 (sigma = 0.08)



2 Days Prior to Impulse on sigma layer 16 (sigma = 0.64)



Representer:

A representer function indicates the influence or impact a measurement over all the model variables in space and time. It may be considered to be a vector of correlations between the measurement impulse and all other model variables. Thus the representer function shows where, when and on which variables the measurement has the most impact. Through symmetry, it also indicates where, when and on which variables measurements should be taken in order to infer specific quantities. A representer function is computed solution of the adjoint model forced by a measurement functional. For the experiments here the measurement functional is the cross-shelf flow just off the shelf break. The representer will indicate when and where observations should be taken to best determine the cross-shelf flow. The adjoint solution is followed by a forward time integration of the tangent linearized perturbation model forced by the covariance-multiplied adjoint solution. The snapshots are below are from a single representer functions that show how the measurement impulse that is driving the adjoint influences the velocity and temperature fields and how it evolves in both 3D space and time. This mesurement is the same as showsn in the adjoint figures to the left.