4DVAR and LETKF Development for NOAA's Chesapeake Bay Operational Forecasting System

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Introduction:

- The Chesapeake Bay Operational Forecasting System (CBOFS) is NOAA's operational hydrodynamic model used to provide two days forecasts of several oceanographic products in Chesapeake Bay
- CBOFS forecasts of sea surface temperature (SST) and salinity (SSS) can be improved
- We are evaluating the performance of both the strong constraint 4D-Variational (4D-VAR; Moore et al., 2011) and Local Ensemble Transform Kalman Filter (LETKF; Hunt et al., 2007) data-assimilation systems to assimilate satellite-derived sea surface temperature in order to improve SST forecasts in CBOFS
- We describe the initial implementation, testing and results of assimilating AVHRR SST into CBOFS using 4D-VAR

Model and Data:

Model Description

- Study Domain: Figure 1.
- CBOFS based on ROMS 3.6
- Resolution: 33m in rivers to 4km in coastal area
- Grid size 292 by 332 , vertical 20 S layers
- Time step: 10 s

Data / Input

- IS4DVAR for adjusting initial conditions only
- Decorrelation scales: 17 km (x,y), 3 m (z)
- Archived CBOFS forcing and open boundary conditions
- Randomized normalization coefficient calculation.
- Background error is from standard deviation calculated with yearlong CBOFS results with tidal and annual signals removed
- Assimilation/Forward run window: 6 hours.

Work Performed

- Assimilate daily composite AVHRR SST dating from 08/14/2012 to 09/15/2012
- Evaluate with in-situ temperature and salinity observations from Chesapeake Bay Program (CBP; CTD T/S) and Chesapeake Bay Interpretive Buoy System (CBIBS T/S)

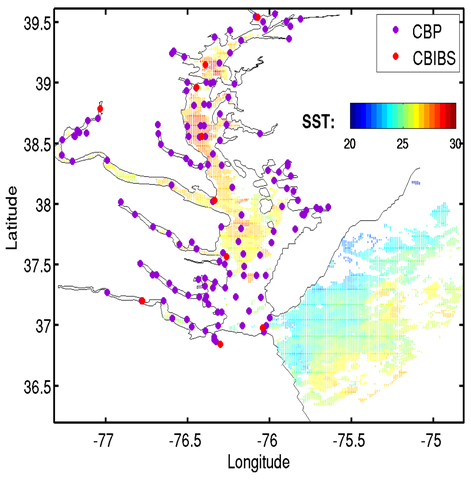

Figure 1. Model domain and stations. CBP = Chesapeake Bay Program CTD casting locations, CBIBS = Chesapeake Bay Interpretive Buoy Systems. Image: daily AVHRR composite for 22 August 2012.

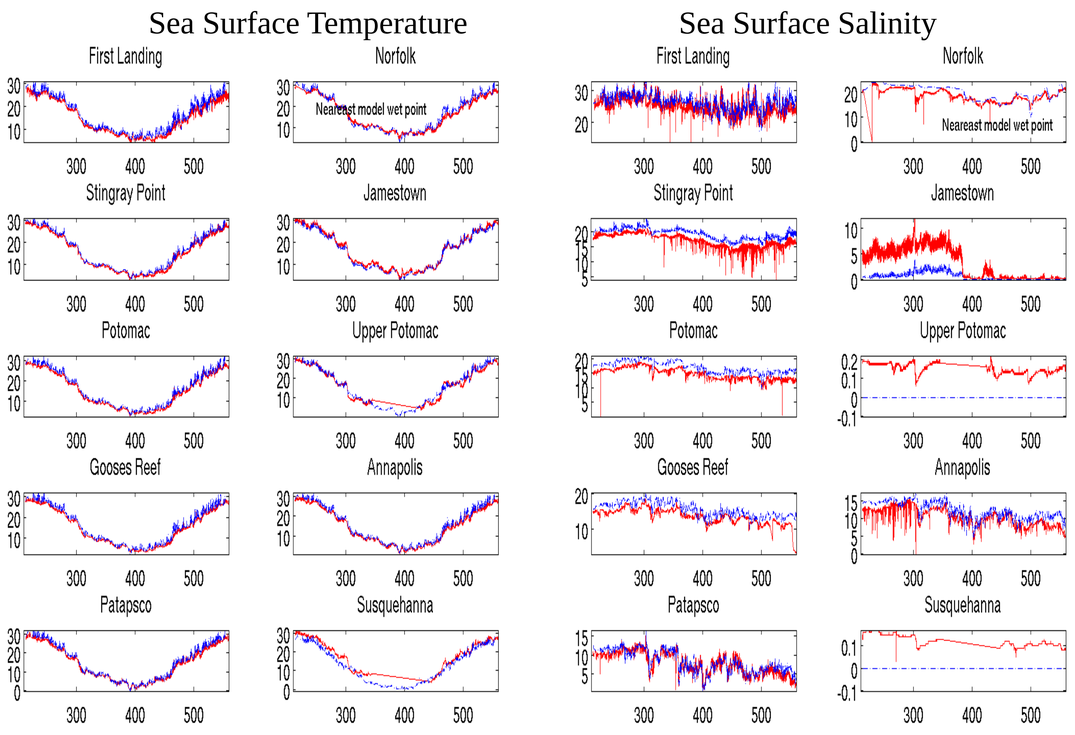

Figure 2. Comparison of the surface temperature(left two panels) and salinity (right two panels) between the forward run model results and the CBIBS (red lines) and the CBOFS (blue lines) measurements at ten CBIBS buoy locations.

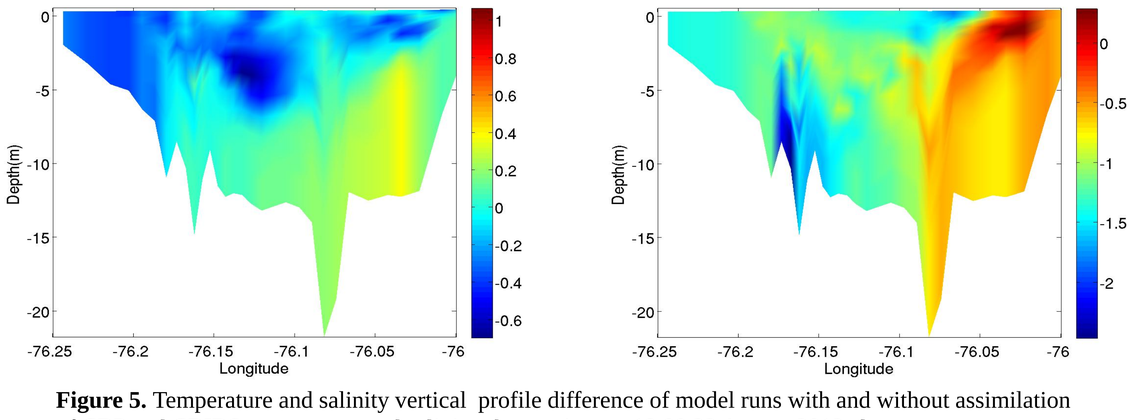

Figure 5. Temperature and salinity vertical profile difference of model runs with and without assimilation of CBP and CBIBS temperature and salinity observations at 18:00 22 August 2012 along a transect across mid Chesapeake Bay along 37.41ºN. The assimilation cycle is carried out within 06:00 to 12:00. Both cases are assimilated with AVHRR SST.

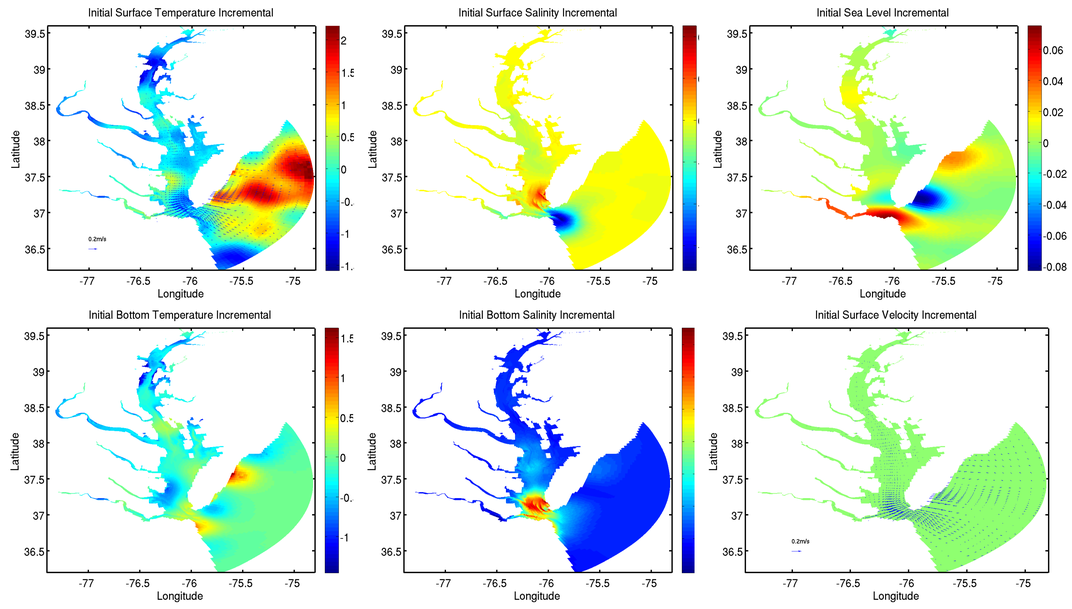

Figure 3: Incrementals of initial conditions after SST assimilation in window of 6:00-12:00 on 15 August 2012.

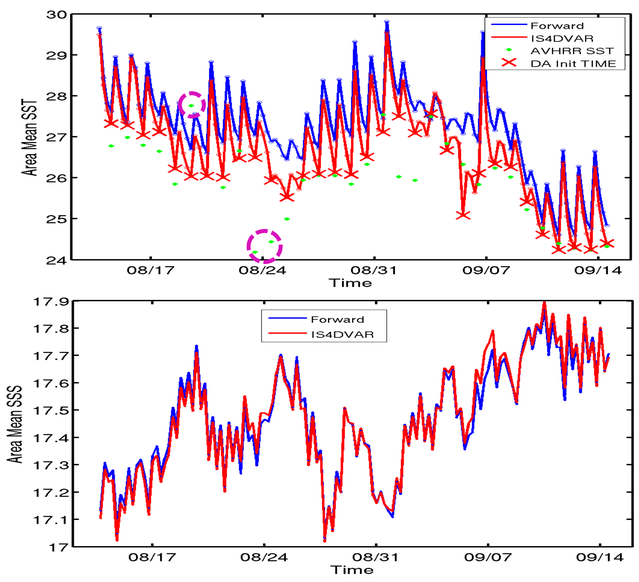

Figure 4. Time series of SST and SSS every 6 hours with data assimilation. The significant differences (pink circle locations) between AVHRR SST and model SST are caused by fewer SST estimates due to cloud contamination.

Results:

- Assimilating satellite-derived SST not only modifies the initial surface temperature but also changes the vertical profiles of T/S (Fig.3). The impact to other variables mainly occurs near the lower Chesapeake Bay and its mouth area.
- One month sequential assimilation (Fig. 4) of AVHRR SST successfully lowers the SST bias by 0.5 ºC.
- Assimilating CTD profiles with SST data significantly improves the three dimensional temperature and salinity fields even with small number of CTD observations (Fig.5). Specifically, salinity bias is reduced from 1.09 to -0.38 at the observational locations in the next forward run window. The mean salinity over the whole model grids is reduced by 0.13 within one assimilation window.
- IS4DVAR with CBOFS is very computationally expensive (Table 1), but is likely viable in an operational mode with the current CBOFS setup.

Table 1. IS4DVAR computational cost statistics based on 96 Intel Xeon 2.6GHz CPUs. The normalization coefficients calculation is carried on one time only.

Forward Run (6 hour window)	IS4DVAR with SST only(6 hours window with 10 Inner loops)	IS4DVAR with all data(6 hour window with 30 inner loops)	NormalizationCoefficients (3200 Radomized Steps)	
			3D variable	2D Variable
3 minutes	4 hours	18 hours	72 hours	12 hours

Conclusions:

- IS4DVAR data assimilation has been successfully adapted to CBOFS.
- Assimilation of AVHRR SST into CBOFS reduces the model bias by 0.5 ºC.
- Assimilation of SST and T/S vertical profiles reduces the salinity bias by 0.13, even though the CTD castings are sparsely distributed.

Future Work:

- Assimilate SST estimates from the the Visible and Infrared Imager and Radiometer Suite (VIIRS) of the Suomi National Polar-orbiting Partnership
- Configure LETKF with CBOFS and assess performance and computational cost in order to compare with 4DVAR results

References:

- Moore, A. M., H. G. Arango, G. Broquet, B. S. Powell, A. T. Weaver, J. Zavala-Garay , 2011: The Regional Ocean Modeling System (ROMS) 4-dimensional variational data assimilation systems: Part I – System overview and formulation Original Research Article, *Progress in Oceanography, Volume 91, Issue 1, October 2011, Pages 34-49*
- Hunt, B. R., E. J. Kostelich and I. Szunyogh, 2007: Efficient Data Assimilation for Spatiotemporal Chaos: A Local Ensemble Transform Kalman Filter. Physica D, 230, 112-126.

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