4DVAR Data Assimilation with Chesapeake Bay Operational Forecasting System

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Outline

- Project brief introduction and objectives
- Comparison of CBOFS with observations
- 4DVAR Data assimilation with CBOFS
- Comparison results before and after 4DVAR assimilation
- Summary and future works

Scientific Basis/Approach

- Temperature and salinity are critical in understanding the coastal ocean and ecosystems, yet difficult to forecast synoptically
- NOAA's operational Chesapeake Bay Operational Forecasting System (CBOFS) forecasts T/S, but would benefit from the assimilation of satellite-derived SST.
- Several data assimilation techniques available; evaluate whether 4D-VAR (Moore et al.,2011) or LETKF (Hunt et al. 2007) is better for assimilating SST retrievals into CBOFS
- Satellite SST retrievals have previously been assimilated into hydrodynamic models, but not operationally by NOAA

Overall Goal:

- Determine whether 4DVAR or LETKF should be used when assimilating VIIRS SST, together with other available observations, into CBOFS.
- Quantify the improvement of retrievals from VIIRS vs AVHRR SST.

Only 4DVAR results are reported here.

Funded by Joint Polar Satellite System Proving Ground and Risk Reduction Program.

Chesapeake Bay Operational Forecasting System

- Currently Running at NOAA NOS CO-OPS With Regional Ocean Modeling System 3.0

  Small bugs needed to be fixed.

  No full support for latest 4DVAR scheme.

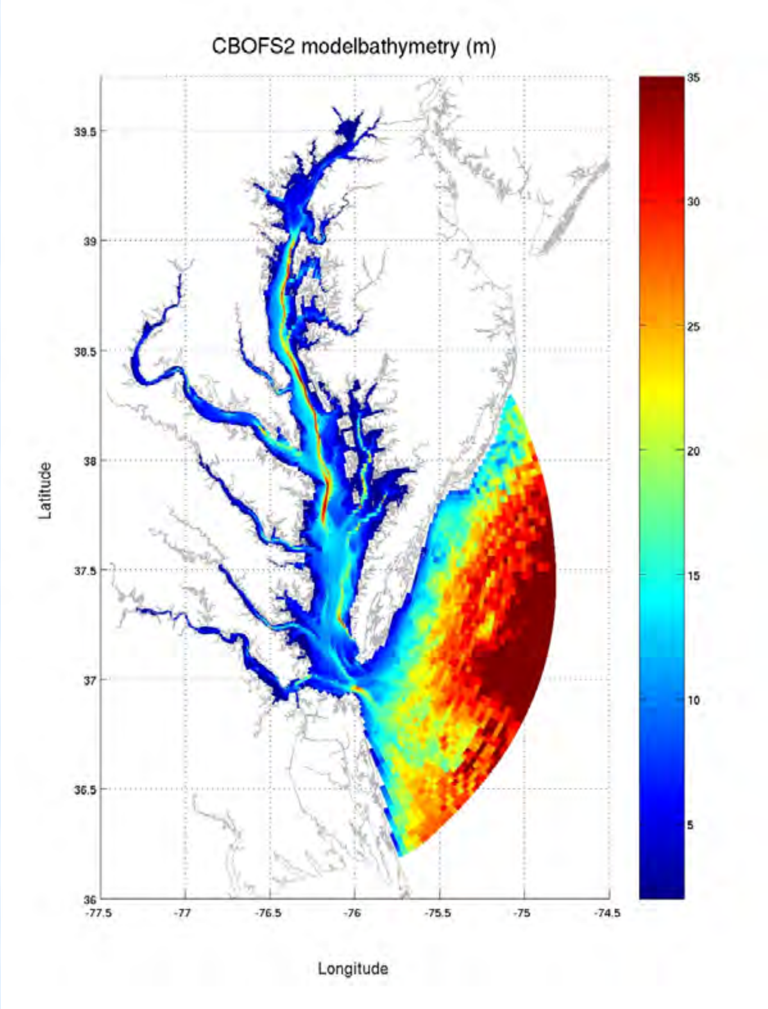
- Updated the CBOFS to ROMS 3.6

  Open boundary conditions suitable for two-way nesting, moved into the input files instead of CPP options.

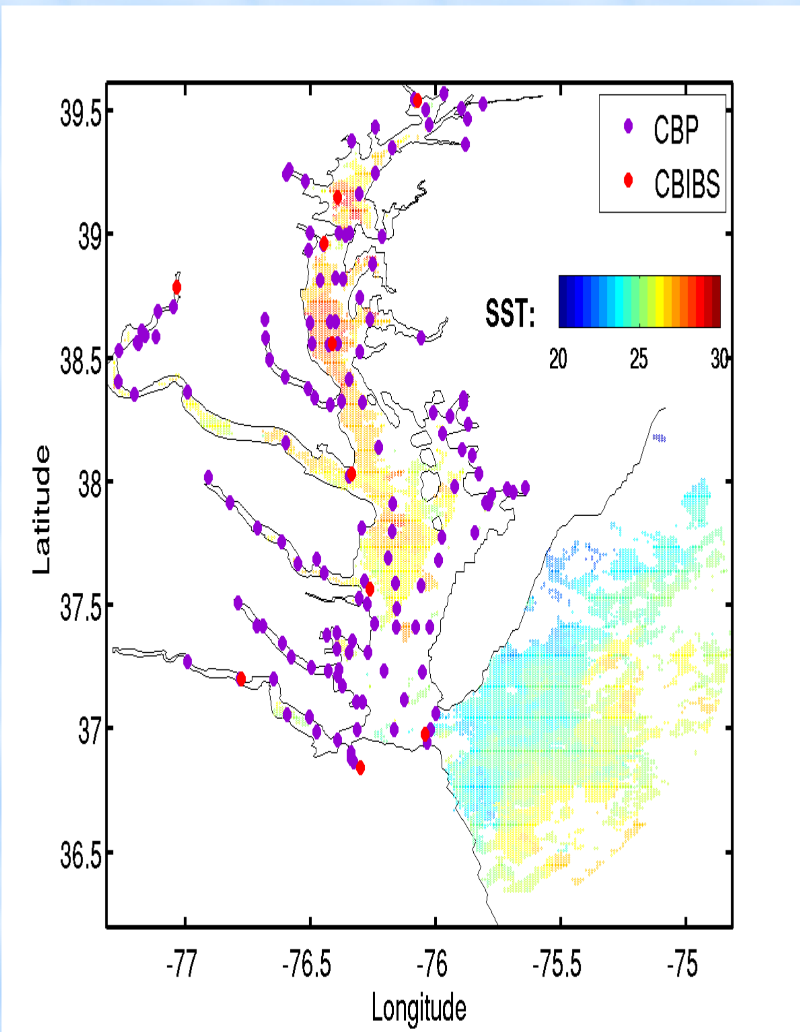
- Forcing and open boundary files

  NAM, USGS rivers, RTOFS

  Provided by Aijun Zhang and Ainsley Gibson of NOAA



Chesapeake Bay Water/Current Observations

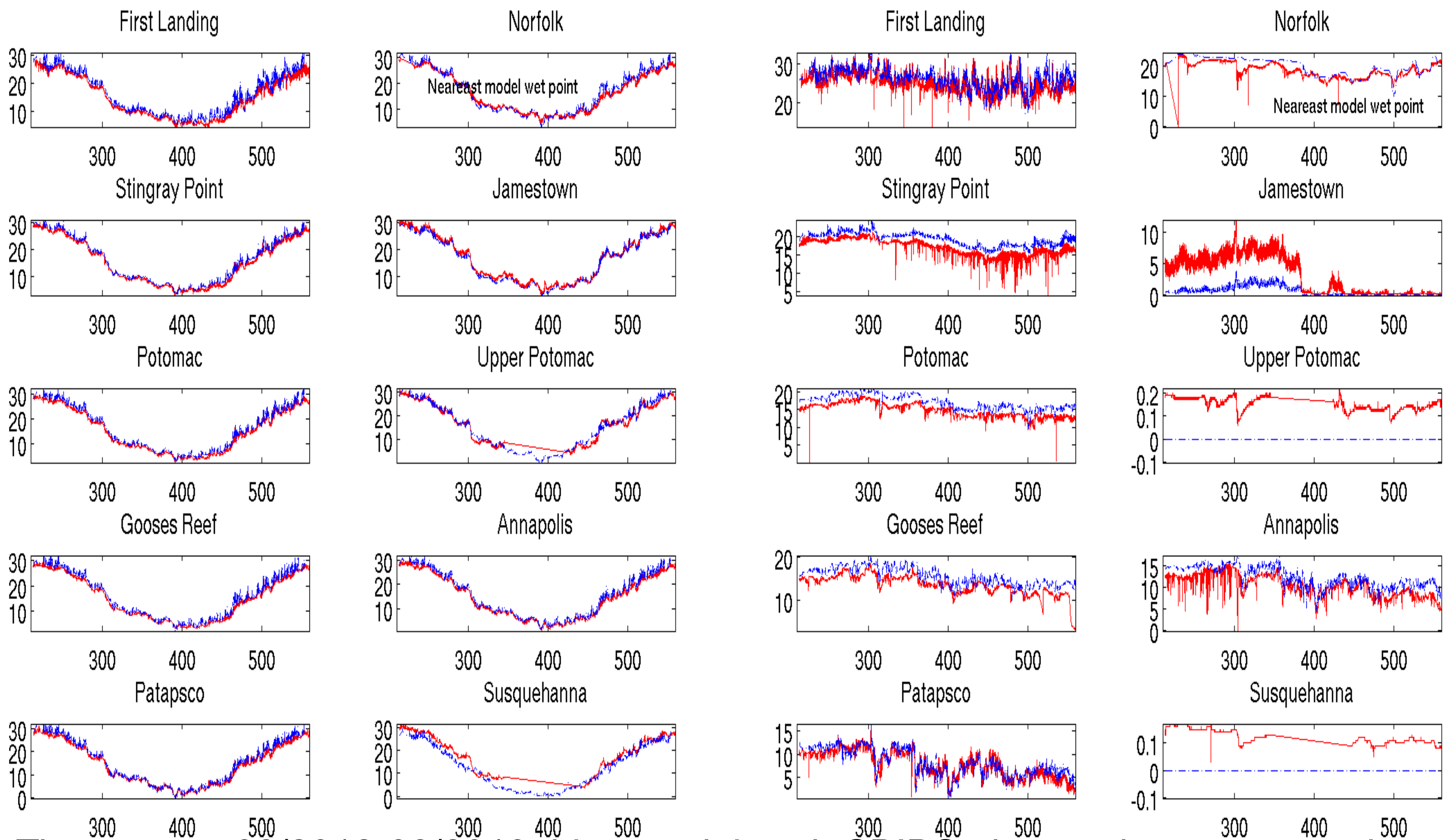


- Chesapeake Bay Program (CPB):
  ~ Every two weeks CTD casting of T/S
- Chesapeake Bay Interpretive Buoy System (CBIBS)
  15 minutes surface T/S, real time.
- SST from NOAA Coastal Watch
  AVHRR (1km, composite and granule)
  GOES (SST)
  Terra/Aqua MODIS SST
  S-NPP VIIRS SST (750 m at nadir)
- HF Radar from ODU
  1km resolution surface current near Bay mouth
- Occasionally in-situ CTD/ADCP
- USGS river
- Tide gauges

CBOFS Comparison with Observations

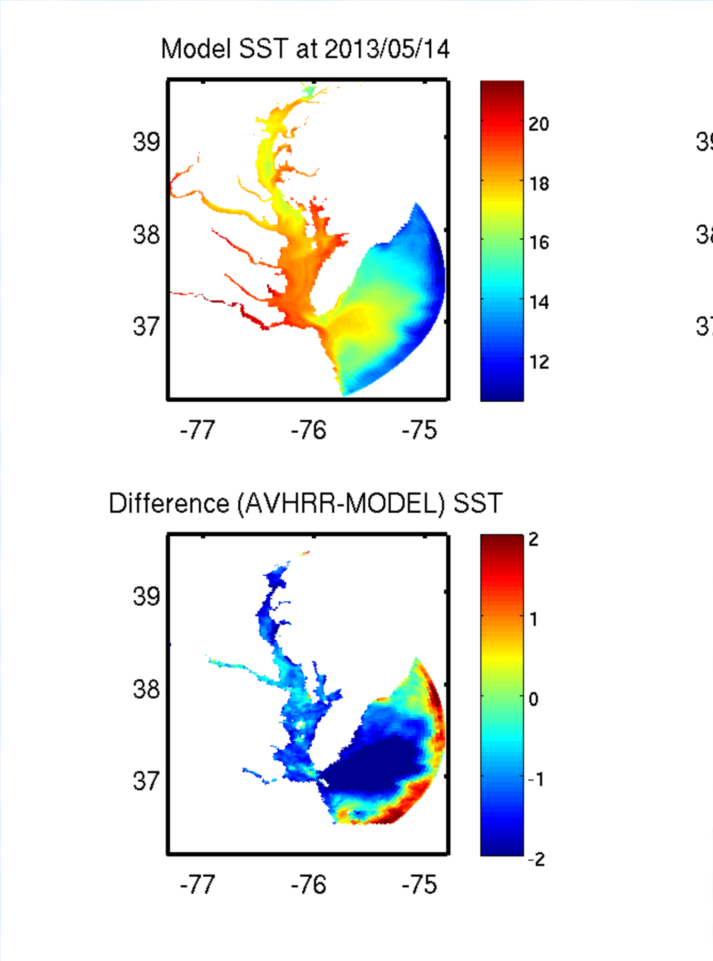
Surface Temperature

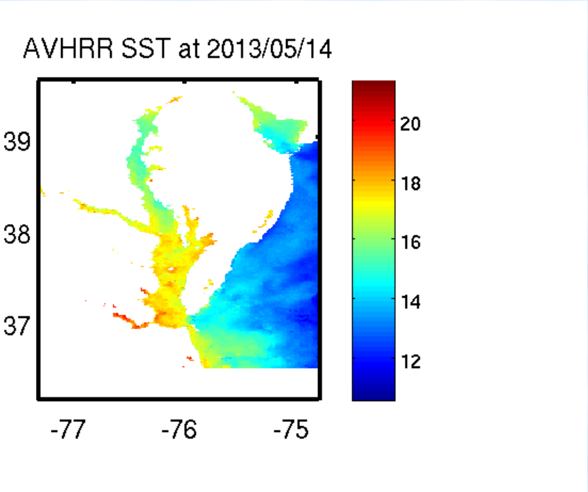
Surface Salinity

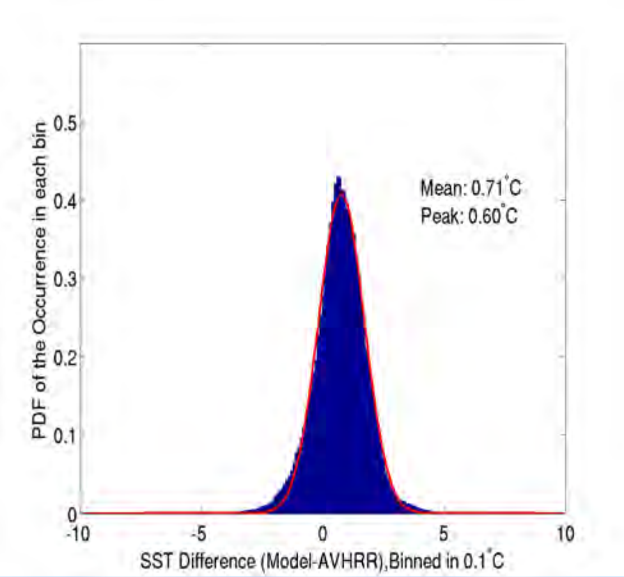


Time range: 08/2012-08/2013, blue model, red, CBIBS observations, a general warm and saline bias.

CBOFS Comparison with Observations







AVHRR SST is from NOAA coastal watch daily composite.

ROMS 4DVAR

- Incremental Strong Constraint (IS4DVAR)

  Primal form

  Initial conditions, surface forcing, open boundary conditions

- Physical-Space Statistical Analysis (PSAS)

  Dual forms, in model and observational spaces.

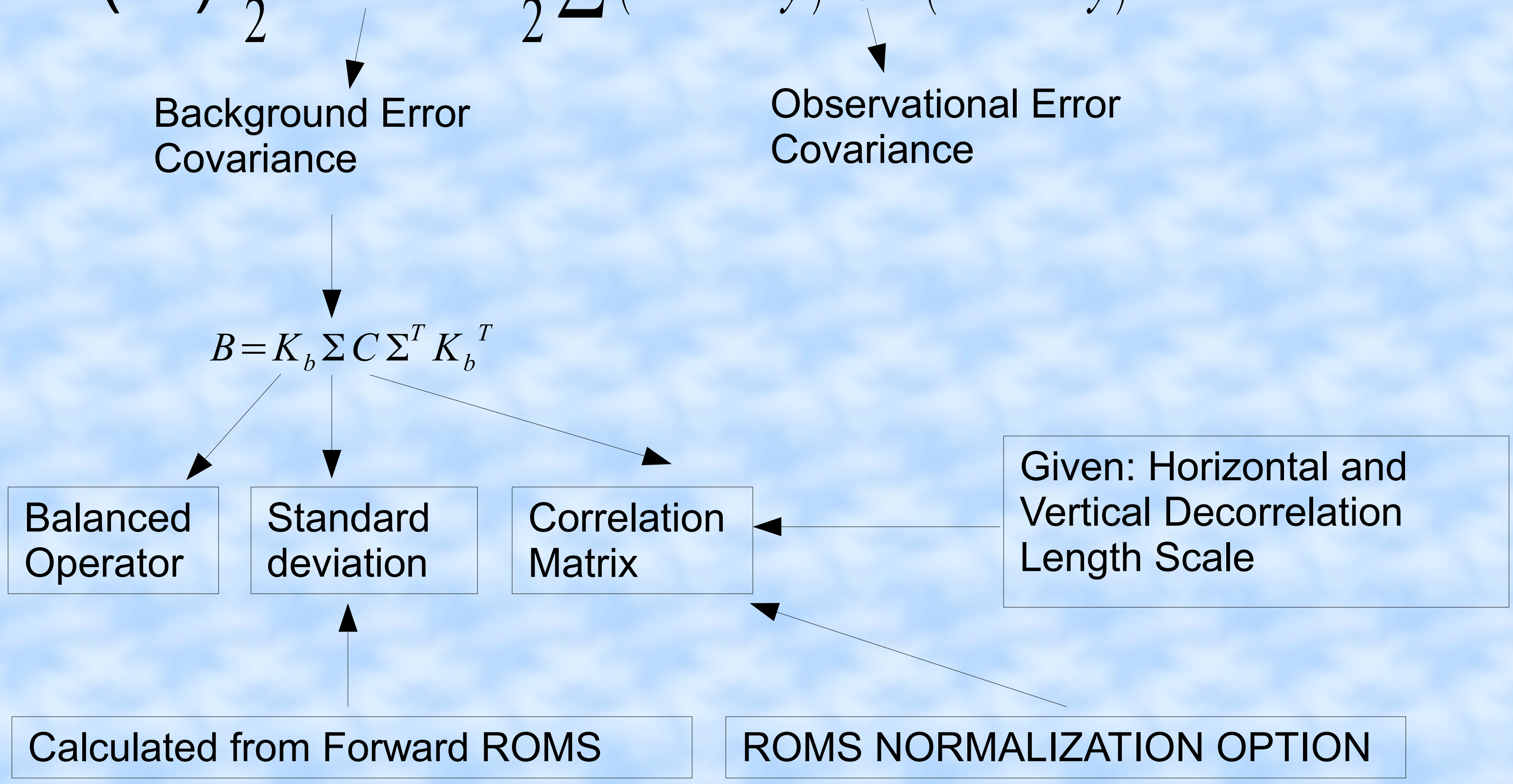
  Strong constraint; Weak constraint (Considering model errors).

- Representer 4DVAR (R4DVAR)

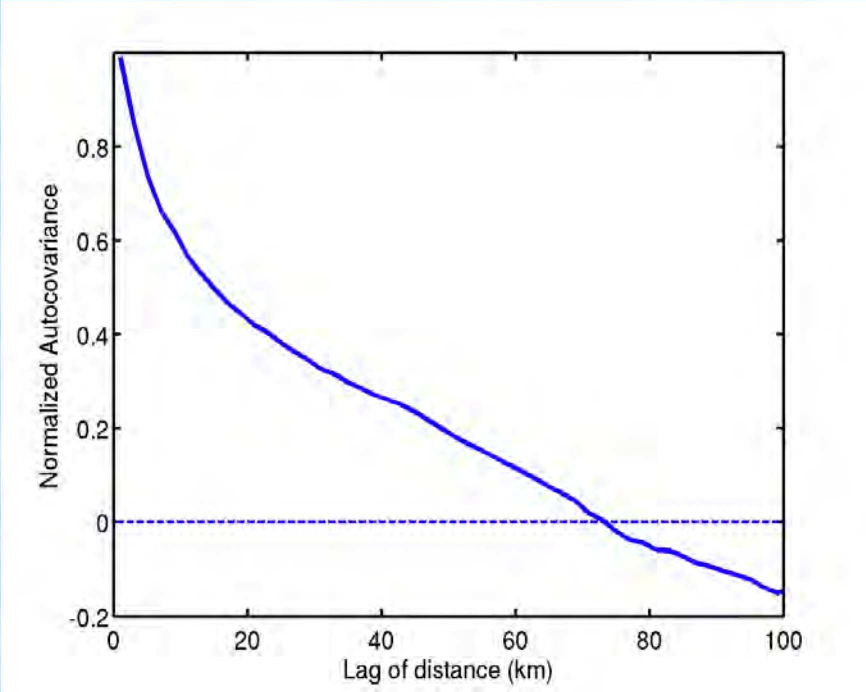
Here, we use IS4DVAR and adjust initial condition only. Other forms will be test in later studies.

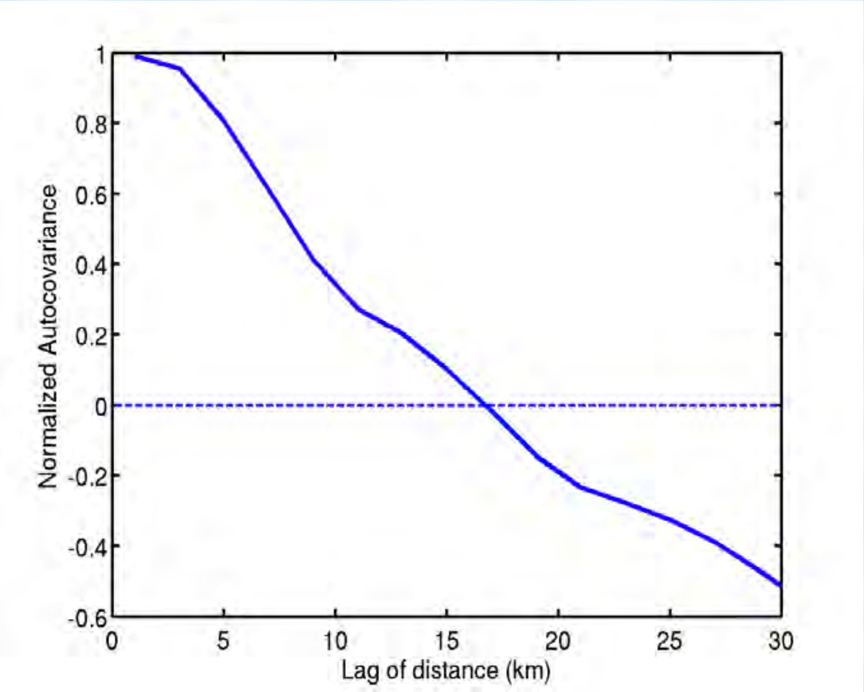
IS4DVAR Preparation

- $J(\delta x) = \frac{1}{2}\delta x^T B^{-1} \delta x + \frac{1}{2}\sum (H\delta x - y)^T O^{-1} (H\delta x - y)$



Decorrelation Scales (from SST)





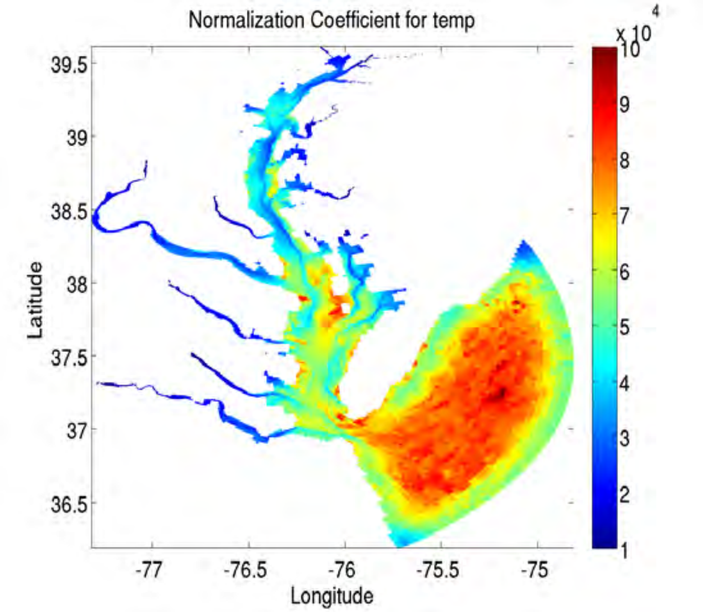
Overall: 73Km

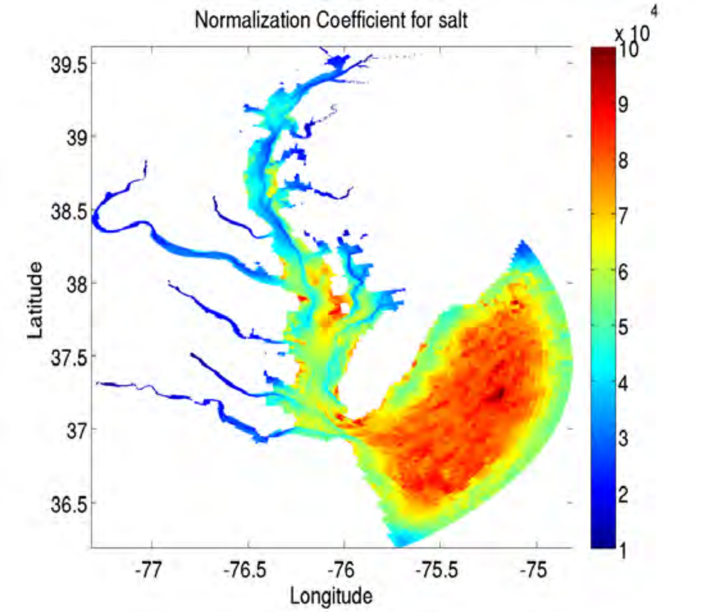
East Direction: 17Km

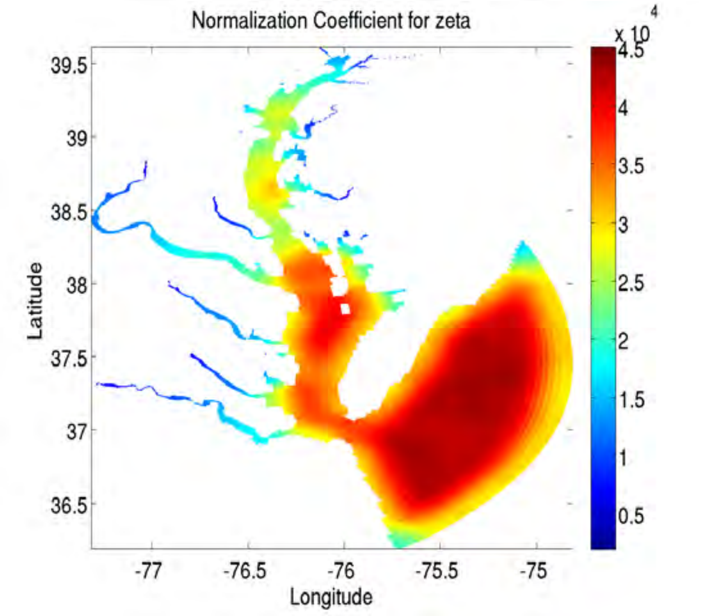
In the vertical, it is hard to get a statistically meaningful decorrelation scale with the shallow depth, we just choose the minimum vertical mixed layer depth to avoid over smoothing. Here we choose it to be 3 m. The surface mixed layer depth ranges from 3m -10m

Ref: http://aslo.org/meetings/santafe1999/abstracts/CS57FR0900E.html

Normalization Coefficients



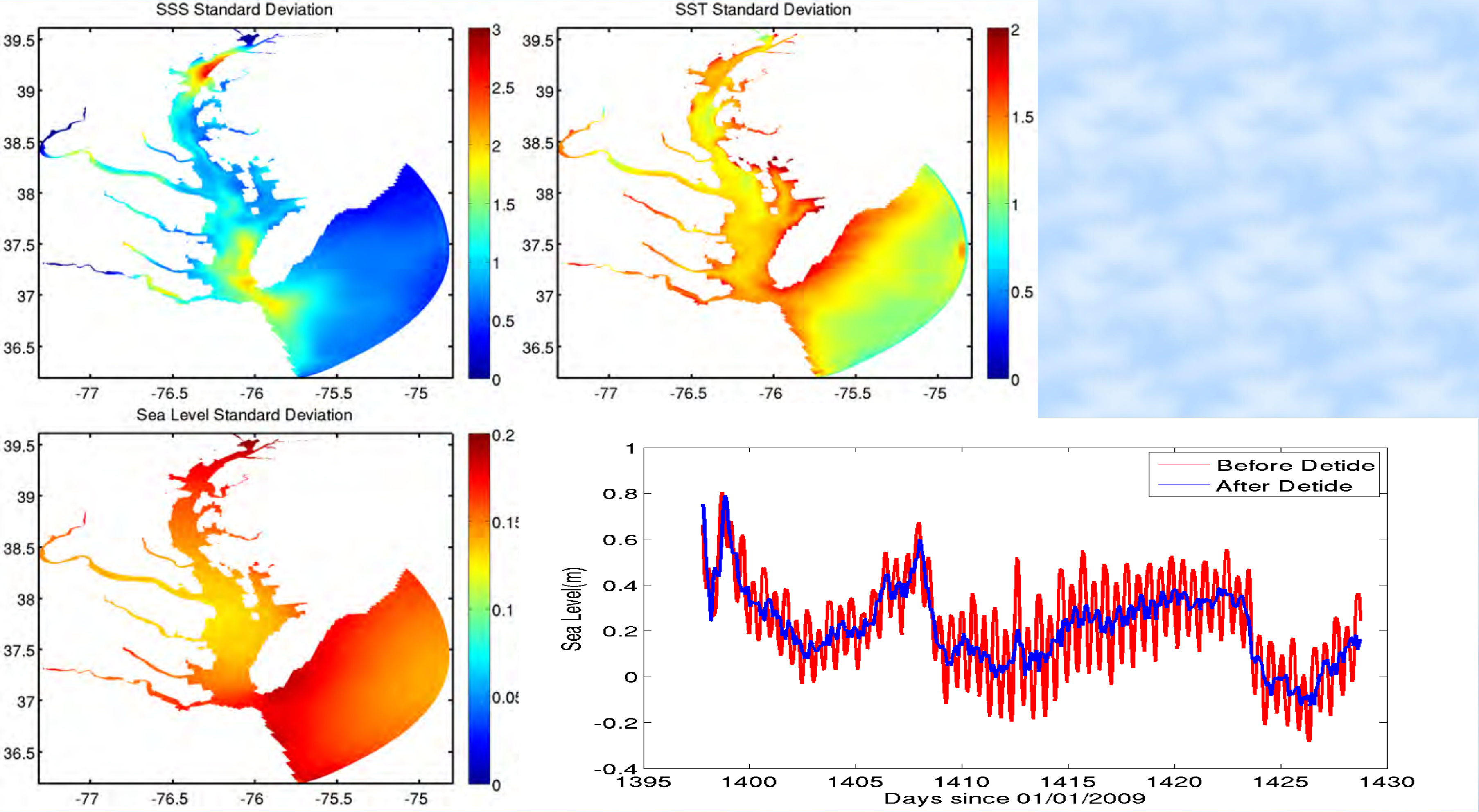




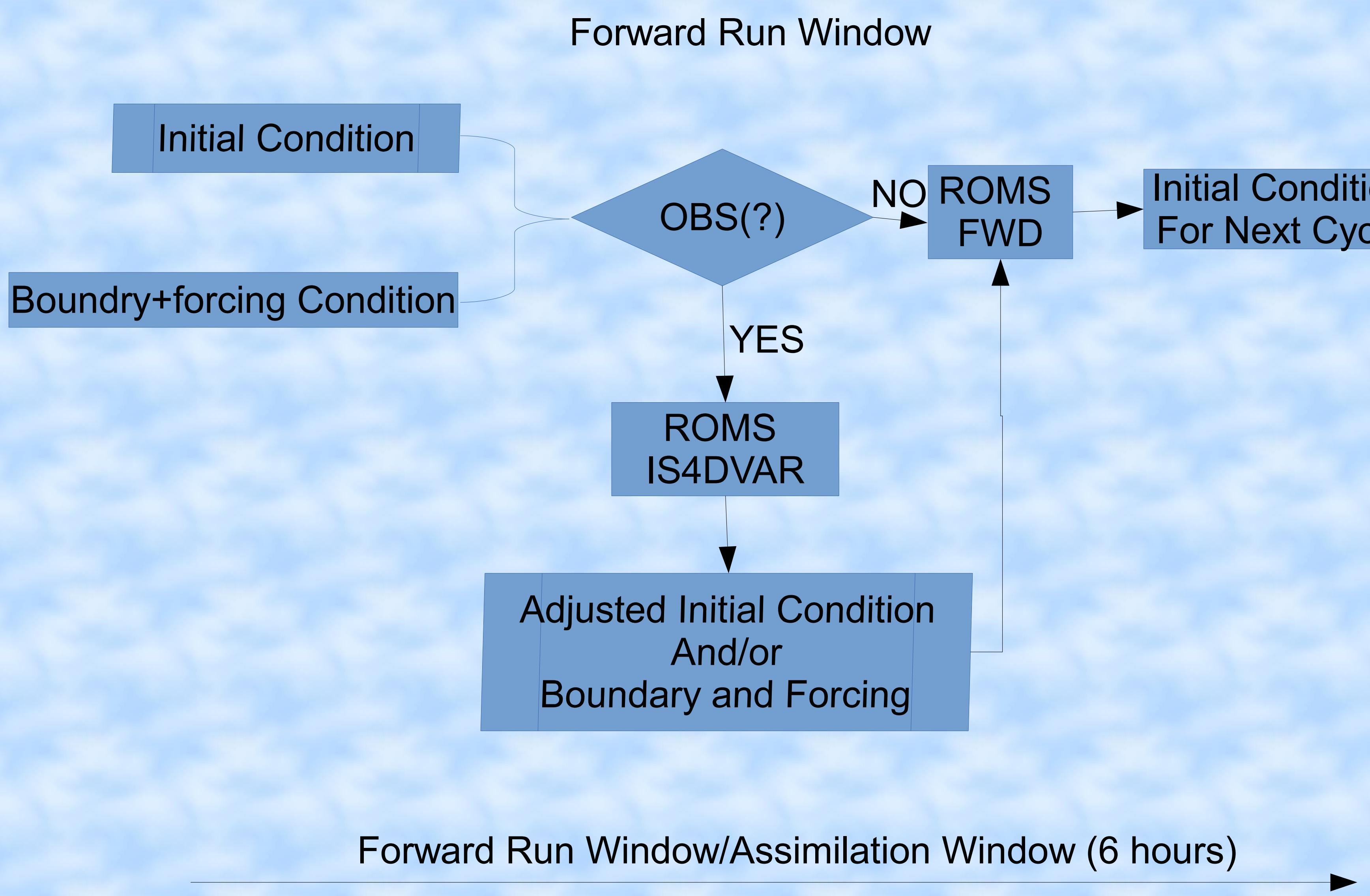
- Solve a heat diffusion equation
- Randomized method
- Need sufficient iterations.
- Lengthy Calculations
- One time calculation if the model grids do not change.

(Background) Standard Deviation

- Model hindcast for one year, save data with three hourly interval.
- Inline least square analysis to calculate tidal harmonics for (T,S,u,v,η).
- Remove periodical signals in the three hourly data (tides and annual signal), and calculate the standard deviation.



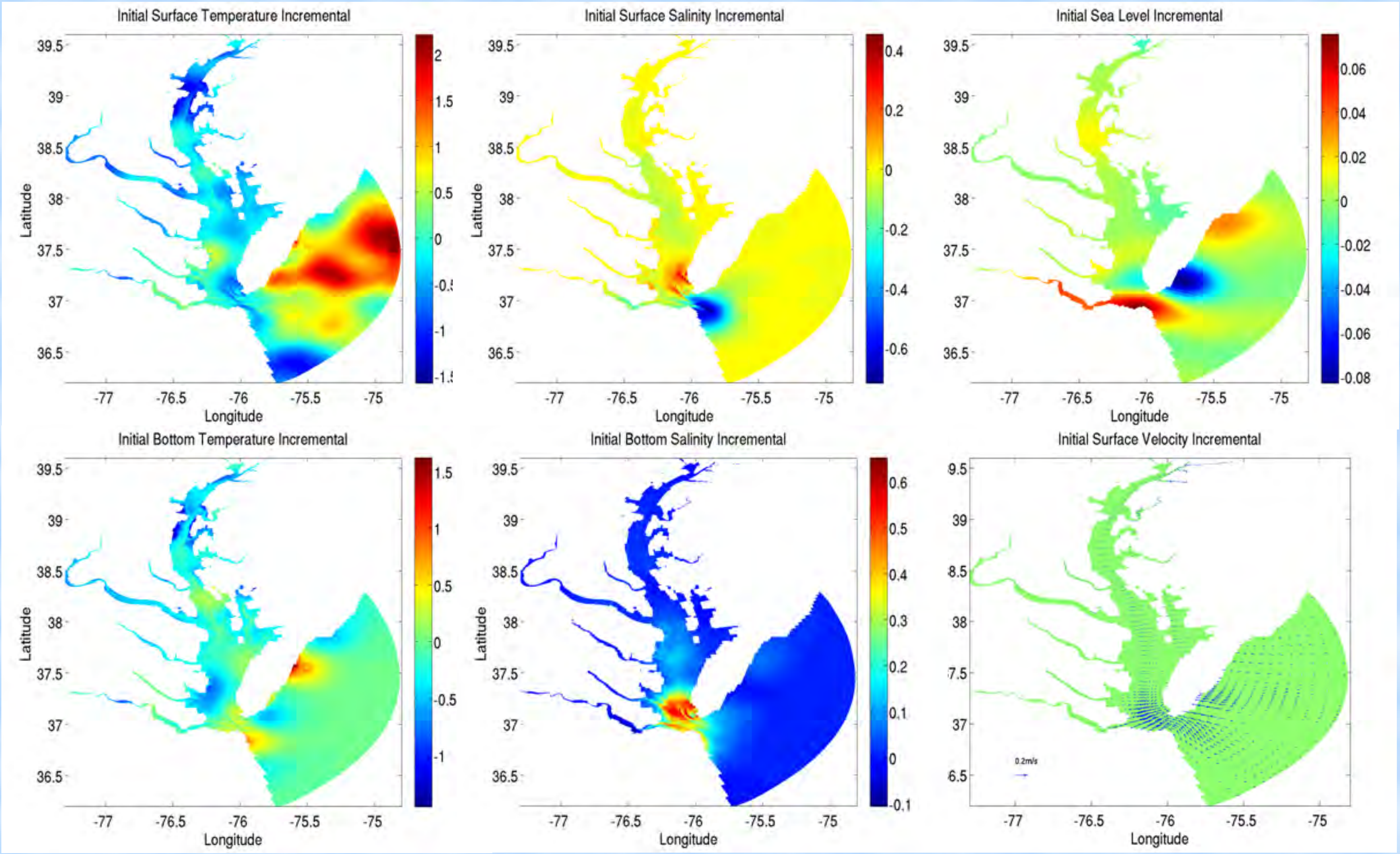
Flow Chart for IS4DVAR



Sequential run from 08/14/2012 12:00 to 09/16/2012 00:00

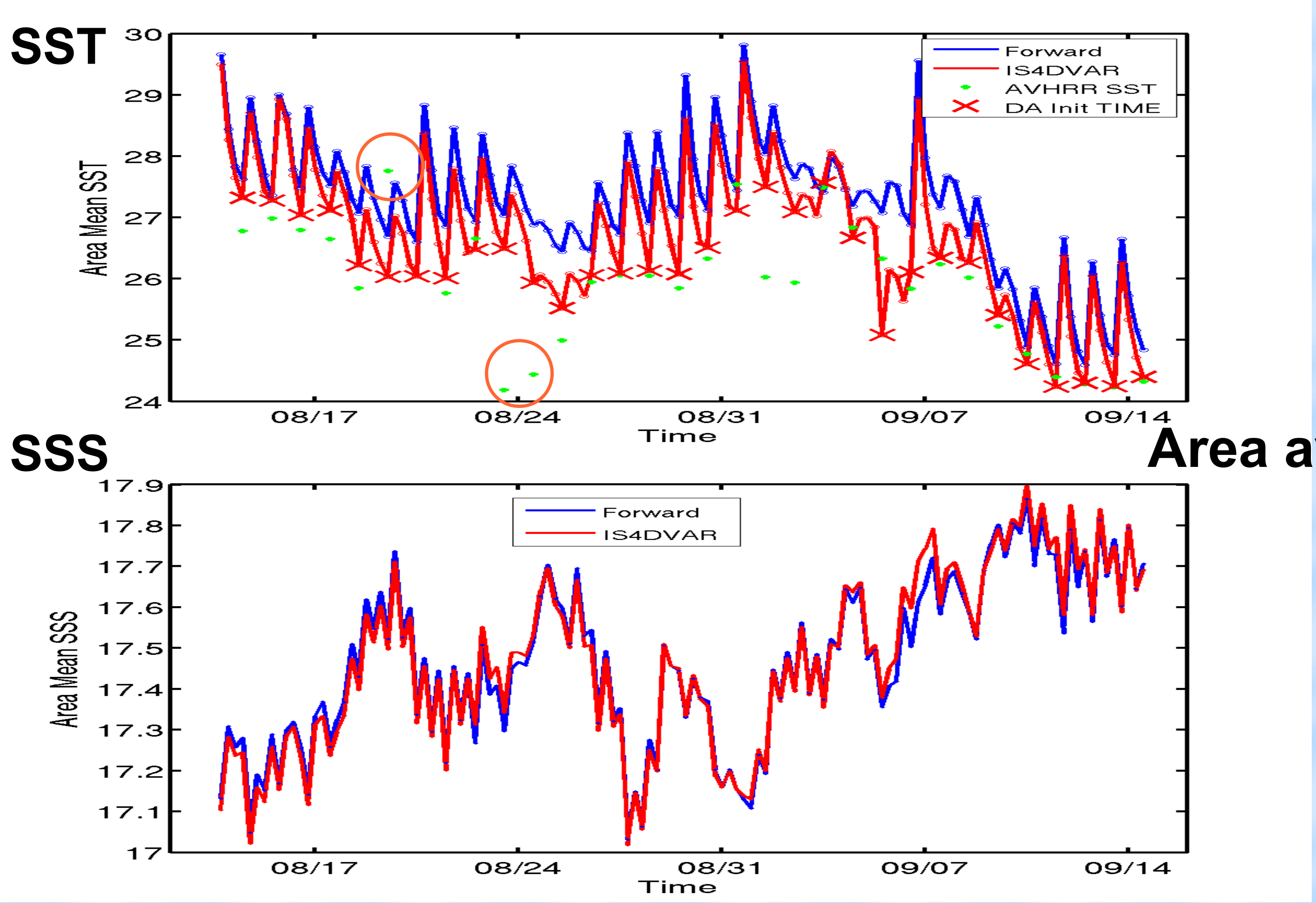
IS4DVAR (Incrementals)

Initial Condition Difference before and after IS4DVAR. 08/15/2012 12:00



The temperature is modified by SST assimilation but salinity and velocity changes mostly in the Chesapeake Bay mouth region. The adjustment of salinity and velocity in the mouth area is more sensitive to the SST than other area.

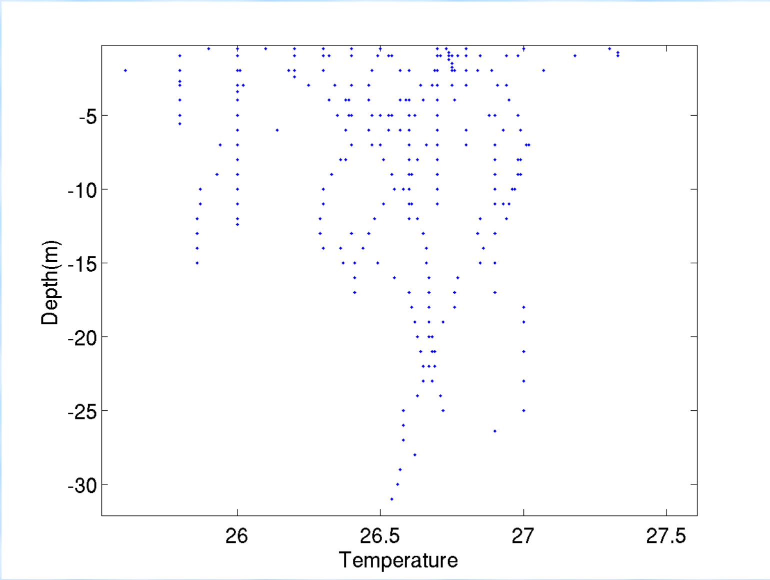
One month Sequential Adjustment of Initial Condition with AVHRR SST

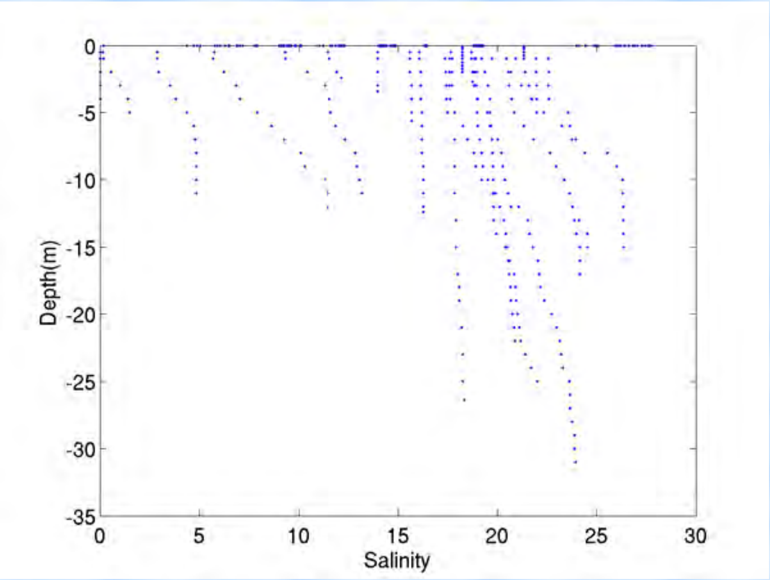


Mean FWD SST: 26.74 Mean DA SST: 27.25; Mean FWD SSS: 17.469;
Mean Sat SST: 25.89 Mean DA SSS: 17.467;

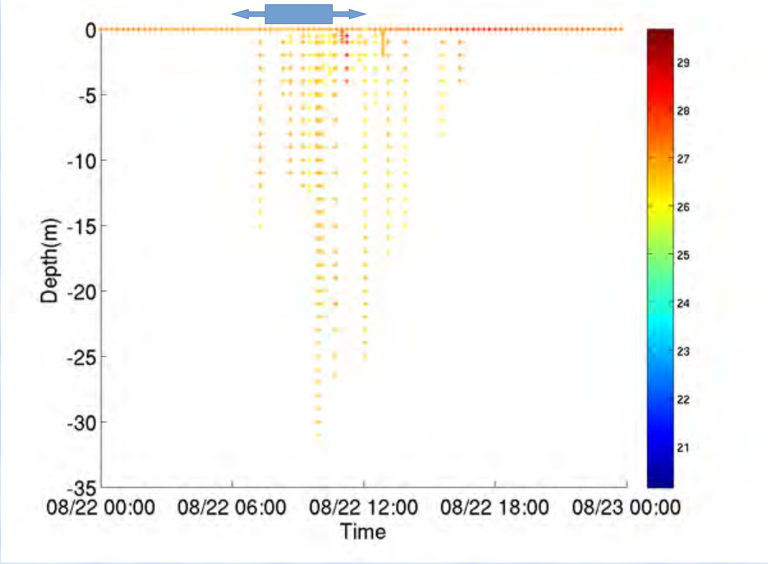
Assimilation with T/S data

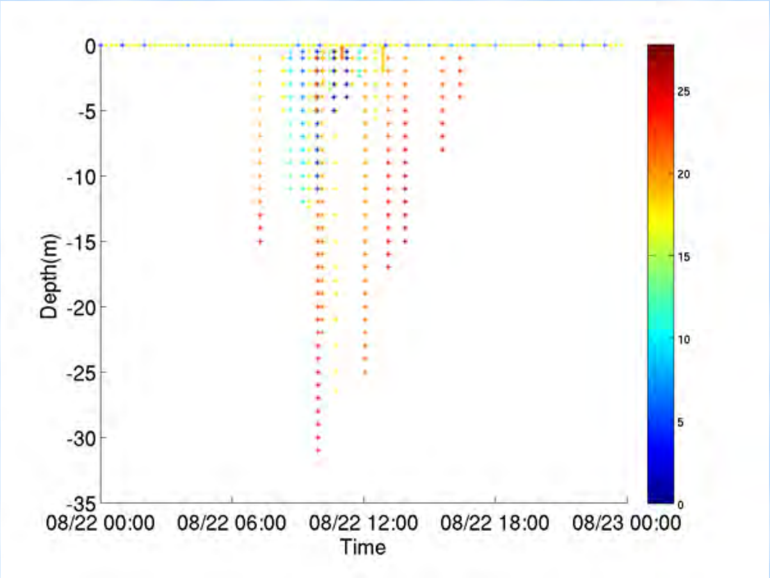
Observational Data at CBIBS (surface) and CBP





Assimilation Window

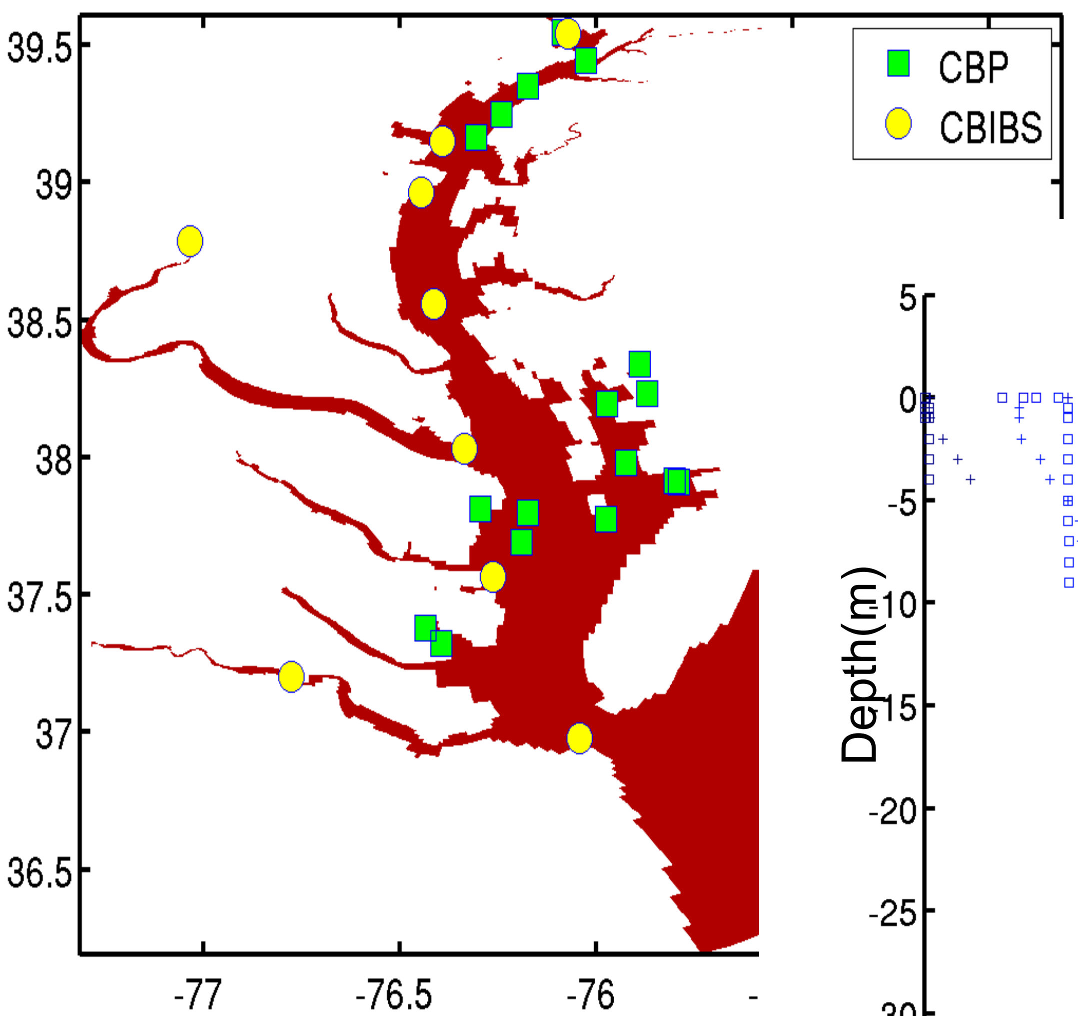


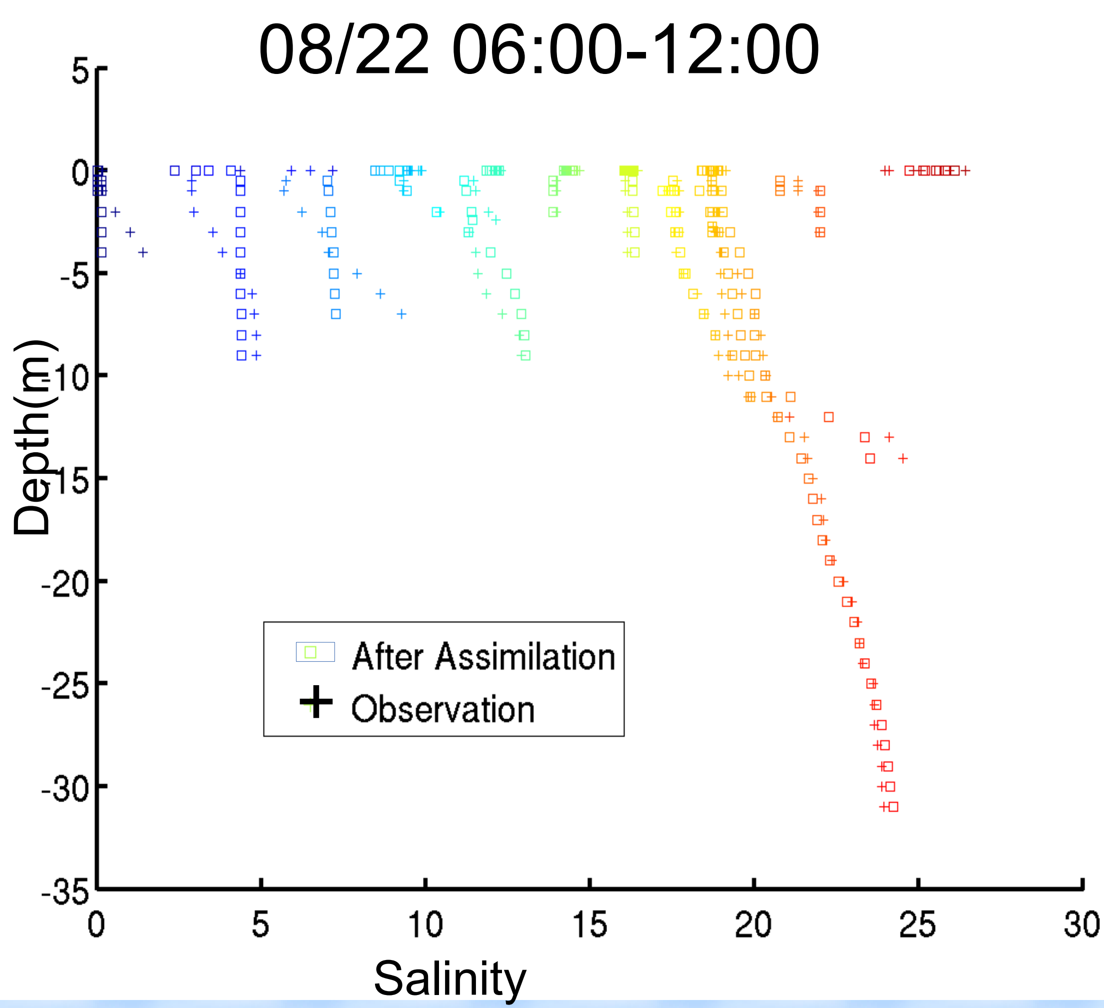


Temperature

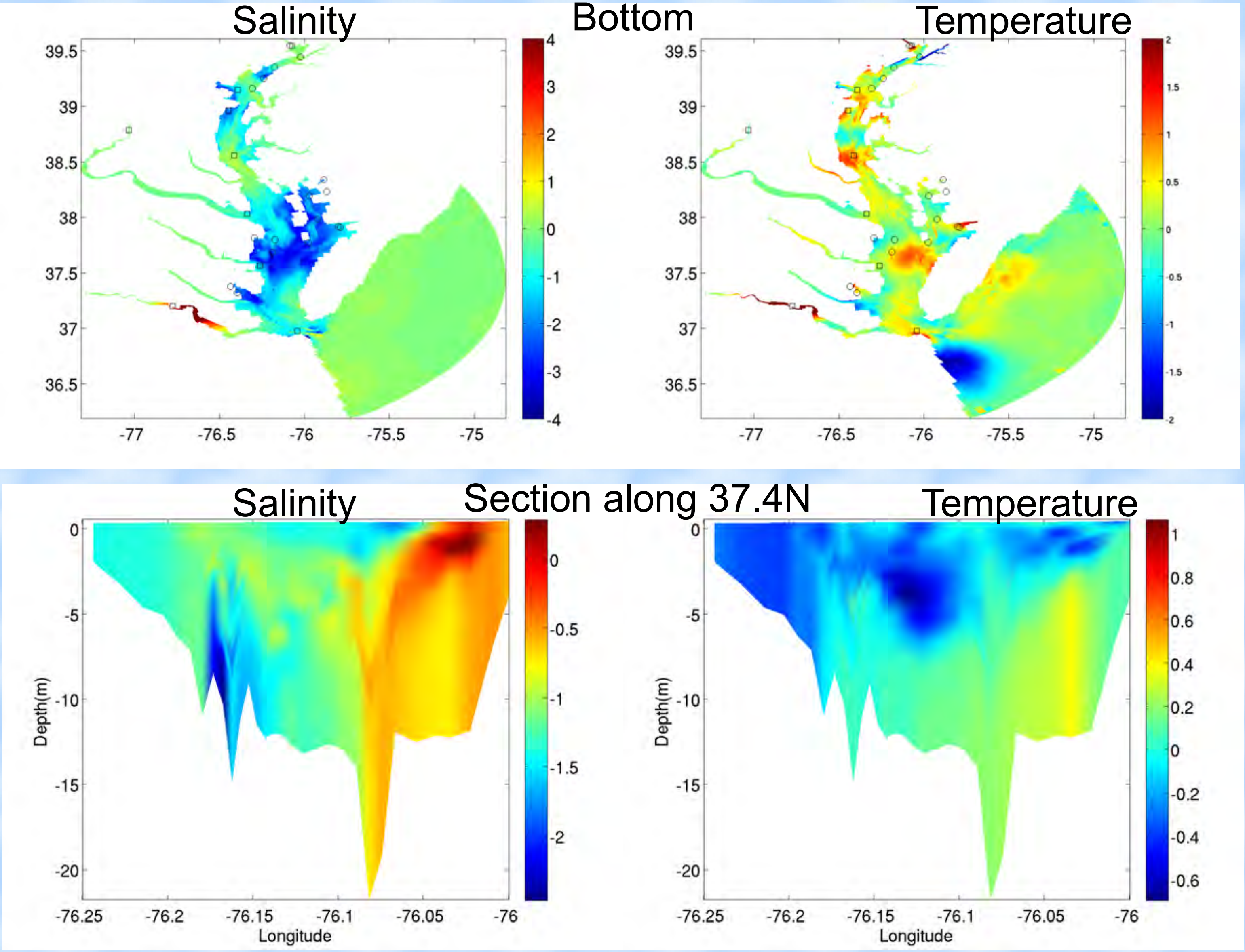
Salinity

Assimilation with T/S data





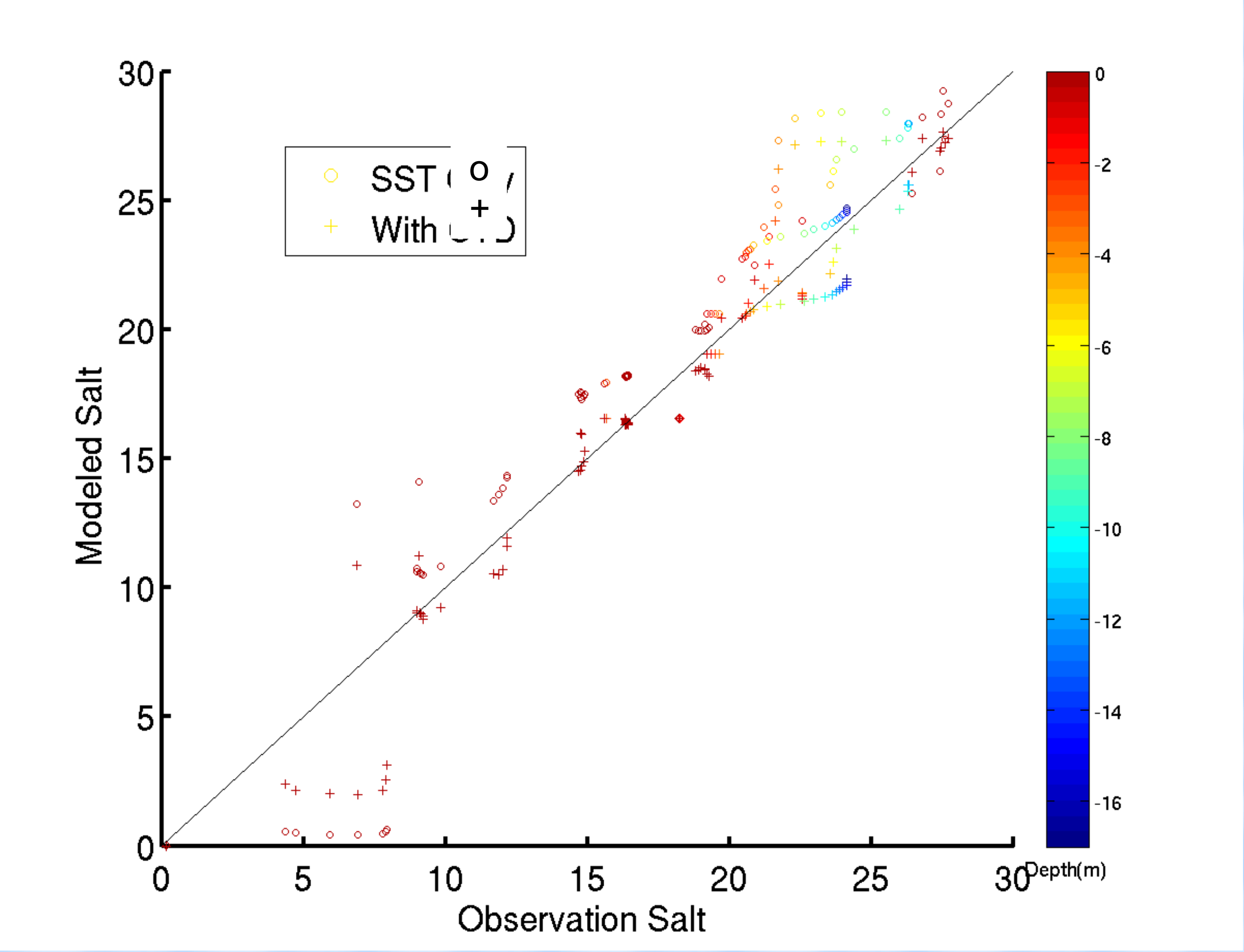
Salt/Temp Changes



Temperature and salinity 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 37.41ºN. Both cases are assimilated with AVHRR SST.

Validation using unassimilated data at forecasting window

08/22 12:00-18:00



Computational Time Evaluation

Forward Run (6 hour window)	IS4DVAR with SST only(10 Inner loops)	IS4DVAR with all data (30 inner loops)	Normalization Coefficients (3200 Randomized Steps)
3 minutes	4 hours	18 hours	72 hours /3D; 12hours/2D

Summary

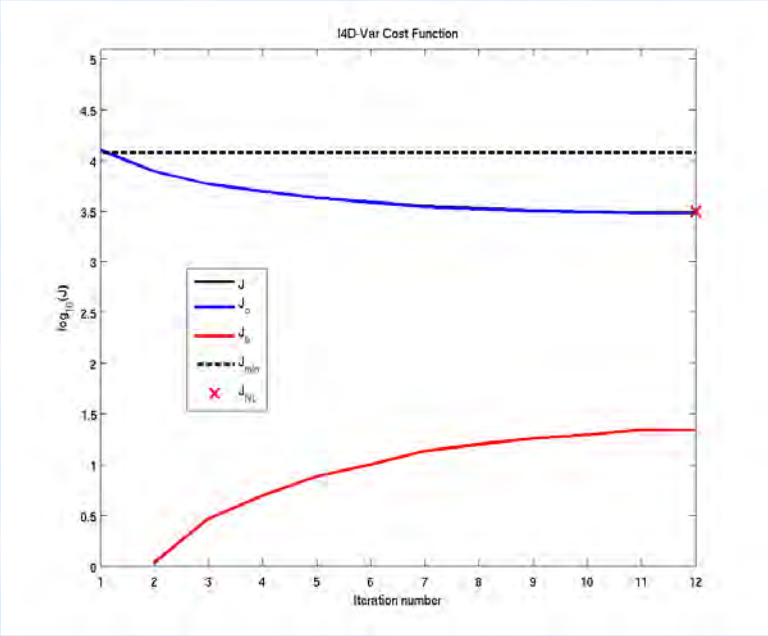
- IS4DVAR has been successfully adapted to CBOFS.
- Assimilating satellite-derived SST not only modifies the initial surface temperature but also changes the vertical profiles of T/S. The impact to other variables mainly occurs near the lower Chesapeake Bay and its mouth area.
- A one month sequential assimilation of AVHRR SST reduces surface SST bias by 0.5°C.
- Assimilating T/S profiles with SST data significantly improves the three dimensional temperature and salinity fields even with small number of CTD observations. 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. The bias in temperature reduction is not significant compared to results with only SST assimilation.
- 4DVAR is computationally expensive.

Future work

- Assimilating VIIRS SST.
- Compare results from LETKF.
- Transfer one of data assimilation method into operational mode (regarding the computational cost, performance etc) to CSDL/CO-OPS.

Thanks

IS4DVAR Cost Function (Adjustment of Initial Condition only)



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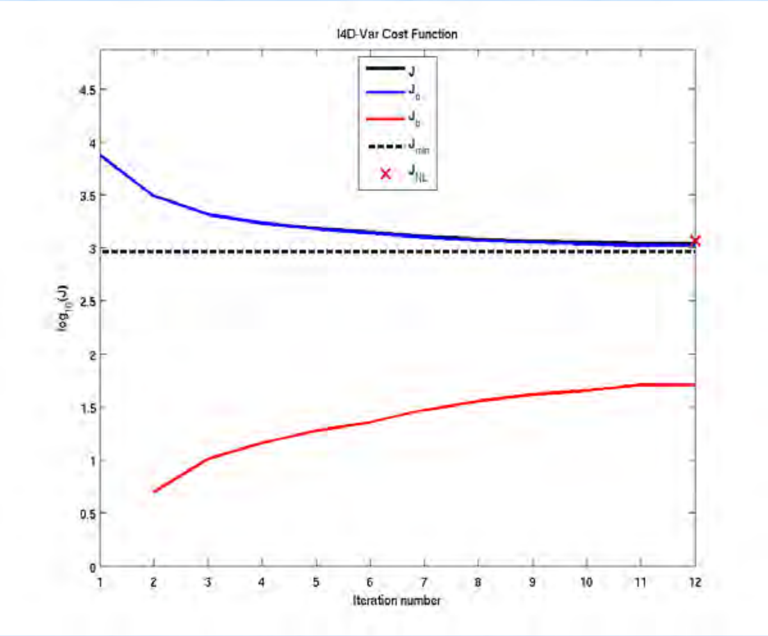

08/23/2012 12:00
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The total penalty function J decreases to a near-stable number in a 10 inner loops.