

# Data Assimilative Modeling of the U.S. Mid-Atlantic Bight Shelf

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RUTGERS

Near Real Time Splinter session  
Ocean Surface Topography Science Team, Boulder, CO, 10 Oct 2013

ESPreSSO\* real-time ROMS system

<http://myroms.org/espresso>

\*Experiment

# Satellite-based Ocean Analysis for the Mid Atlantic Bight

J Zavala-Garay

*John Wilkin, and Julia Levin*

IMCS, Rutgers, The State University of New Jersey, USA

The assimilation system is as described in by Javier Zavala-Garay in Wednesday's Splinter IV – Large scale oceanography



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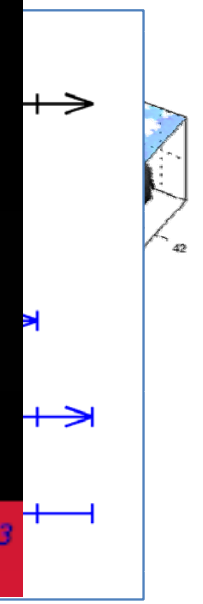
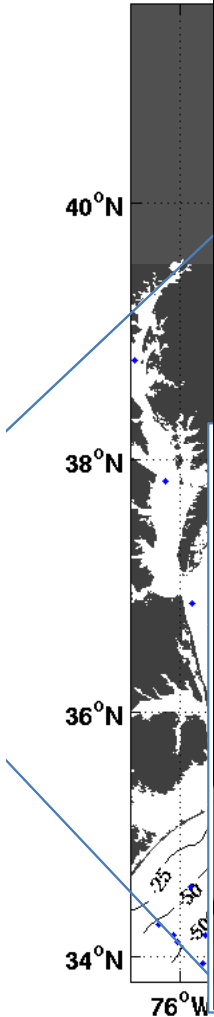
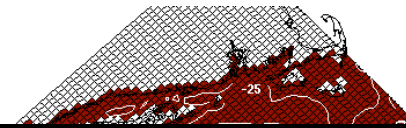
<http://marine.rutgers.edu>

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OSTST 2013

<http://maracoos.org>

Mid-Atlantic Regional Association of Coastal Ocean Observing Systems



## Data streams in the NRT system

### Model surface and boundary forcing:

- 72-hour forecast NAM 0Z cycle at 2 am EST
- USGS daily average flow available 11:00 EST
- HYCOM NCODA 7-day forecast updated daily

### Assimilation data sets:

- Regional CODAR hourly: 4-hour latency delay
- RU glider T,S (1 hour delay)
- AVHRR IR passes 6-8 per day (2 hour delay)
- REMSS MW-IR blended SST daily average
- **Jason-2, CryoSat, AltiKa** along-track OGDR
- SOOP XBT/CTD, Argo floats, on GTS

## *NRT real-time data source*

*NCEP NOMADS Grads DODS Server*

*waterdata.USGS.gov*

*Naval Research Laboratory*

*Rutgers TDS\**

*Rutgers TDS*

*U. Delaware via tds.maracoos.org*

*NASA PO-DAAC*

*RADS*

*OSMC.noaa.gov using ERDDAP*

*\*THREDDS Data Server unidata.ucar.edu*

# Work flow for Near Real Time ESPreSSO 4DVar

*Daily schedule for real-time system*

*All times local U.S. EST*

- 03:30: 4D-Var assimilation analysis of last 3 days of observations
- 07:30: Run forecast for next 72 hours
- 09:00: Forecast is complete and transferred to OPeNDAP/THREDDS FMRC
- ...
- 10:00: Get HYCOM output for OBC
- 23:00: Get 1-day composite REMSS blended SST (B-SST)
- 00:00: Get daily average river discharge from USGS
- 01:00: Get NAM surface meteorology forcing from NCEP NOMADS
- 03:00: Get IR SST passes; process and combine with B-SST
- 03:00: Get CODAR surface currents; process tide adjustment
- 03:10: Get Jason, Cryosat and AltiKa along-track data from RADS; process tide adjustment, add MDT



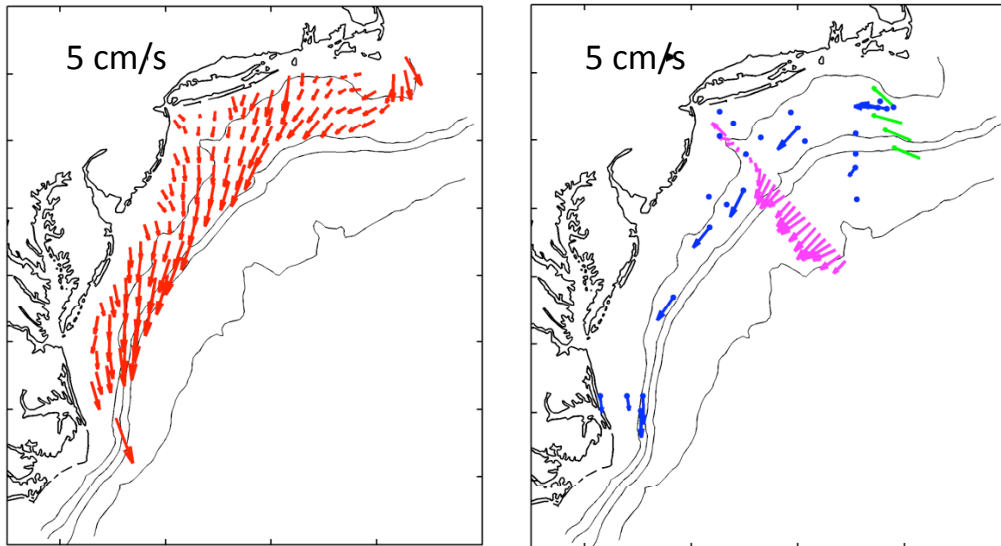
# Work flow for Near Real Time ESPreSSO 4DVar

## *Input pre-processing*

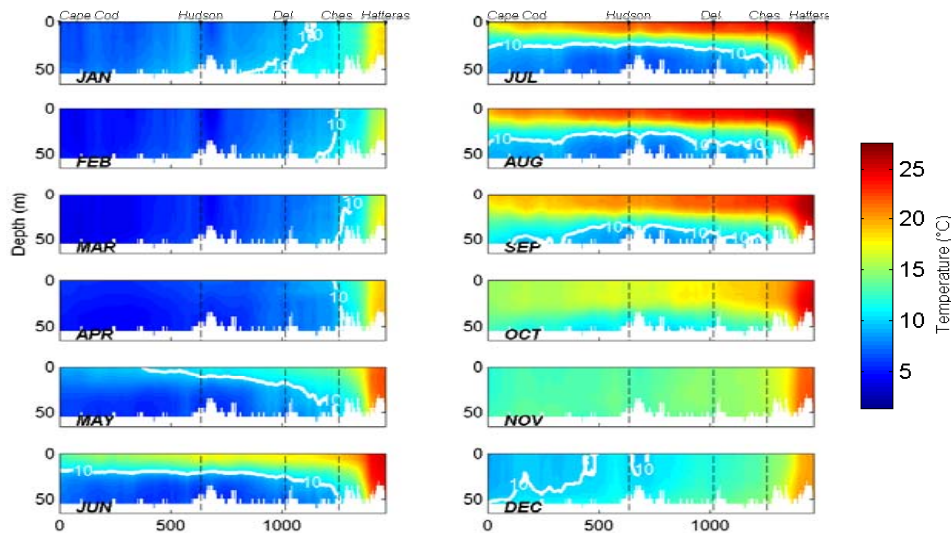
- RU CODAR de-tided (harmonic analysis) and binned to 5km
  - variance within bin & OI combiner expected  $u\_err$  (GDOP) used for QC
    - >> ROMS tide added to de-tided CODAR – reduces tide phase error contribution to cost function
- RU glider T,S averaged to ~5 km horiz. and 5 m vertical bins
  - need thermal lag salinity correction to statically unstable profiles
- AVHRR IR individual passes 6-8 per day
  - U. Del cloud mask; bin to 5 km resolution
  - REMSS daily SST OI combination of AVHRR, GOES, and microwave SST
- Altimetry along-track 5 km bins (with coastal corrections) from RADS
  - MDT from 4DVAR on climatological observations: 3D T,S, velocity (moorings, Oleander, CODAR), mean  $\tau^{wind}$ 
    - >> add ROMS tide solution to SSH
- USGS daily river flow is scaled to account for un-gauged watershed
- Open boundary data from HYCOM adjusted to remove mean bias (using 4DVAR climatological analysis)

# 4DVAR analysis of mean climatological ocean state

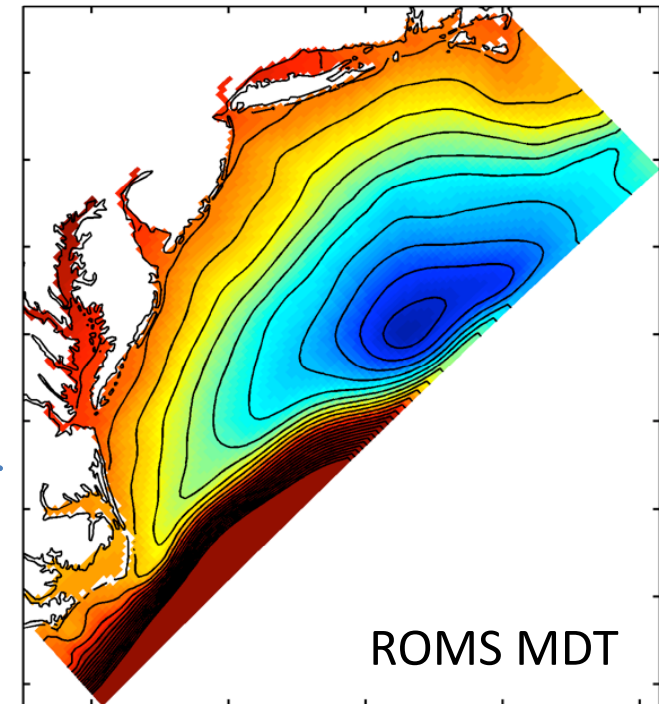
velocity obs. from CODAR (red), moorings (blue, green) and ship ADCP (magenta) ...



+ high-res regional T/S climatology

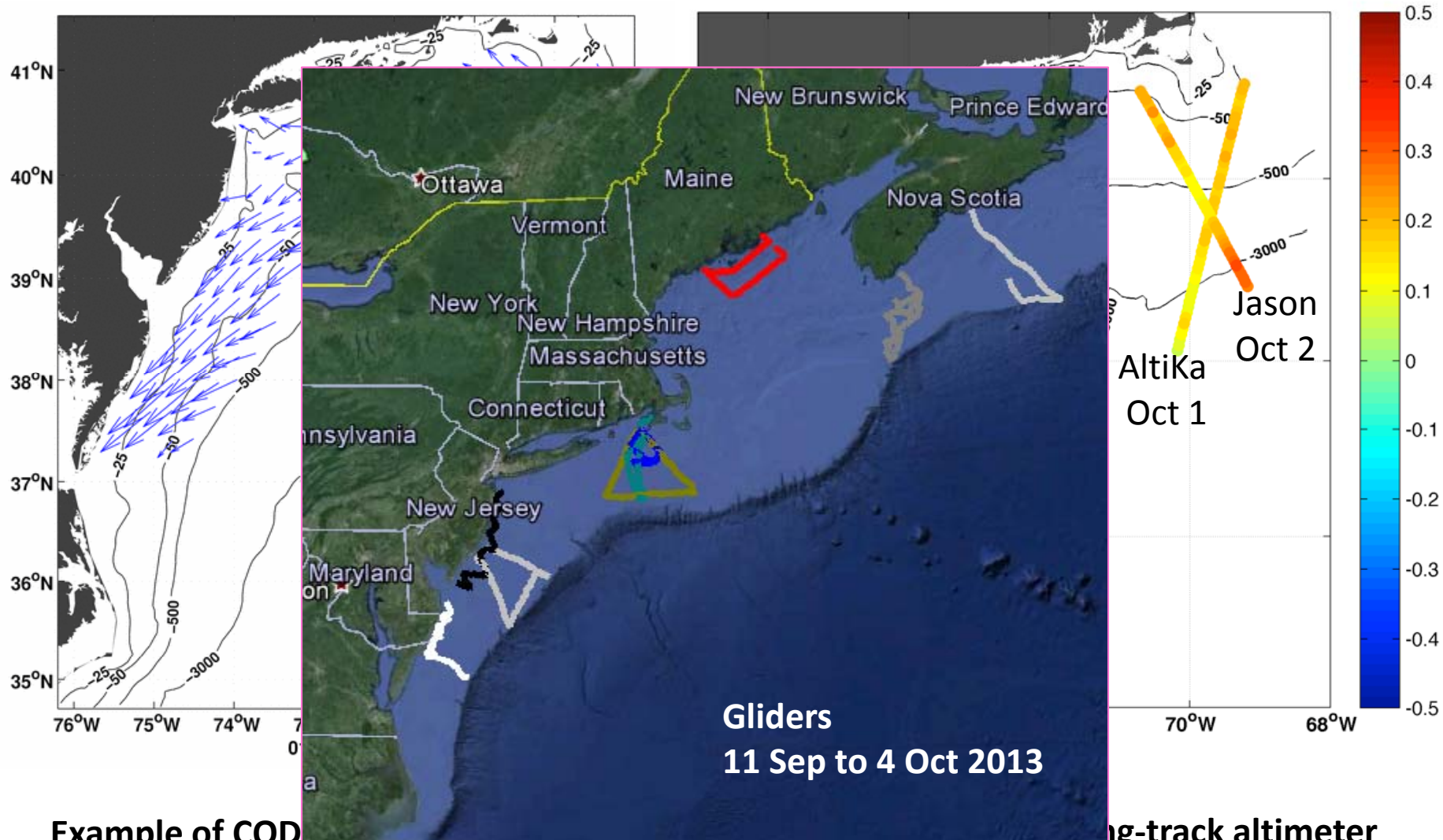


4DVAR seasonal and annual mean



ROMS MDT

Dynamically & kinematically adjusted MDT, and seasonal T,S,u,v for OBC bias removal

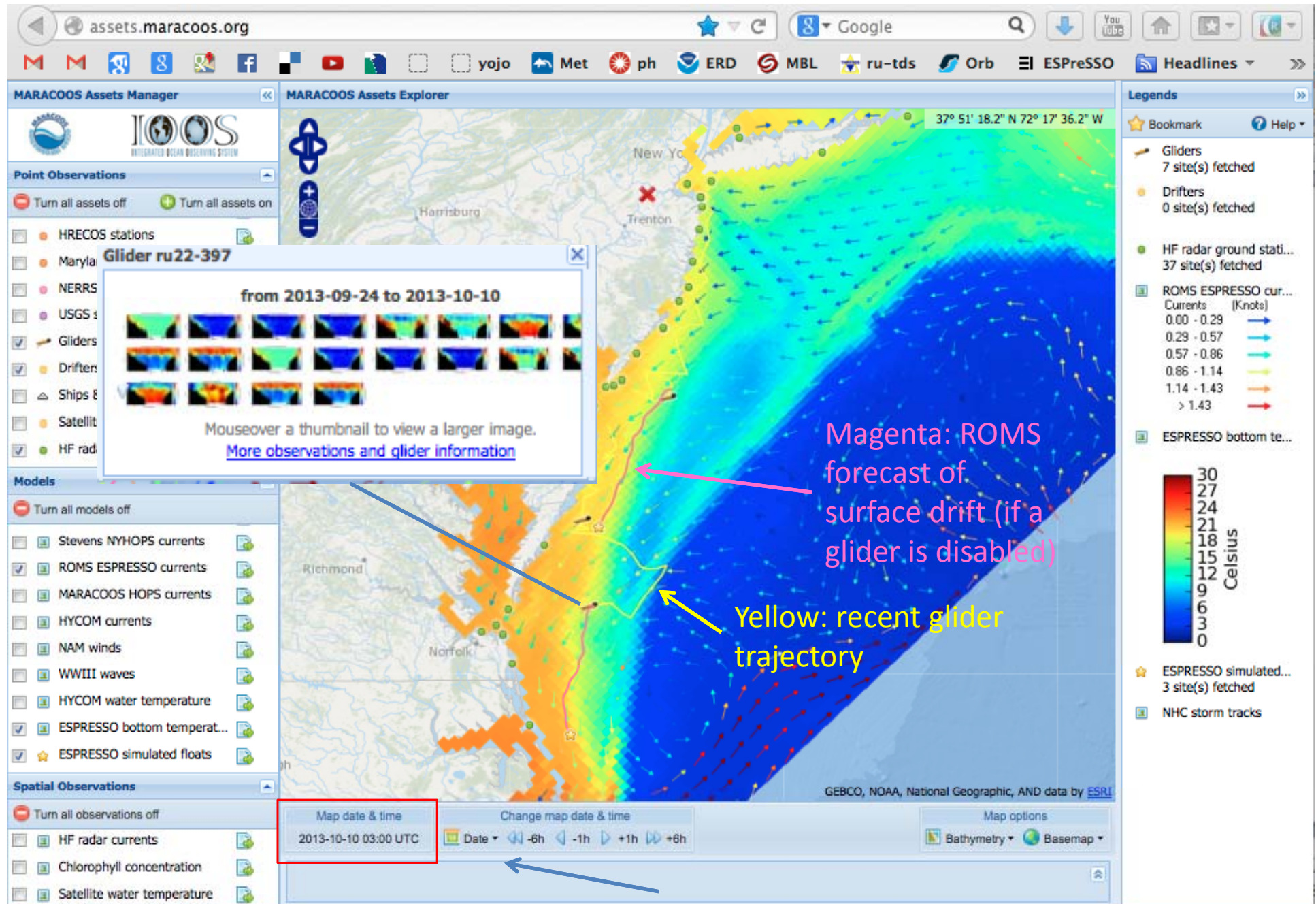


Example of COD control, binning and decimation to a set of independent observations.

Gliders  
11 Sep to 4 Oct 2013

Along-track altimeter sea level anomaly data during a single 3-day analysis window.

# MARACOOS [assets.maracoos.org](http://assets.maracoos.org) map server displays Near Real Time data and models





Output goes to THREDDS server Forecast Model Run Collection\* (FMRC) at [tds.marine.rutgers.edu/thredds](https://tds.marine.rutgers.edu/thredds)

\*[unidata.ucar.edu](https://unidata.ucar.edu)

The screenshot shows a web browser window displaying a THREDDS catalog page. The address bar shows the URL: [tds.marine.rutgers.edu:8080/thredds/roms/espreso/catalog](https://tds.marine.rutgers.edu:8080/thredds/roms/espreso/catalog). The main content area lists several datasets, including 'ROMS ESPRESSO Real-Time Operational IS4DVAR', 'ESPRESSO Real-Time v2 Averages Best Availa', 'ESPRESSO Real-Time v2 Averages Runs and Ot', 'ESPRESSO Real-Time v2 History Best Availab', 'ESPRESSO Real-Time v2 History Runs and Other Collections/', 'Floats/', 'Files/', 'ROMS ESPRESSO 2006-2012 IS4DVAR reanalysis', 'Averages', 'History', 'ROMS ESPRESSO 2009-2012 Nonassimilative', 'History', 'ROMS ESPRESSO 2006-2012 IS4DVAR', 'Averages', 'History', and 'UNIDATA FMRC test 1/'. A blue box highlights the 'ESPRESSO Real-Time v2 History Runs and Other Collections/' dataset, and a 'Dataset' popup window is open, showing its contents: 'Forecast Model Run Collection (2D time coordinates)', 'Forecast Model Run/', 'Constant Forecast Offset/', and 'files/'.

Dataset	Forecast Model Run Collection (2D time coordinates)
ESPRESSO Real-Time v2 History Runs and Other Collections	Forecast Model Run/
	Constant Forecast Offset/
	files/

# Forecast Model Run: Output from a single analysis and forecast

The screenshot shows a web browser interface for a file repository. The address bar indicates the URL: `tds.marine.rutgers.edu:8080/thredds/roms/espesso/catalog`. The main content area displays a directory tree with the following items:

- ROMS ESPRESSO Real-Time Operational IS4DVAR
- ESPRESSO Real-Time v2 Averages Best Availa
- ESPRESSO Real-Time v2 Averages Runs and Ot
- ESPRESSO Real-Time v2 History Best Availab
- ESPRESSO Real-Time v2 History Runs and Other Collections/
- Floats/
- Files/

Two callout boxes provide a detailed view of the selected directory:

**Callout 1 (Top):** Shows the directory structure for `ESPRESSO Real-Time v2 History Runs and Other Collections`. It contains a sub-directory `Forecast Model Run Collection (2D time coordinates)`, which includes:

- Forecast Model Run/
- Constant Forecast Offset/
- files/

**Callout 2 (Bottom):** Shows the contents of the `Forecast Model Run` directory, listing several individual run files with their full paths and timestamps:

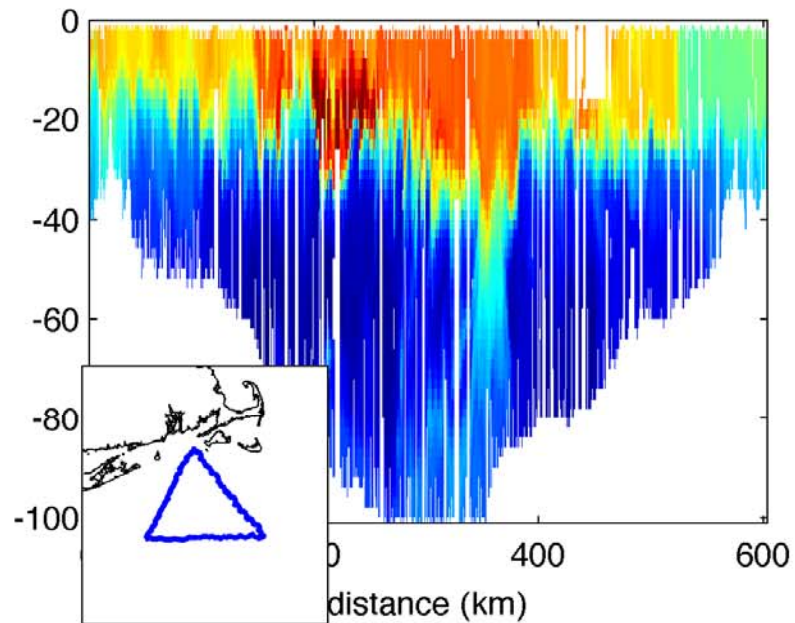
- ESPRESSO Real-Time v2 History Runs and Other Collections\_RUN\_2013-09-29T00:00:00Z
- ESPRESSO Real-Time v2 History Runs and Other Collections\_RUN\_2013-09-28T00:00:00Z
- ESPRESSO Real-Time v2 History Runs and Other Collections\_RUN\_2013-09-27T00:00:00Z
- ESPRESSO Real-Time v2 History Runs and Other Collections\_RUN\_2013-09-26T00:00:00Z
- ESPRESSO Real-Time v2 History Runs and Other Collections\_RUN\_2013-09-25T00:00:00Z
- ESPRESSO Real-Time v2 History Runs and Other Collections\_RUN\_2013-09-24T00:00:00Z
- ESPRESSO Real-Time v2 History Runs and Other Collections\_RUN\_2013-09-23T00:00:00Z

# Constant Forecast Offset: Every realization of a given date from all forecasts

The screenshot shows a web-based file explorer interface. The main directory view on the left lists several folders, including 'ROMS ESPRESSO Real-Time Operational IS4DVAR', 'ESPRESSO Real-Time v2 Averages Best Availa', 'ESPRESSO Real-Time v2 Averages Runs and Ot', 'ESPRESSO Real-Time v2 History Best Availab', and 'ESPRESSO Real-Time v2 History Runs and Other Collections/'. The 'ESPRESSO Real-Time v2 History Runs and Other Collections/' folder is selected, and a callout box titled 'Dataset' shows its contents: 'Forecast Model Run Collection (2D time coordinates)', 'Forecast Model Run/', 'Constant Forecast Offset/', and 'files/'. A second callout box, also titled 'Dataset', shows the contents of the 'Constant Forecast Offset' folder, listing files with offsets: 'ESPRESSO Real-Time v2 History Runs and Other Collections\_Offset 0.0hr', 'ESPRESSO Real-Time v2 History Runs and Other Collections\_Offset 1.0hr', 'ESPRESSO Real-Time v2 History Runs and Other Collections\_Offset 2.0hr', 'ESPRESSO Real-Time v2 History Runs and Other Collections\_Offset 3.0hr', 'ESPRESSO Real-Time v2 History Runs and Other Collections\_Offset 4.0hr', 'ESPRESSO Real-Time v2 History Runs and Other Collections\_Offset 5.0hr', 'ESPRESSO Real-Time v2 History Runs and Other Collections\_Offset 6.0hr', and 'ESPRESSO Real-Time v2 History Runs and Other Collections\_Offset 7.0hr'.

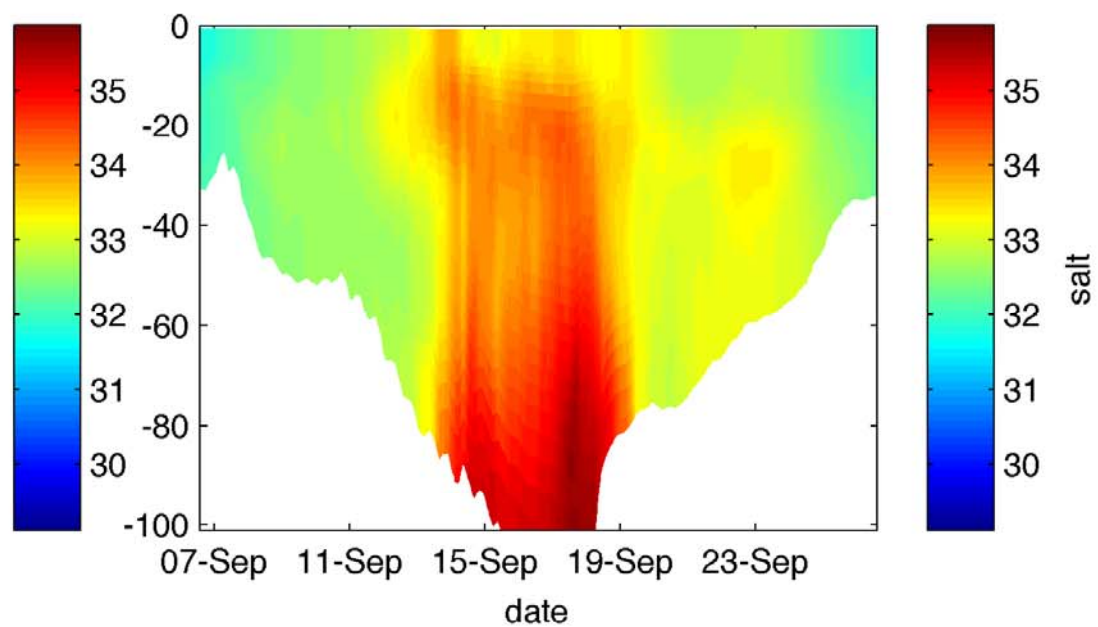
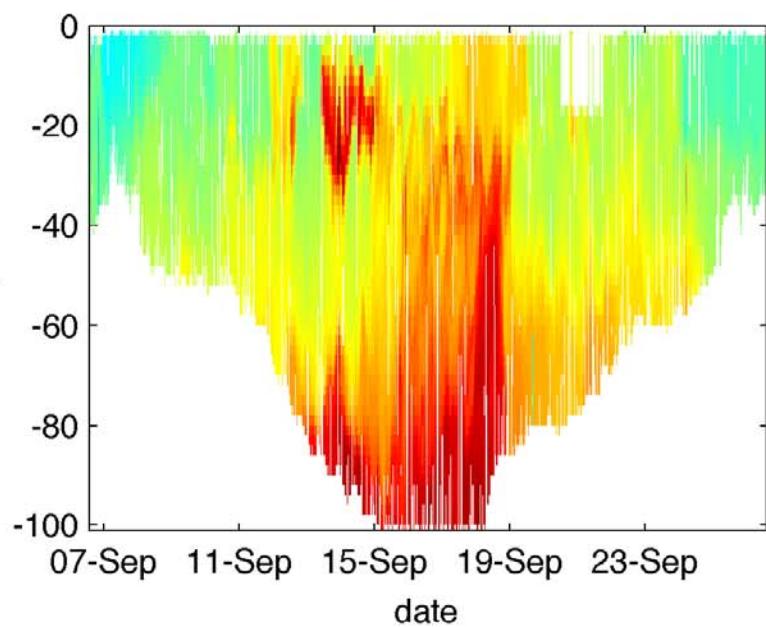
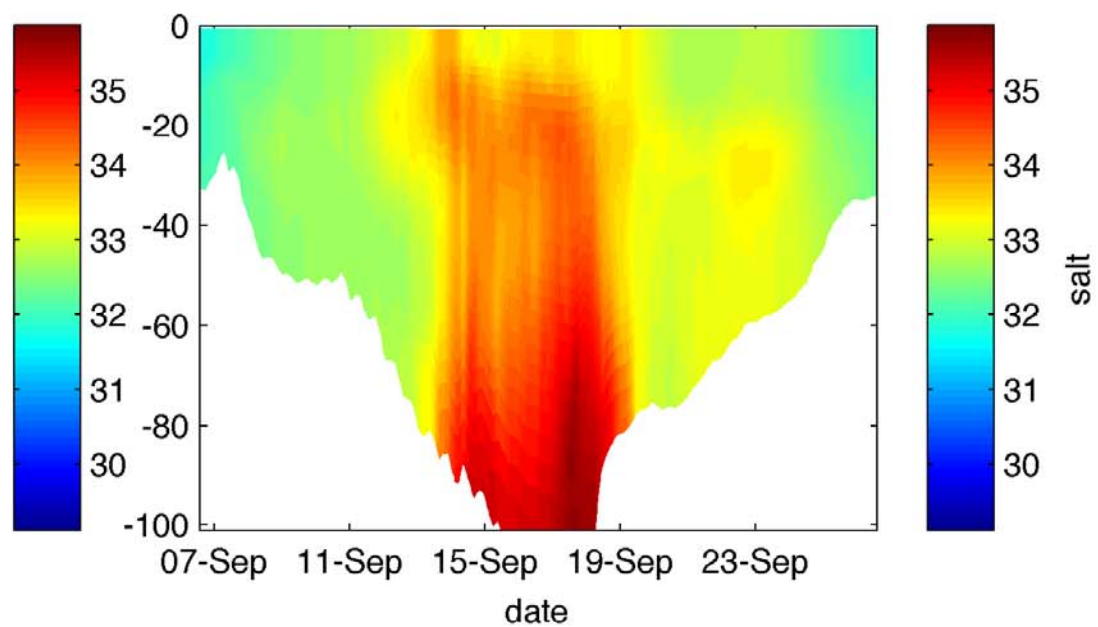
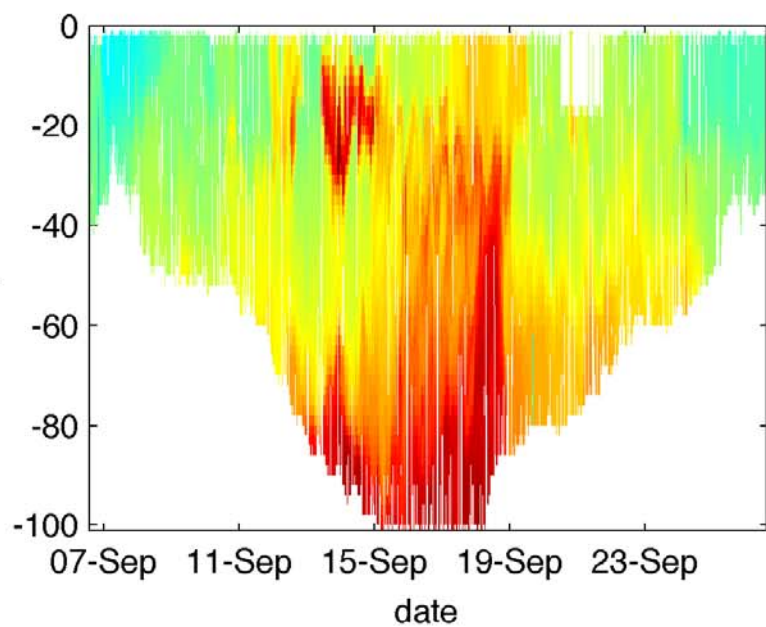
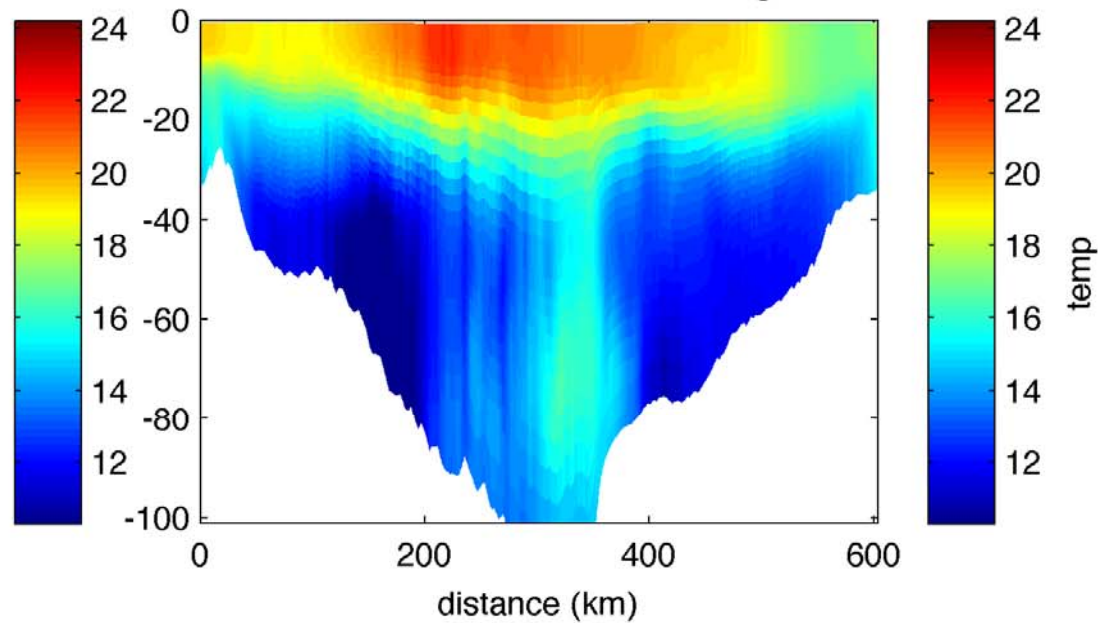
## Glider observations

20130906T000000\_20130926T000000

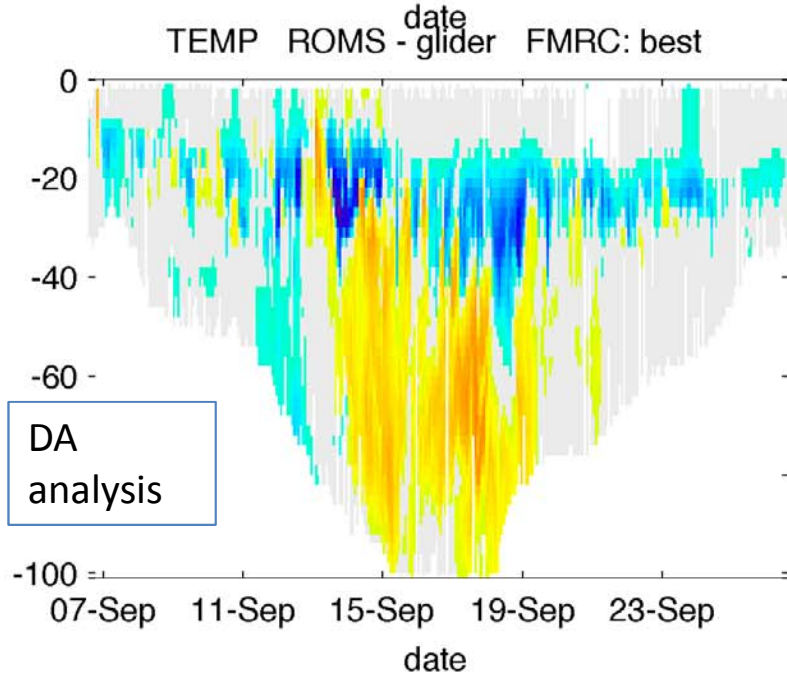
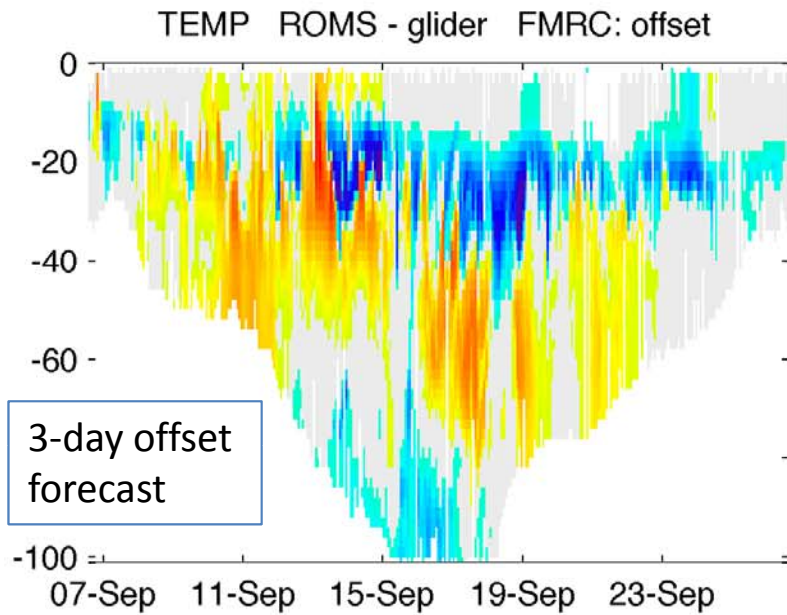


## ROMS IS4DVAR analysis

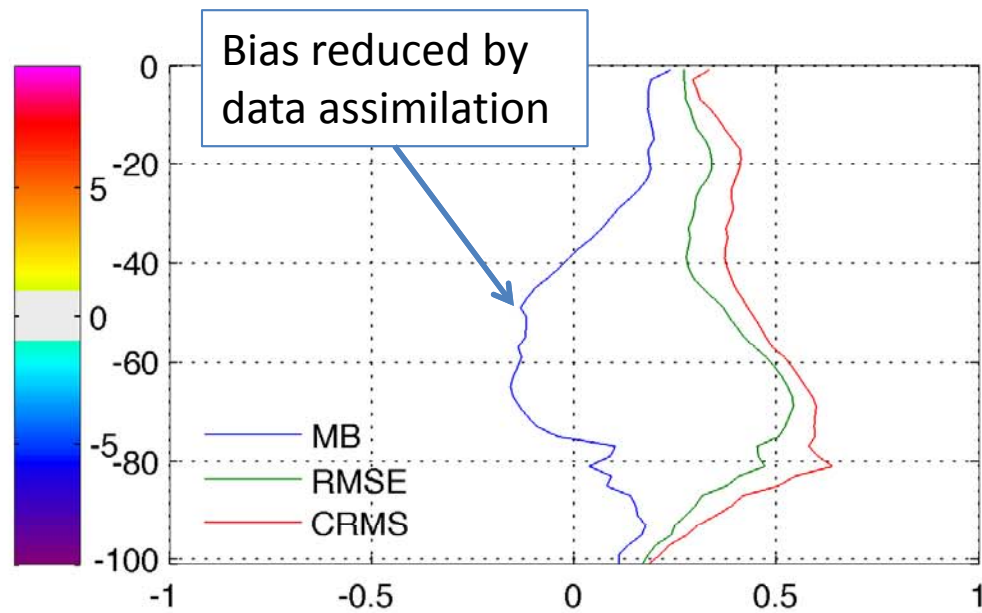
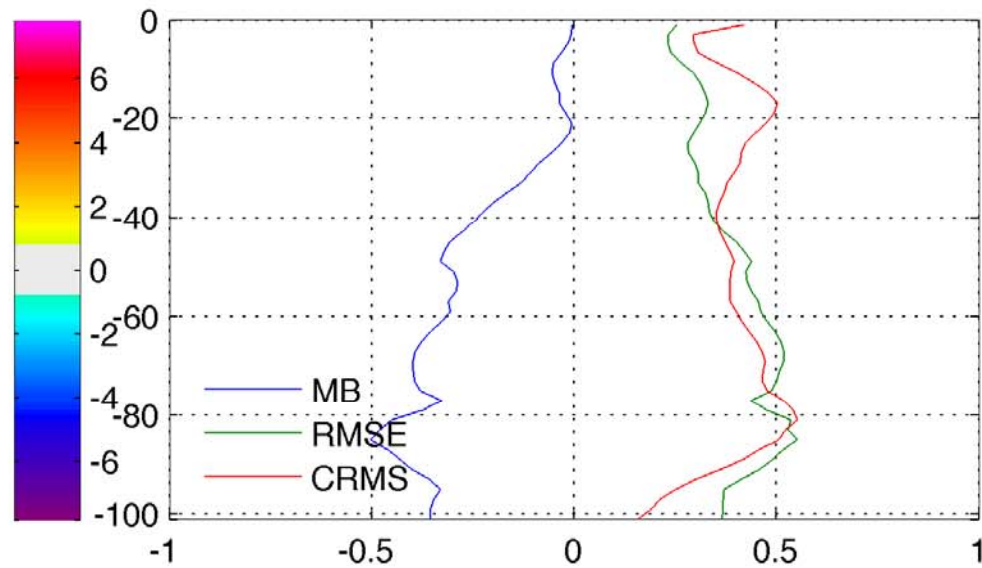
ESPRESSO\_Real-Time\_v2\_Averages



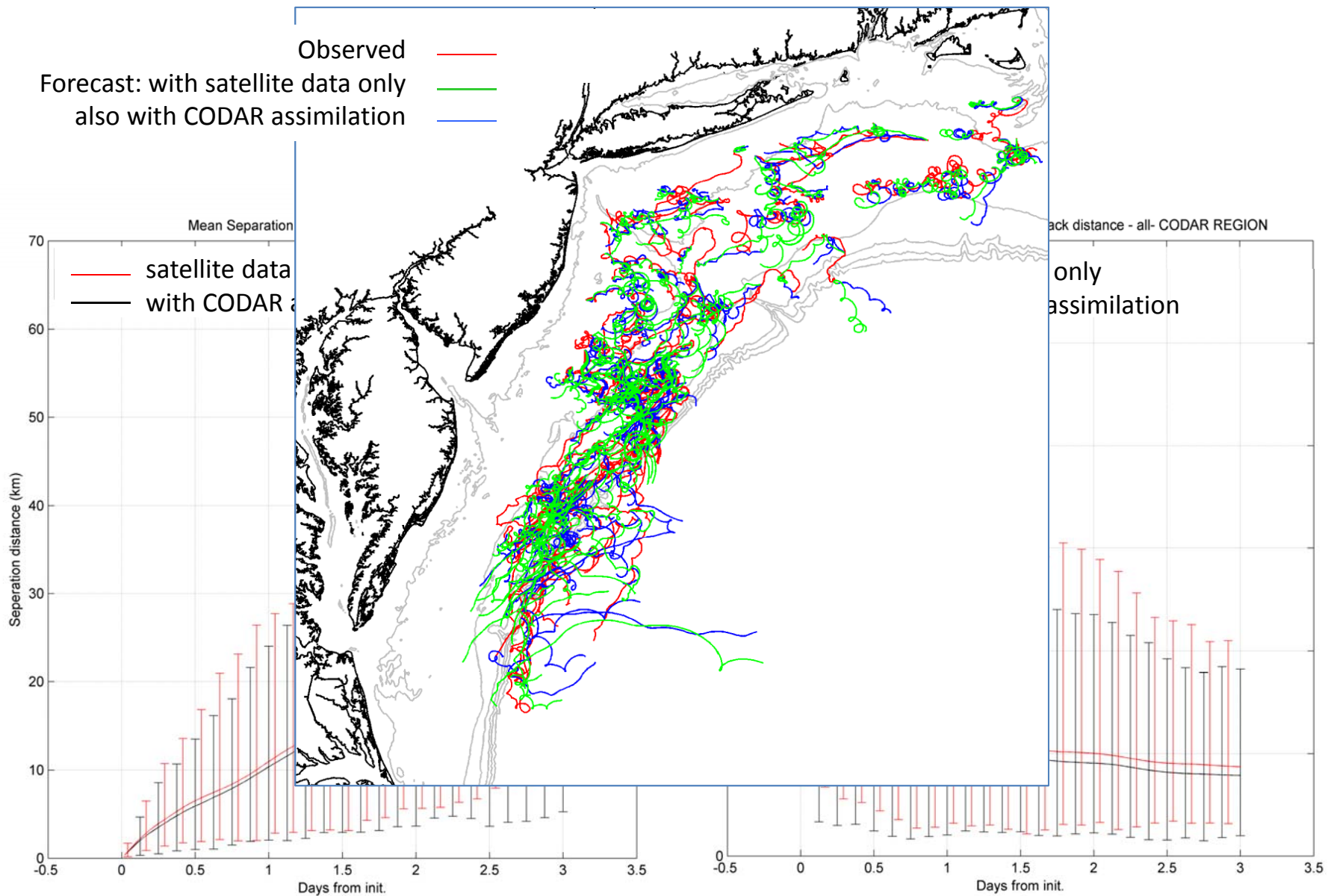
### Model minus glider obs.



### Skill score vs. depth

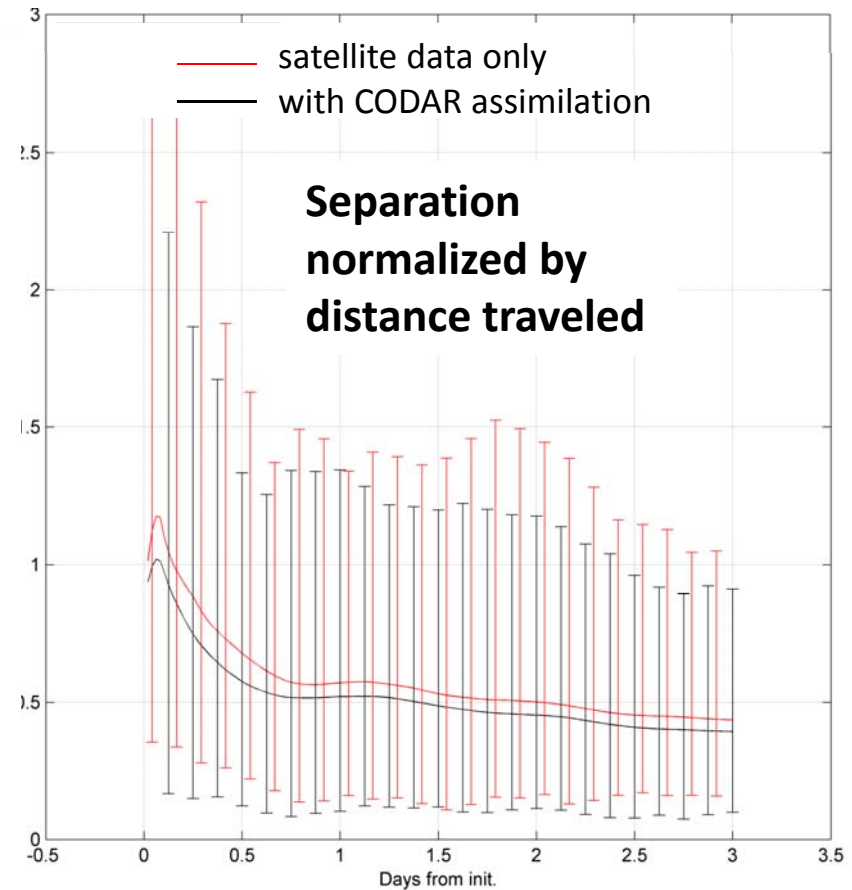
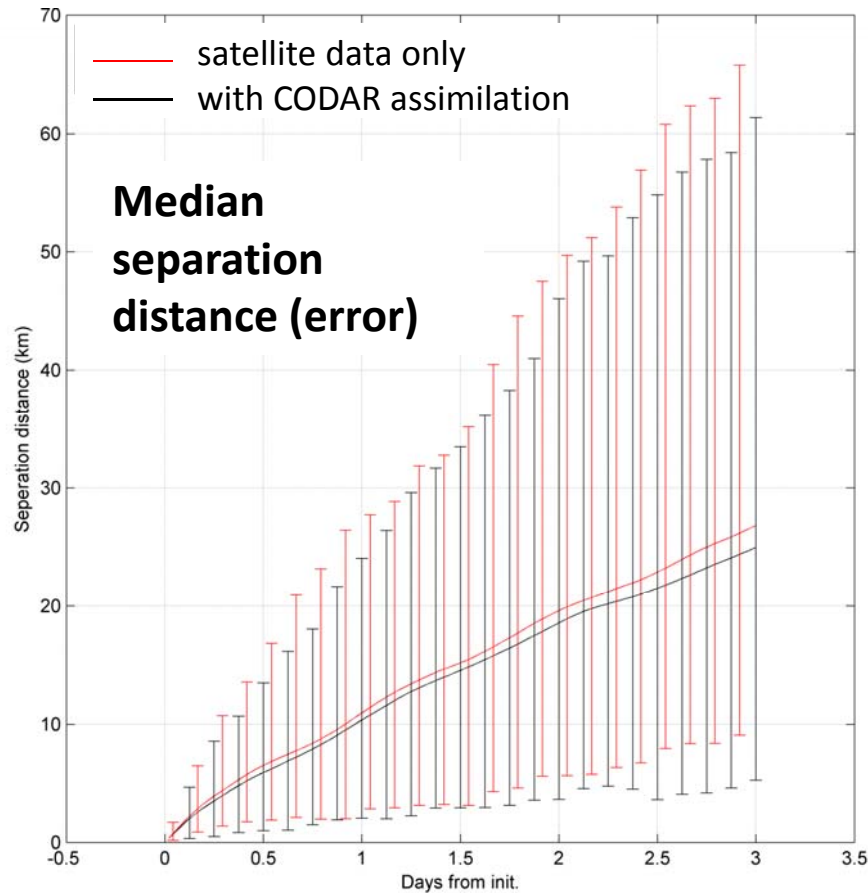
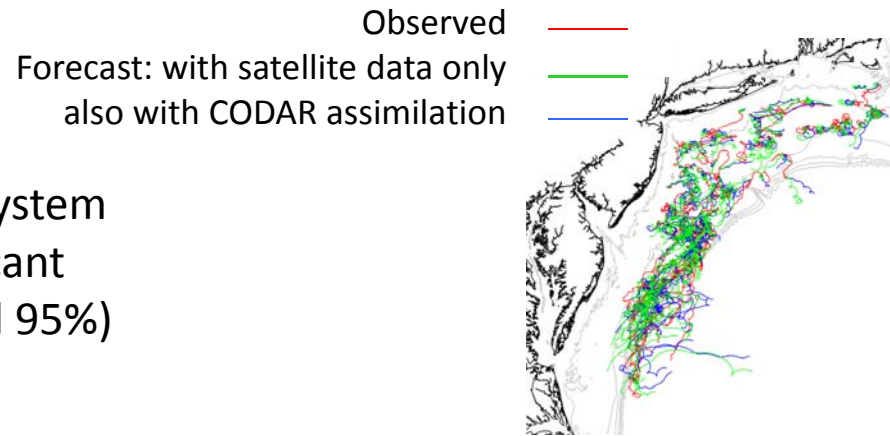


# Lagrangian forecast skill w.r.t. U.S. Coast Guard (SLDMB) drifters



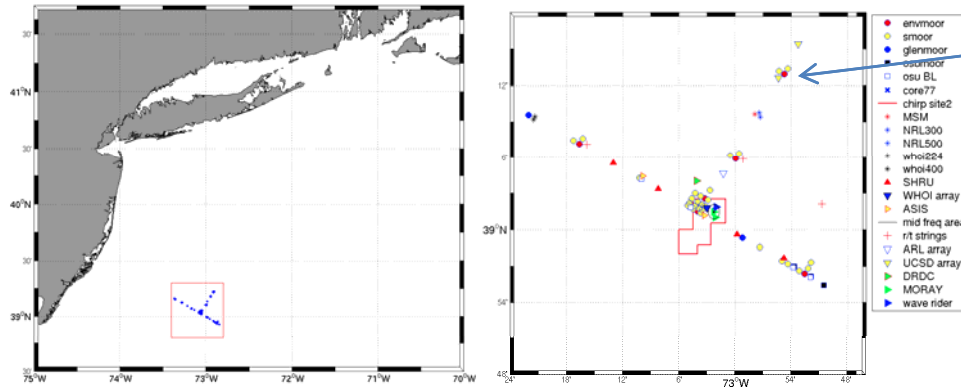
# Lagrangian forecast skill w.r.t. U.S. Coast Guard (SLDMB) drifters

Addition of HF-radar (CODAR) to assimilation system gives modest error reduction, but more significant reduction in uncertainty (error bars are 5% and 95%)



# Sub-surface velocity analysis skill

## Shallow Water 2006

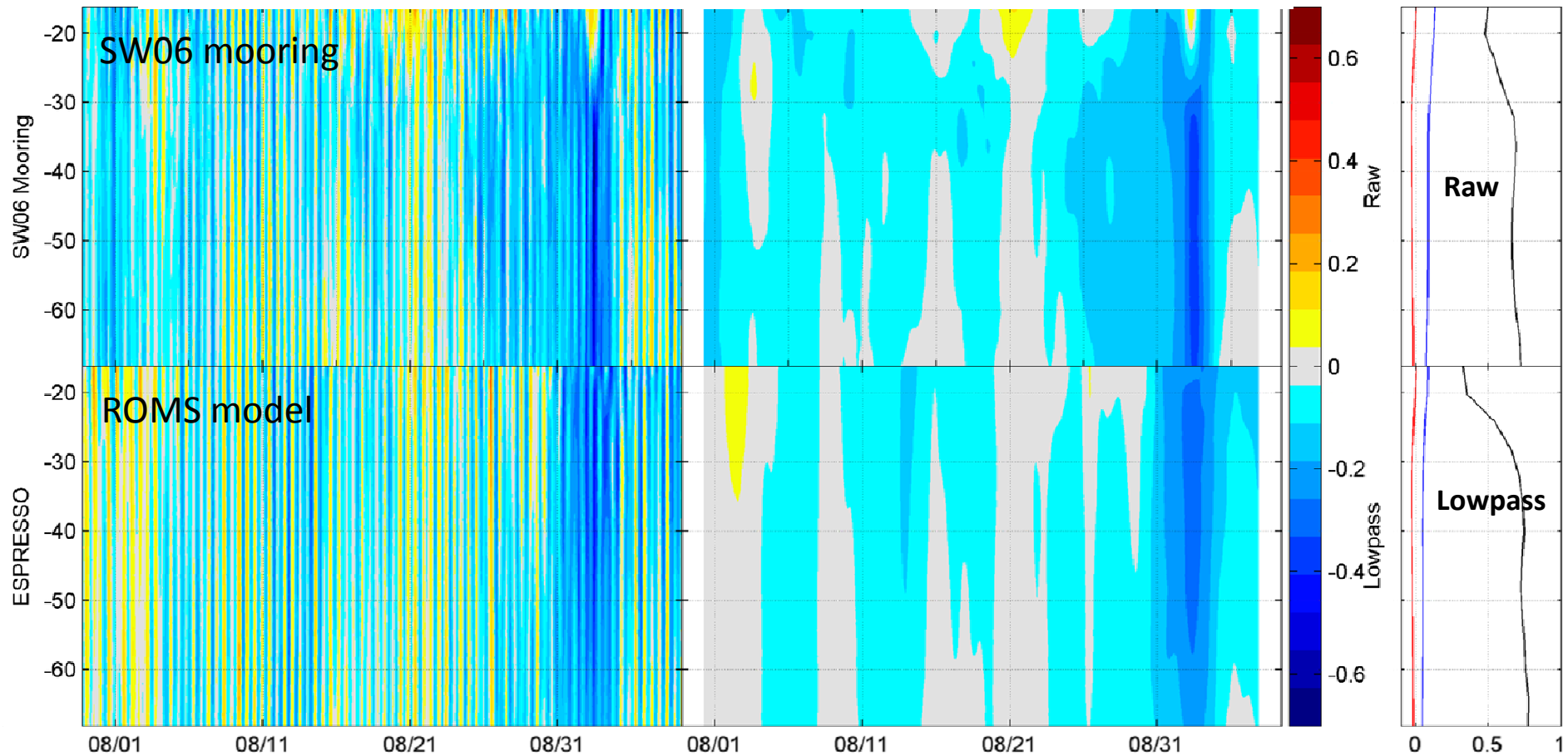


SW06 mooring 32  
N-S velocity  
skill scores

R (corr. coeff.)  
BIAS ( $m s^{-1}$ )  
CRMS ( $m s^{-1}$ )

Raw (hourly)

Lowpass (33-hr cutoff)

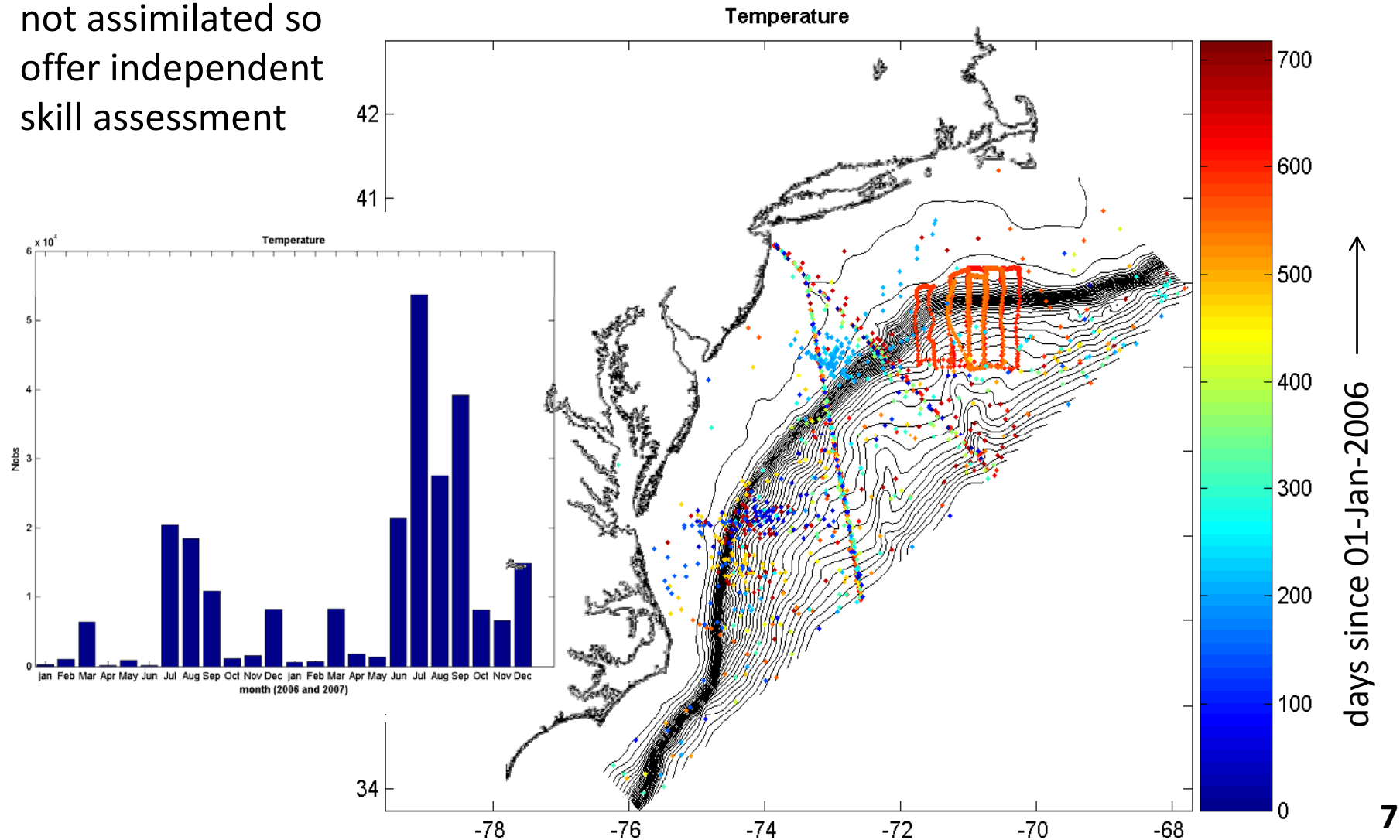




# Sub-surface T/S analysis and forecast skill

*In situ* T and S observations are not assimilated so offer independent skill assessment

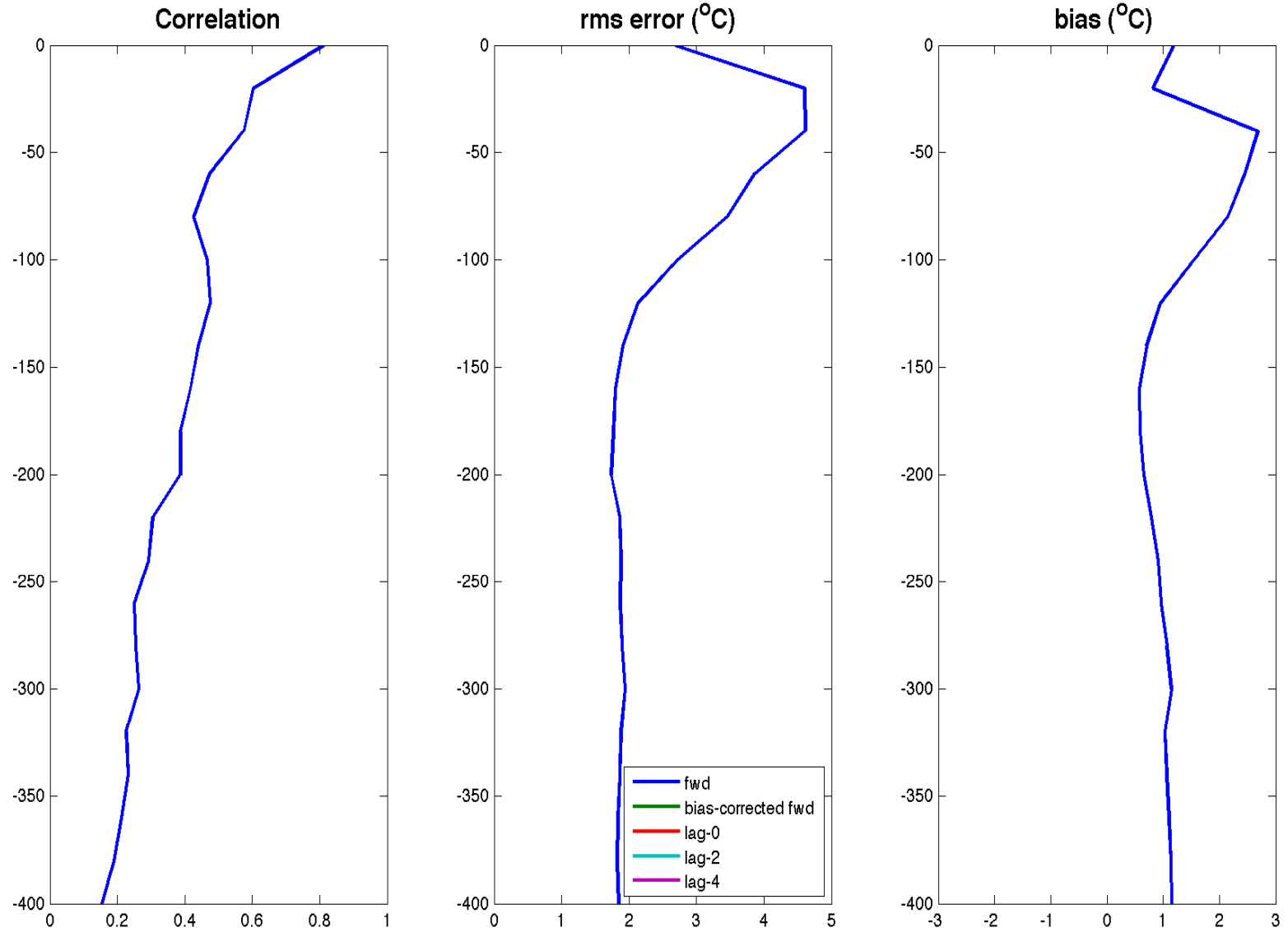
There is a sizeable archive of observatory data from CTD, gliders and XBTs for 2006 (SW06) and 2007



Analysis/forecast skill with respect to subsurface OBS that are NOT assimilated

Temperature

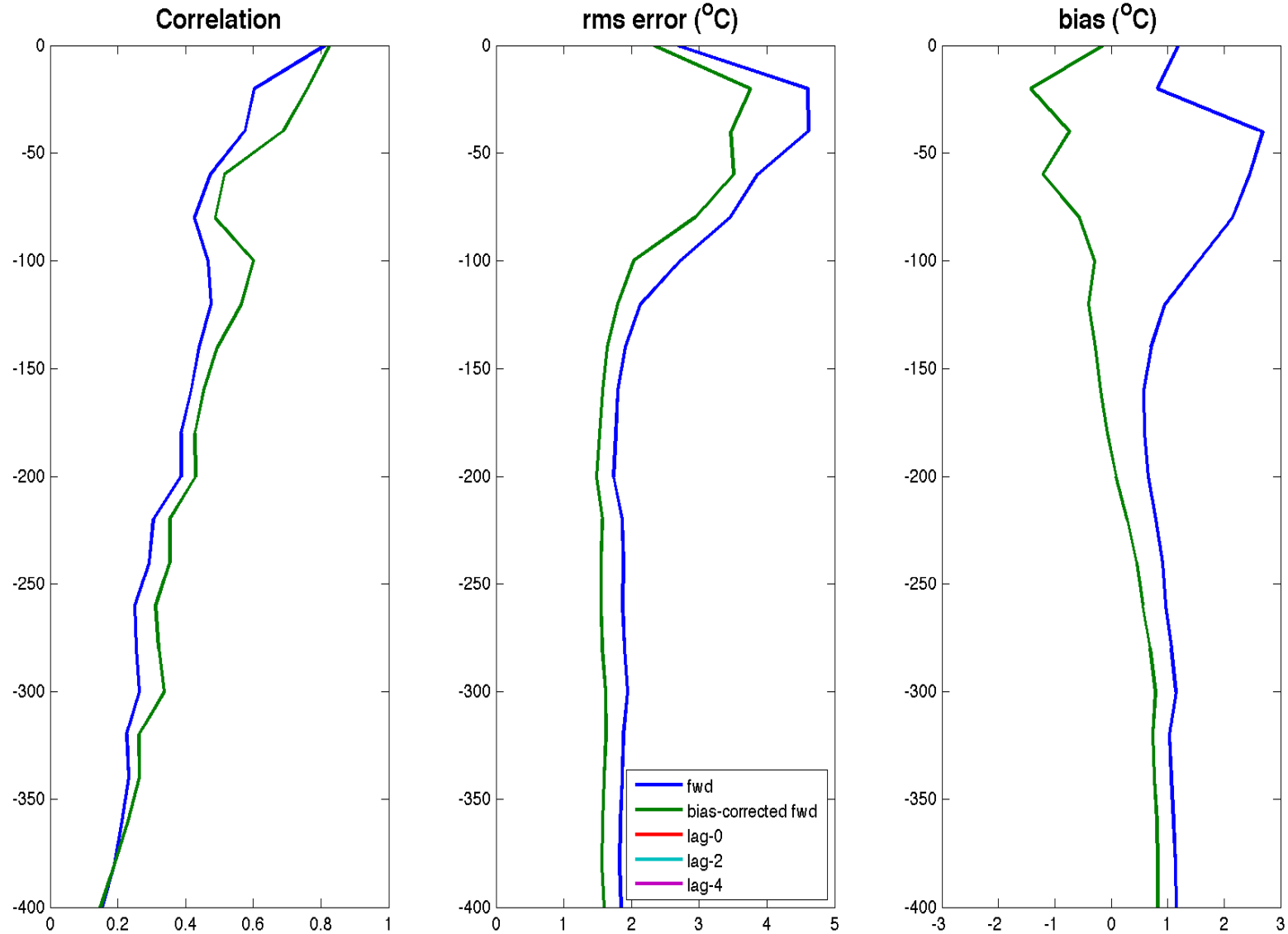
**Forward model**



Analysis/forecast skill with respect to subsurface OBS that are NOT assimilated

Temperature

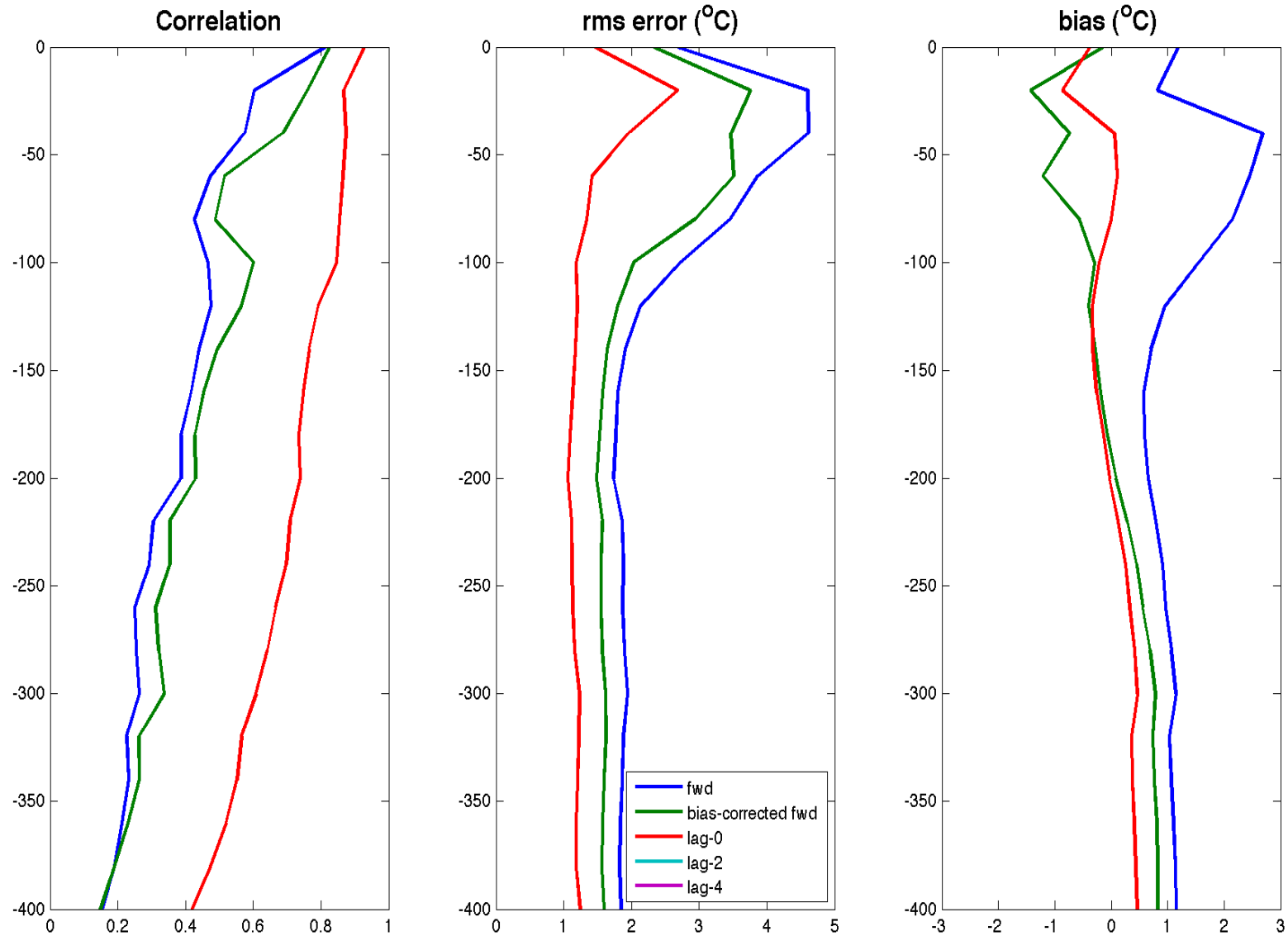
**Forward model after bias removal**



Analysis/forecast skill with respect to subsurface OBS that are NOT assimilated

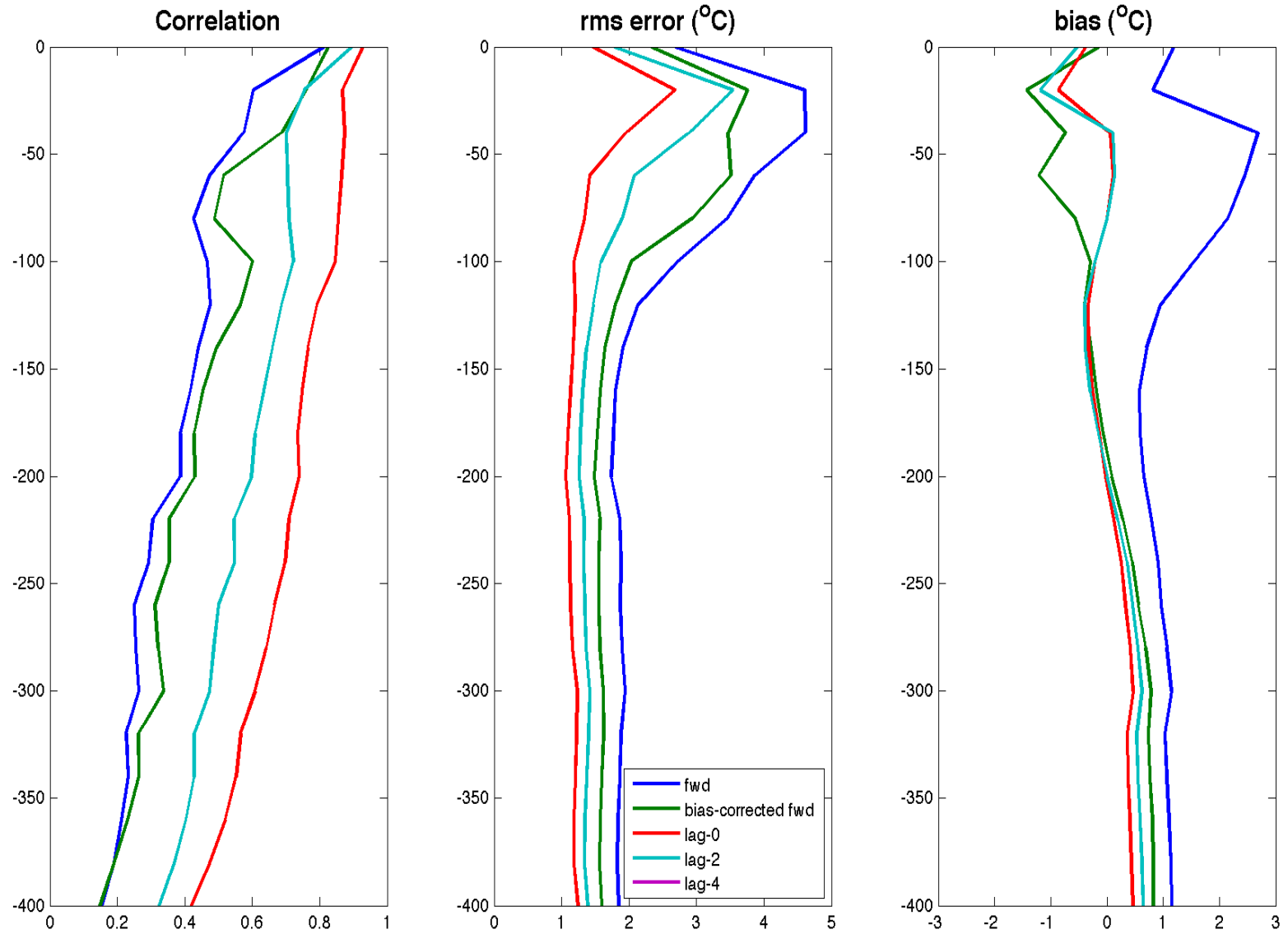
Temperature

Data assimilation analysis/hindcast



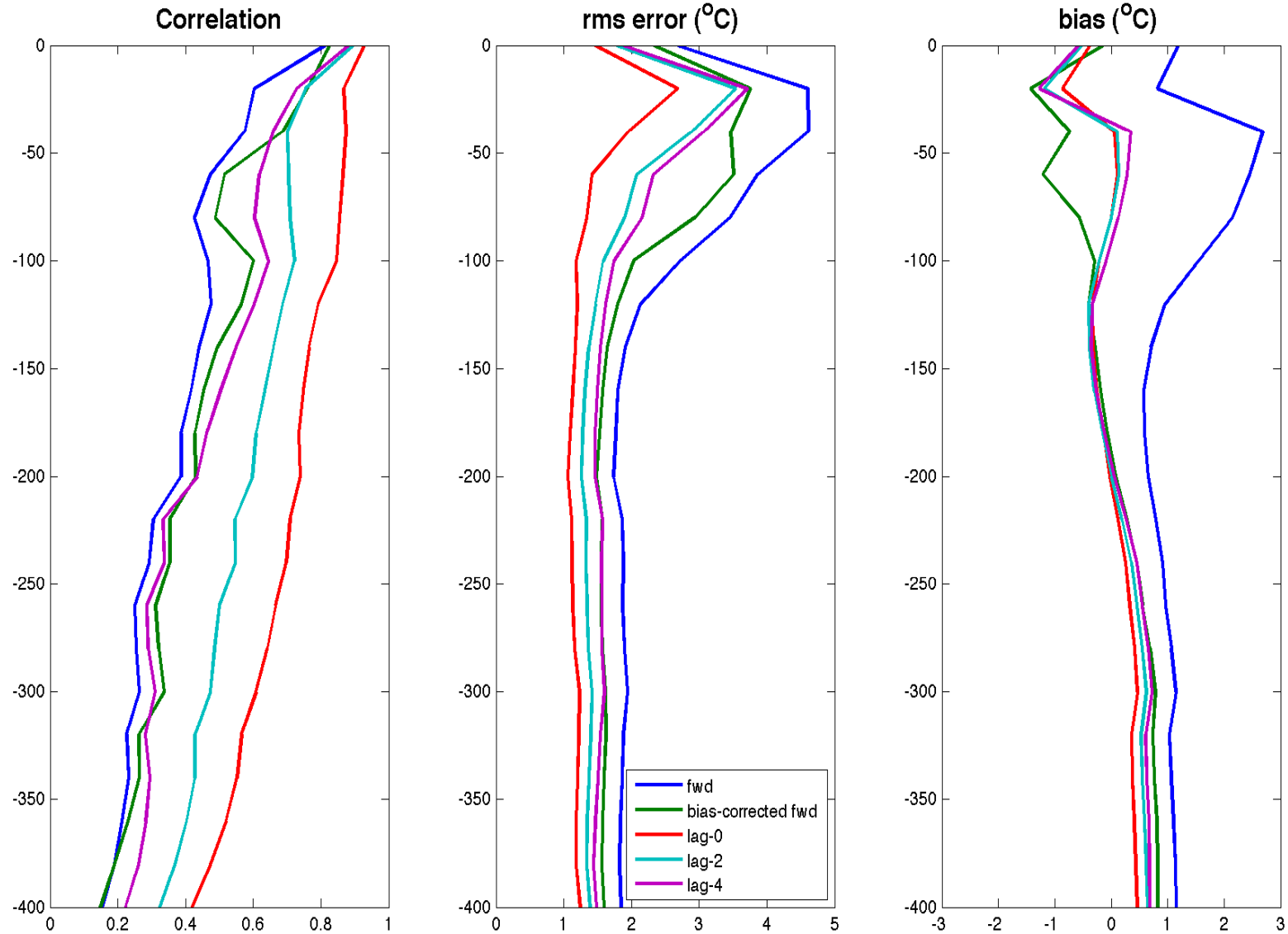
Analysis/forecast skill with respect to subsurface OBS that are NOT assimilated

Temperature  
2-day forecast



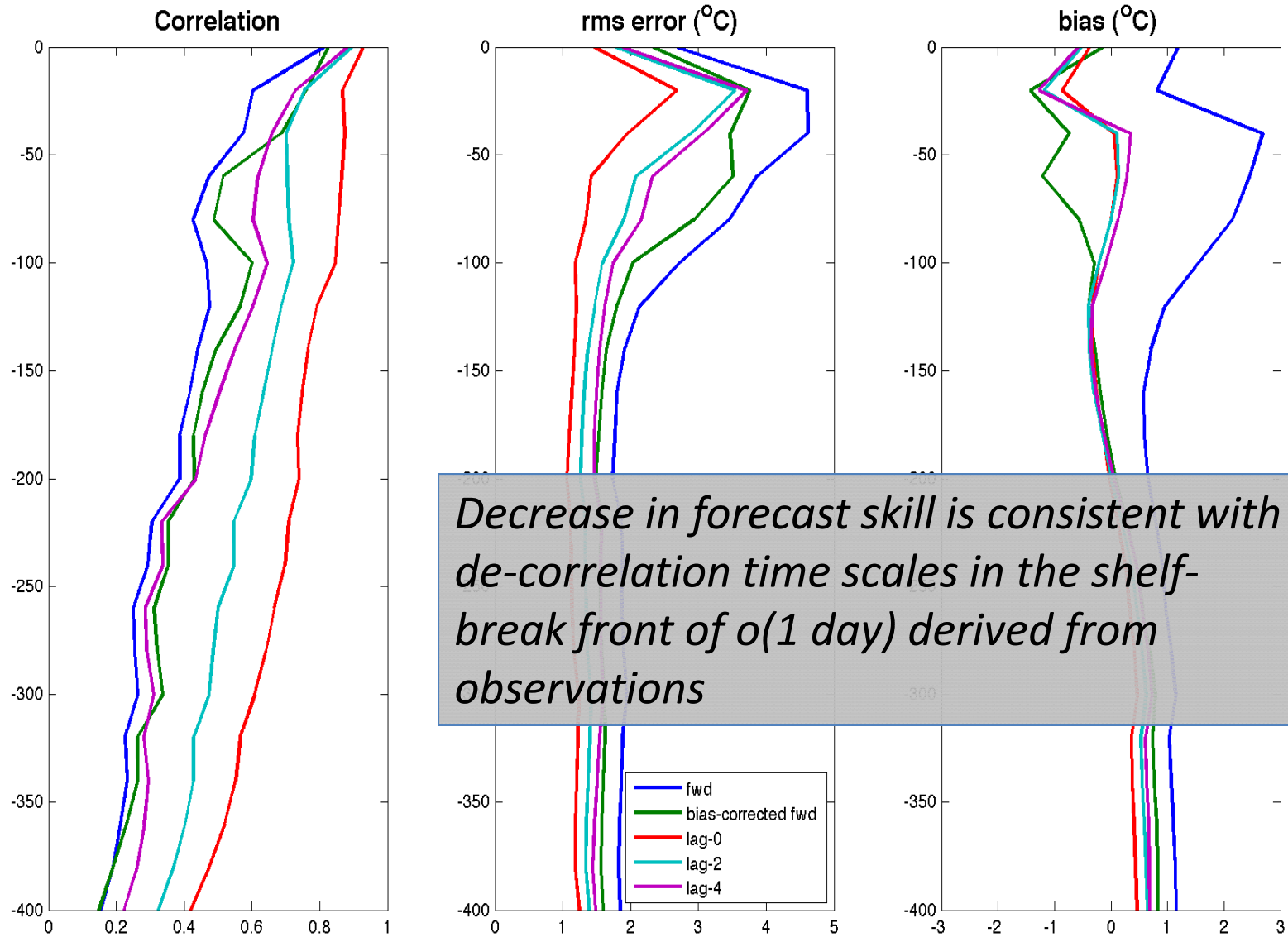
Analysis/forecast skill with respect to subsurface OBS that are NOT assimilated

Temperature  
4-day forecast



Analysis/forecast skill with respect to subsurface OBS that are NOT assimilated

Temperature

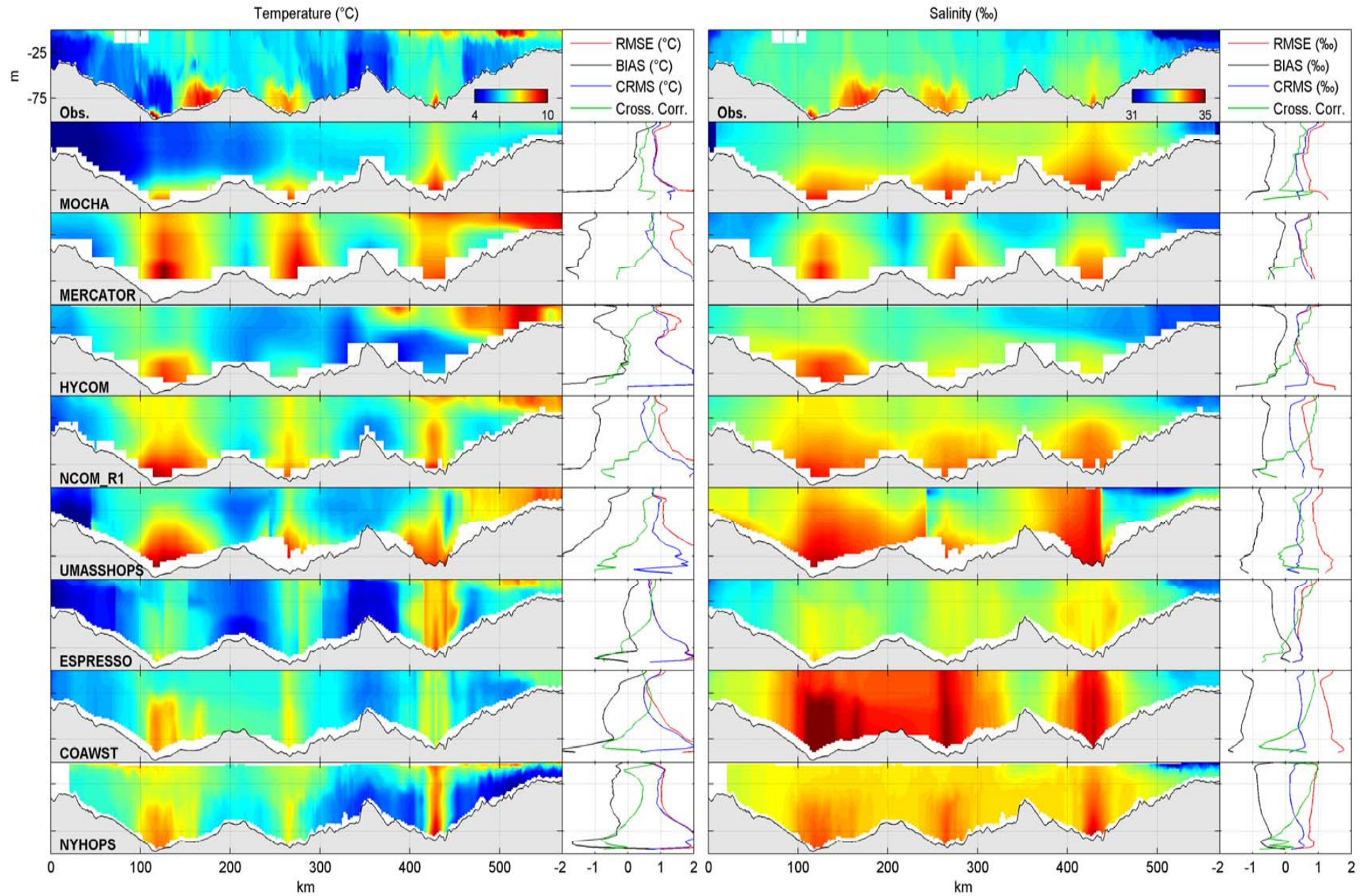


*Decrease in forecast skill is consistent with de-correlation time scales in the shelf-break front of o(1 day) derived from observations*



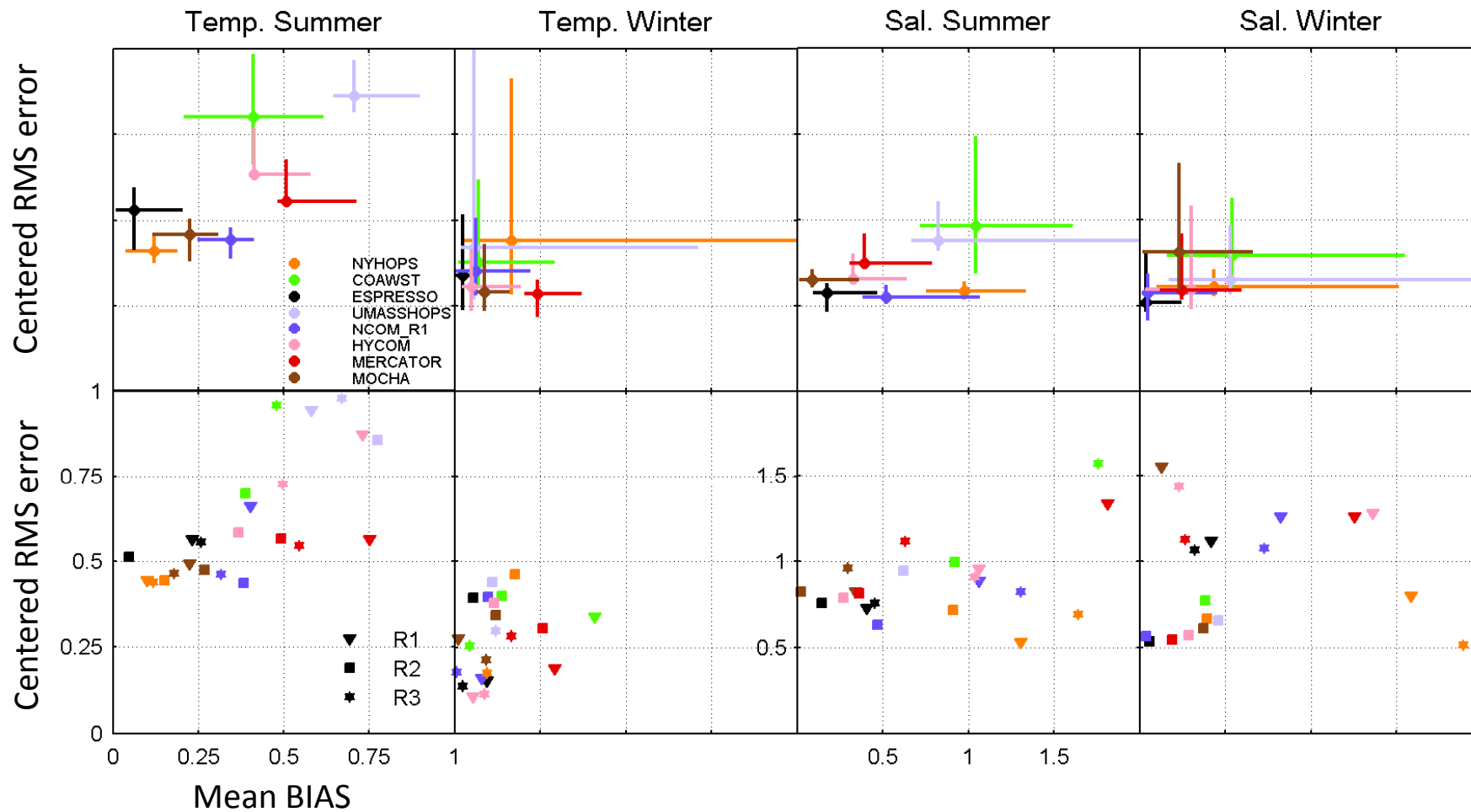


# MAB March 2010



# Multi-model Skill Assessment: 7 real time models of the Mid-Atlantic Bight

Ensemble Mean BIAS (x-axis) and Centered RMS error (y-axis)  
Distance from origin is Root Mean Squared Error (RMSE)



# Summary

- Rutgers ROMS ESPreSSO 4DVAR uses all available data from a modern coastal ocean observing system
  - Satellite SSH and SST, HF-radar, gliders, Argo, GTS XBT/CTD
  - More and diverse data is better
  - *Modest pre-processing for QC, binning to independent obs.*
  - *Bias removal essential: use mean ocean state from 4DVAR-based climatology*
  - *Data ingest exploits web services (OPeNDAP/THREDDS) and interoperability of data conventions (CDM, CF-conventions, NetCDF/HDF)*
- Useful skill for real-time applications
  - 4 days for temperature and salinity; 1-2 days for velocity
- *Output of full model solution to THREDDS/FMRC Forecast Model Run Collection*
  - Available to high-level users servicing numerous end-users
- Future developments
  - Adjoint sensitivity and Observation Impact analysis using variational tools
  - representer-based observing system design/operation
  - Nested 4DVAR; Coupling to waves and meteorology