Effective Assimilation of Altimeter observations by Cheng Da (UMD)

Preliminary notes

We used a CFS-LETKF (Travis Sluka) with WCDA.

What did we use as truth?: We use independent (not used in the DA) ocean temperature and salinity profiles during the same experiment period to verify the analysis.

ADT: Altimeter Dynamic Topography= Sea Surface Height=SSH

SLA: Sea Level Anomaly (Usually this is the variable that is assimilated)

SLA=ADT-MDT where MDT=Mean Dynamical Topography (from long model integrations). Assimilating SLA has not yet worked well (Travis Sluka).

Introduction of the Altimeter ADT Obs

- One special thing of our experiments is that we assimilate the Altimeter Absolute Dynamic Topography (ADT), instead of the Sea Level Anomaly (SLA) obs. SLA Assimilation has never been really successful according to Travis Sluka.

- Why effective SLA assimilation is difficult?

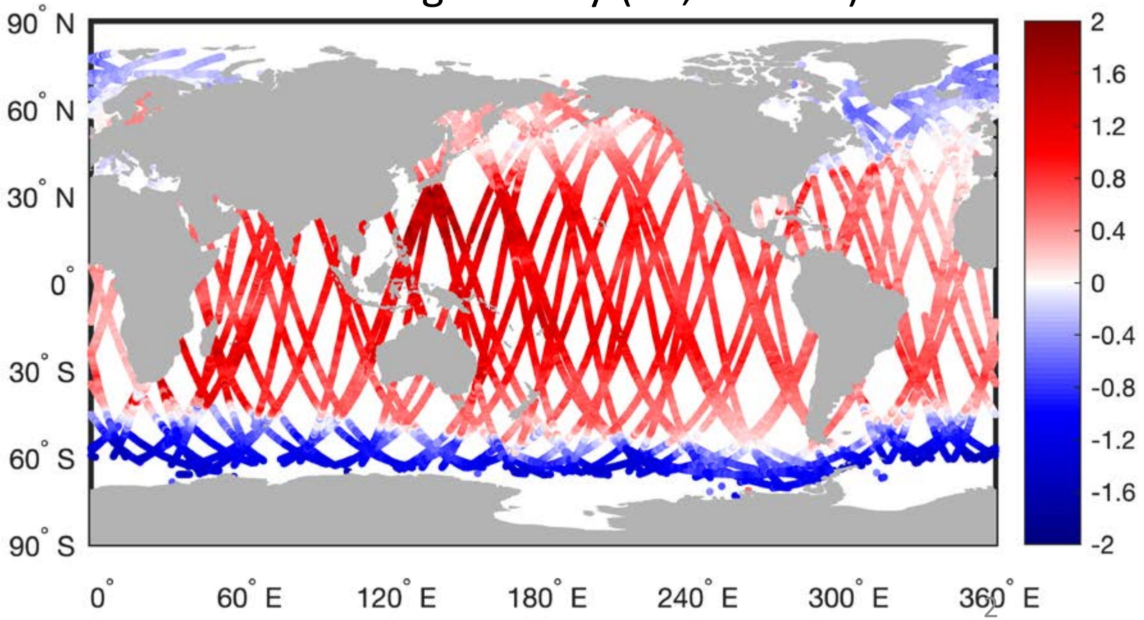
Relationship between ADT and SLA: SLA = ADT - Mean Dynamic Topography

and the Mean Dynamic Topography is calculated by averaging a very long realistic model integration. In practice the choice of the model has a major influence on SLA calculation.

- Our experiment is from June 1 to June 14 in 2006. We collect ADT obs from 3 satellites: GFO, Jason-1, and Envisat-1

The figure shows the typical distribution of ADT in one day.

Distribution of altimetry ADT obs (unit: m) after thinning in 1 day (50,098 obs)



Our first DA attempt: treat Altimeter ADT obs as a surface obs

- Model settings:

	Nudging settings	Obs	Ocn obs localization
EXP_CTL	SST, SSS nudging turned on	PrepBUFR obs w/o ocn obs	
EXP_ADTSFC	SST, SSS nudging turned on	PrepBUFR w/ ADT obs	Horizontal: 300km at EQ to 80km at Poles Vertical: 50m (cutoff: ~180 m)

(1) All experiments are from 00UTC June 1 to 00UTC June 14 in 2006.

(2) Initial 40 members are from the IITM's analysis members.

(3) Atmosphere DA every 6 hours, while Ocean DA every 24 hours.

- Obs localization is important for the successful application of an ensemble LETKF system with small ensemble size.

Our first DA attempt: treat Altimeter ADT obs as surface obs

- Independent ocean profiles during the same experiment period are used to verify the analysis w/ and w/o ADT assimilation

Temperature Analysis RMSE

SH

NH

GL

TR

empty: w/ alt.

solid: w/o alt.

+: Improved

-: Degraded

Salinity Analysis RMSE

SH

NH

TR

GL

+: Improved

-: Degraded

- RMSE reduction for temperature and salinity analysis due to ADT obs are limited to the top 100m.
- Prof. James Carton's comments: Localizing the ADT obs at sea surface is not a good choice.

Why shouldn't we localize ADT obs at sea surface?

- The surface height error δh and temperature error δT and salinity error δS at depth *z* should look like:

$$\delta T \approx \frac{\partial T(x,y,z,t)}{\partial z}\delta h$$
$$\delta S \approx \frac{\partial S(x,y,z,t)}{\partial z}\delta h \qquad (1.1)$$

- ADT obs should not be treated as a local surface obs. They are integrated (nonlocal) obs like satellite radiance.

  Assimilating nonlocal obs in the EnKF is a nontrivial problem.

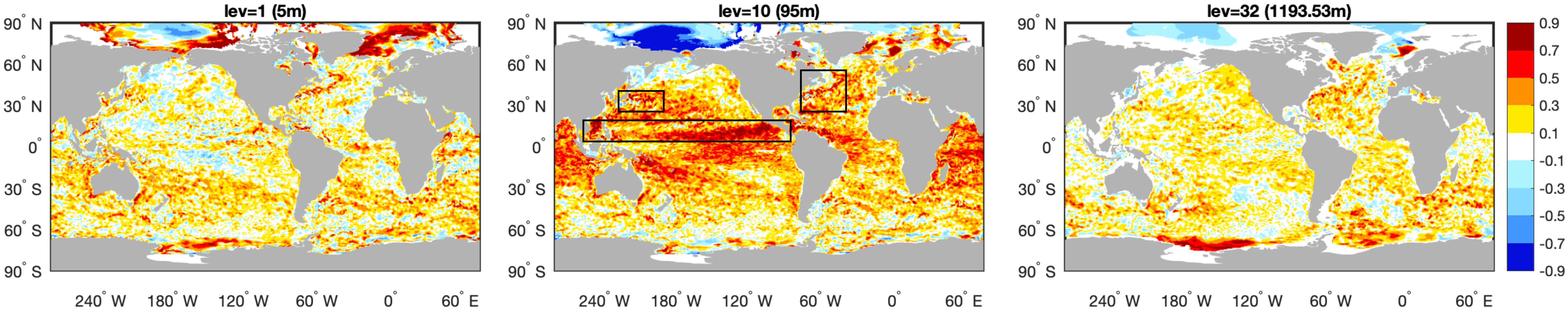
- The correlation strength between temperature and surface height is determined by $\frac{\partial T(x,y,z,t)}{\partial z}$, which has its maximum absolute value near the thermocline. This indicates what we can expect from the ADT assimilation:

  (1) Over the tropics, we expect ADT obs improve temperature in the shallow layer since thermocline is shallow.
  (2) In the NH midlatitude, ADT obs improve temperature in a deeper layer due to deep thermocline.

  (3) In the SH, we should not expect ADT obs improve temperature since $\frac{\partial T(x,y,z,t)}{\partial z}$ is nearly zero.

Correlation Map corr(SSH,T)

- When ensemble size is small, the **small** correlation between model state and observation perturbation will be **over-estimated**. The original purpose of observation localization is to remove this false over-estimated correlation between obs perturbation and state perturbation.
- But how does the vertical localization look like between the surface height perturbation and other variables?
- Let's check the correlation between temperature at model levels and surface height corr(SSH,T) first:



(1) We observe the pattern as $\delta T \approx \frac{\partial T(x,y,z,t)}{\partial z}\delta h$ predicts: The maximum corr(SSH,T) is not at the surface, but below mixed layer.

(2) Strong correlation (>0.7) appears near gulf stream, tropics, and Kuroshio as expected.

(3) corr(SSH,T) is low in deep layers, most places have a correlation <0.5.

EnKF with small size overestimates weak correlation more severely, but not those with high correlations.

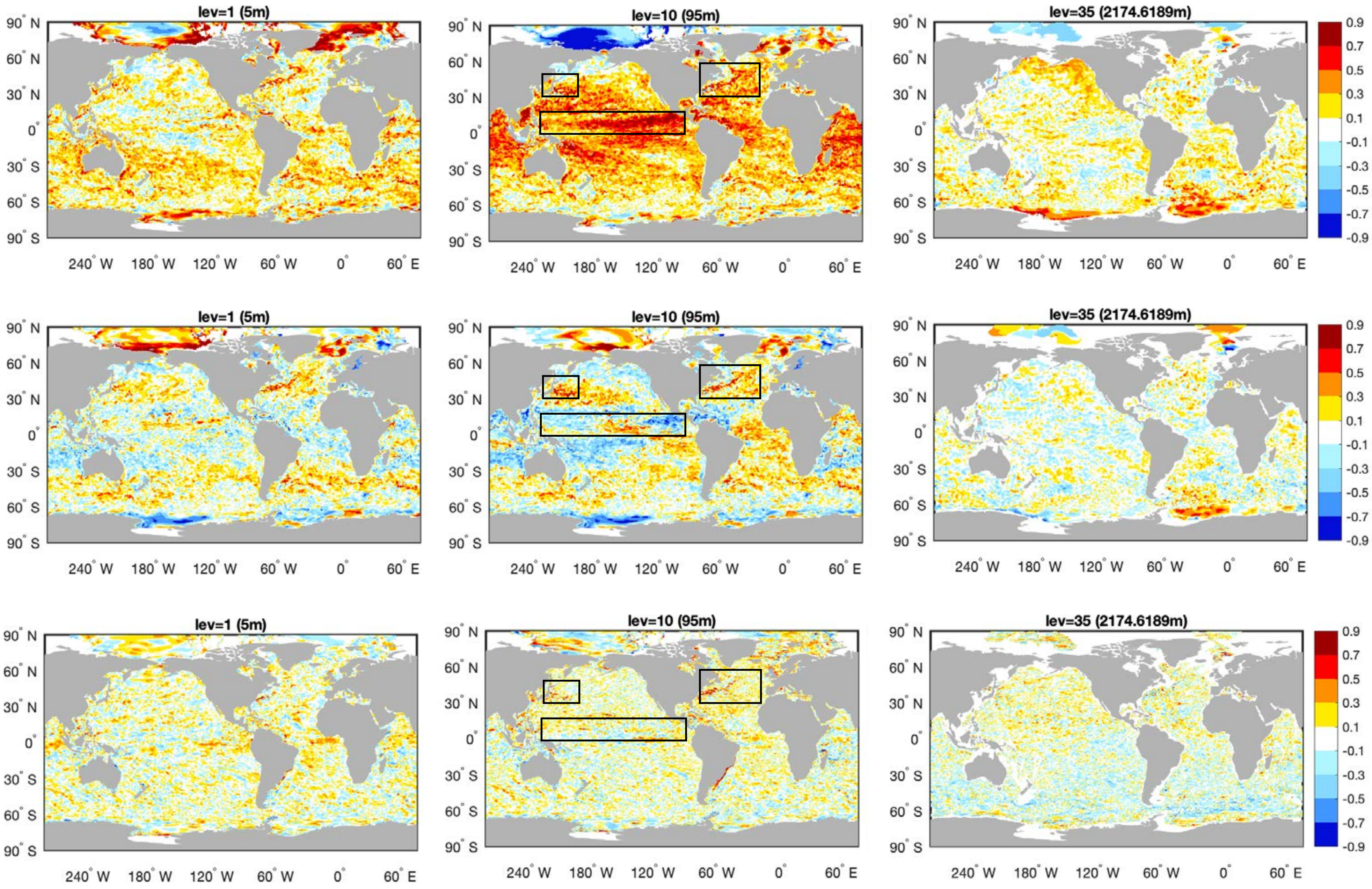
We can utilize this property: Assimilation priority gives to those observations that show high corr(SSH,T).

Model level 1 (5m) | **Model level 10 (95m)** | **Model level 35 (2175m)**

corr(SSH,T)

corr(SSH,Salinity)

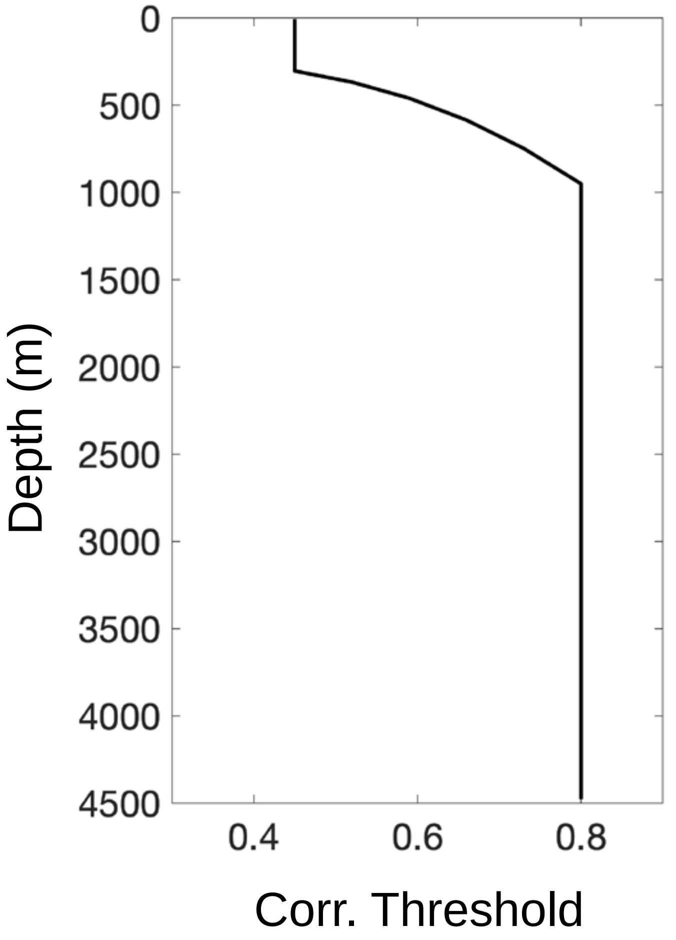
corr(SSH,U-current)



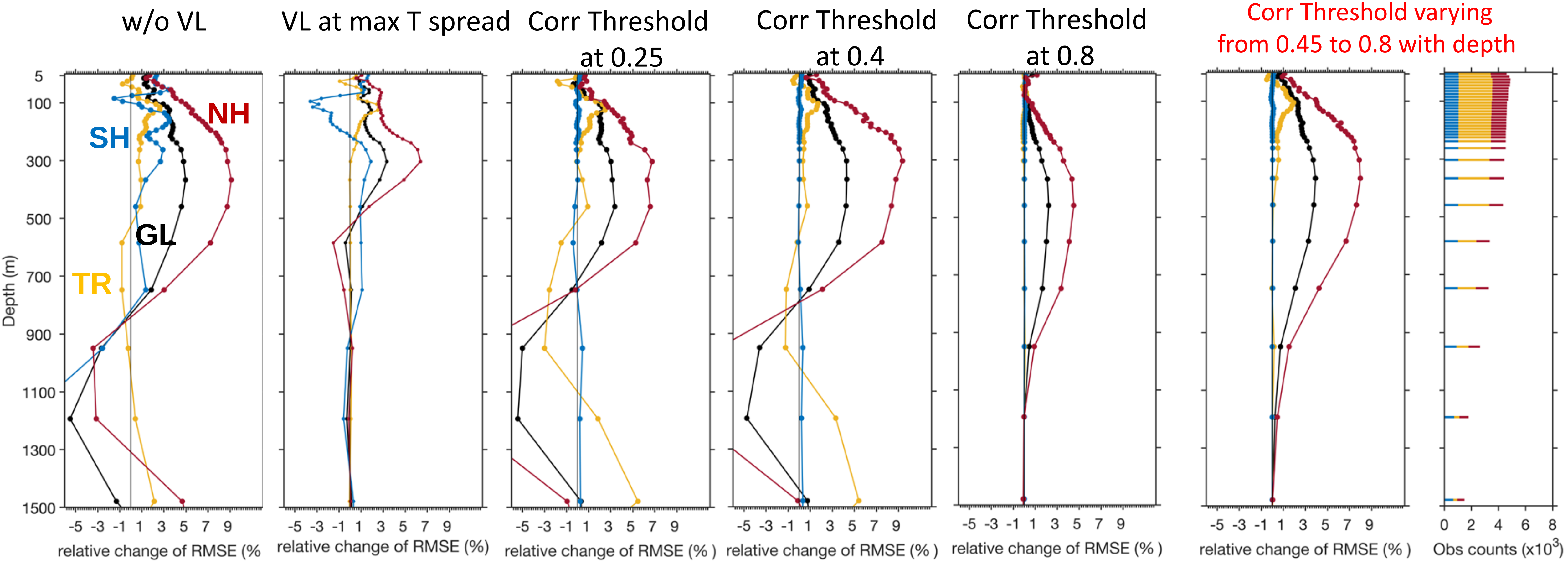
Assimilation Based on Correlation Threshold

Exp. Name	Obs Localization
EXP_CTL	
EXP_ADT_VLTsprd	Horizontal: 300km at EQ to 80km at Poles Vertical: at level with max. Temp. spread cutoff radius is 100m (~360m halfwidth)
EXP_ADT_noVL	Horizontal: 300km at EQ to 80km at Poles Vertical: no vertical localization
EXP_ADT_corr025	Search all obs within a cylinder with a radius changing from 300km at EQ to 80km at Poles Correlation threshold: 0.25
EXP_ADT_corr04	Search all obs within a cylinder with a radius changing from 300km at EQ to 80km at Poles Correlation threshold: 0.4
EXP_ADT_corr08	Search all obs within a cylinder with a radius changing from 300km at EQ to 80km at Poles Correlation threshold: 0.8
EXP_ADT_corr045to80	Search all obs within a cylinder with a radius changing from 300km at EQ to 80km at Poles Correlation threshold: varying from 0.45 to 9.8 with depth

Corr. Thresholds used in EXP_ADT_corr045to08



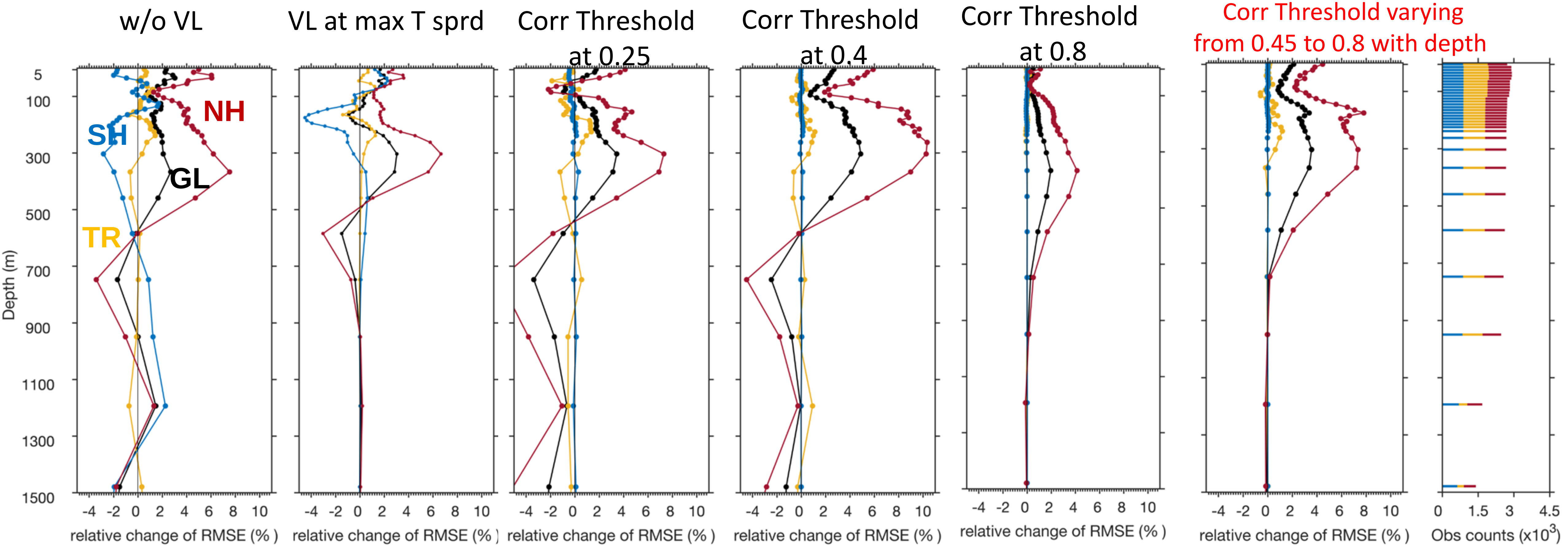
The Average Temperature Analysis RMSE over 13 Days



- C=0.25, 0.4: large degradation in deep layers as expected, because small correlation are not reliable.
- C=0.8: reduced positive impact in the top layers but no degradation in the deep layer.
- C varying with depth: retain large improvement in the top layer and no degradation in the deep layer!
  (1) Largest improvement in the shallower layer over Tropics, and in a deeper layer in the NH.
  (2) No impact in the SH

Both improvements are consistent with the physical properties

The Average Salinity Analysis RMSE over 13 Days



- Similar to the temperature analysis, large improvements in the top 600m and no degradation in the deep layer!

Preliminary results on Assimilation of Altimeter data

- We can use altimeter data (ADT= SSH, sea surface height) directly after an ~ constant bias correction.
- ADT=SSH is strongly correlated to salinity and temperature at the thermocline.
- Assimilating salinity S and temperatures T at levels where corr(SSH,S), corr(SSH,T) is high (> 0.4 but <0.8) gives very good results for S and T.
- Correlation varying with depth retains large improvement in the top layer and no degradation in the deep layer for both S and T!
- The shallow thermocline in the tropics, deep thermocline in the NH, no impact in the SH, are exactly what could be expected due to the ocean physics (Prof. J Carton), and should be very beneficial for DA.