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: \[ SLA = ADT - \text{Mean Dynamic Topography} \]
  
  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.
Our first DA attempt: treat Altimeter ADT obs as a surface obs

- Model settings:

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

(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

- 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 $\delta h$ and temperature error $\delta T$ and salinity error $\delta S$ at depth $z$ should look like:

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

(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 $corr(SSH,T)$. 
$\text{corr}(\text{SSH,} T)$

$\text{corr}(\text{SSH, Salinity})$

$\text{corr}(\text{SSH, U-current})$
## Assimilation Based on Correlation Threshold

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