Ocean data assimilation in Indian and Pacific Oceans

Changxiang Yan  Jiang Zhu  Jiping Xie
Guokun Lv  Lijing Cheng

Institute of Atmospheric Physics
Chinese Academy of Sciences
Beijing, China

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Outline

- Data assimilation method
- Application of assimilation method in Indian ocean and Pacific ocean
- Conclusions
Assimilation method

- **EnOI (Ensemble Optimal Interpolation):**

  A method that uses an ensemble from long-time model integration to estimate the background error covariance matrix. The analysis equation is given by

  \[ X_a = X_b^f + P^f H^T (HP^f H^T + R)^{-1} (Y - HX_b^f) \]

  \( X_a \): Analysis, \( X_b^f \): Background, \( P^f \): background error covariance matrix, \( R \): observation error covariance matrix, \( H \): observed operator, \( Y \): observation

  EnOI may assimilate all kinds of observations. It is a multivariate data assimilation method. However, for the isopycnic model (e.g. HYCOM), instead of direct assimilation of temperature and salinity profiles, a different new scheme is used to assimilate profiles due to the nonlinear observation operator.
Assimilation scheme for T/S profiles

**Obs:**
- obs temp. $T^o(z)$
- obs sal. $S^o(z)$

**Innovation:**
- layer thickness
- layer temp.
- layer salinity.

**Updating:**
- Layer temp.
- Layer sal.
- Layer thickness
- Layer baroclinic velocity
- Barotropic velocity
- Barotropic pressure

Seawater state eqn.
Performance of new scheme

EXP0 (dashed): no assimilation  WOA01: climatology data
EXP1A / EXP1B (dash-dot-dot): direct assimilation of T/S (in observation level / in model layer)
EXP2T / EXP2S: new scheme (diagnose T/S)

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Fig. 8. Vertical distributions of the RMSDs of temperature and salinity in the experiments of EXP0 (black dash), EXP2T (red solid), EXP2S (cyan dash-dot), EXP1A (blue solid), EXP1B (dark yellow dash-dot-dot) and in WOA01 (green dash-dot) as validated using all withheld profiles. (For interpretation of references to color in this figure legend, the reader is referred to the web version of the article.)

Xie and Zhu, 2010
Ensemble

The ensemble is usually static, and keeps unchanged during the assimilation experiment period. That means the background error covariance is unchanged. The unchanged background error covariance means the structure of flow is not changed due to the flow-dependence. However, in the monsoon-dominated domain, the surface current changed with monsoon. In this case, the static ensemble seems not to reflect the flow-dependence well.

So the ensemble is changed with season in the experiment. That is for each season, different ensemble members are adopted.
Application of assimilation method

- HYCOM(verision 2.2): hybrid coordinate ocean model evolved from Miami isopycnic coordinate ocean model (MICOM)
- Model domain (color shade): including Indian and Pacific oceans with the horizontal resolution of 1/3x1/3 and with vertical 28 layers
- Forcing: 6-hr ERA-interim wind stress, atmospheric temperature, cloud, dew temperature. Sea level pressure, precipitation, and climatology fresh river data
Assimilation experiment

**assimilated data:** remotely-sensed SST, altimetry SLA, Temperature and salinity profiles from ARGO, CTD, TAO, XBT, MBT etc

**assimilation frequency:** 7-day window for profiles.
   for SST and SLA, assimilate once every 7 days

**ensemble:** 120 members

**assimilation period:** 2005-2007

As a comparison, the experiment without assimilation is also carried out.
SLA variability (relative to 2005-2007)
Comparison with independent data

Observations at 18N in 2006–2007 in South China Sea

T/S at (118E,18N) on 2007–08–23

T/S at (116E,18N) on 2006–09–17

T/S at (117E,18N) on 2006–09–17
Comparison with independent data

T/S at (115E,18N) on 2007–08–22

T/S at (118.5E,18N) on 2007–08–23

T/S at (115E,18N) on 2006–09–16

RMSEs of T/S
Comparison with independent data (TAO SST)

RMSE = 1.11 (NDA), 0.38 (DA) for (95W, 2N)

RMSE = 0.44 (NDA), 0.17 (DA) for (147E, 2N)

RMSE = 0.37 (NDA), 0.17 (DA) for (156E, 0N)
Comparison with independent data (TAO SST)

\[
\text{RMSE} = 0.37 \text{(NDA)}, \ 0.16 \text{(DA)}
\]

\[
\text{RMSE} = 0.33 \text{(NDA)}, \ 0.18 \text{(DA)}
\]

\[
\text{RMSE} = 0.32 \text{(NDA)}, \ 0.16 \text{(DA)}
\]

\[
\text{RMSE} = 1.14 \text{(NDA)}, \ 0.55 \text{(DA)}
\]
Application of assimilation method

Model domain (color shade): including Indian and West Pacific oceans

Assimilation experiment (AIPO): assimilate SST, SLA and T/S profiles into HYCOM
Drifters (red dot is the origin of drifer) and sea surface current stream in Nov 6-10, 2006 for Indian ocean
### Indonesian throughflow (ITF) transport

<table>
<thead>
<tr>
<th></th>
<th>Observations (Gordon et al. 2009)</th>
<th>AIPO</th>
<th>ECCO</th>
<th>SODA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Annual mean Inflow (2004-2006)</strong></td>
<td>13Sv</td>
<td>11.9Sv</td>
<td>10.2Sv</td>
<td>8.2Sv</td>
</tr>
<tr>
<td><strong>Annual mean Outflow (2004-2006)</strong></td>
<td>15Sv</td>
<td>14.5Sv</td>
<td>11.7Sv</td>
<td>14.2Sv</td>
</tr>
</tbody>
</table>

**Inflow:** Makassar strait (top-bottom) + Lifamatola (>1250m)

**Outflow:** Lombok (top-bottom), Ombai (top-bottom), Timor (top-bottom)
Comparison with tide gauge sea level data

The statistics comparison of assimilation experiment and tide gauge sea level for 56 stations is made. These stations are mainly from the West Pacific and Indian islands. To eliminate the sea level rise due to continental ice melt and model bias, the linear trend is removed. The correlations between analysis and observed sea level are greater than 0.8 in most stations. The following table further validates it.
## Correlations between analysis and tide gauge sea level

<table>
<thead>
<tr>
<th>Station name</th>
<th>Location</th>
<th>Year</th>
<th>Correlation</th>
<th>Station name</th>
<th>Location</th>
<th>Year</th>
<th>Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beto</td>
<td>1°22′N, 172°56′E</td>
<td>14</td>
<td>0.97</td>
<td>Maisaka</td>
<td>34°41′N, 137°37′E</td>
<td>14</td>
<td>0.79</td>
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<tr>
<td>Majuro</td>
<td>7°6′N, 171°22′E</td>
<td>14</td>
<td>0.95</td>
<td>Nase</td>
<td>28°23′N, 129°30′E</td>
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<td>0.83</td>
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<tr>
<td>Malakal</td>
<td>7°20′N, 134°28′E</td>
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<td>0.99</td>
<td>Nagasaki</td>
<td>32°44′N, 129°52′E</td>
<td>14</td>
<td>0.75</td>
</tr>
<tr>
<td>Yap</td>
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<td>14</td>
<td>0.96</td>
<td>Nishinoo</td>
<td>30°44′N, 130°60′E</td>
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<td>Honiara</td>
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<td>Ishigaki</td>
<td>24°20′N, 124°9′E</td>
<td>14</td>
<td>0.77</td>
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<tr>
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<td>0.95</td>
<td>Lombrum</td>
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<td>0.91</td>
<td>Lautoka</td>
<td>17°36′S, 177°26′E</td>
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<td>0.79</td>
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<td>Port vil</td>
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<td>14</td>
<td>0.94</td>
<td>Tanjong</td>
<td>1°16′N, 103°51′E</td>
<td>14</td>
<td>0.77</td>
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<td>Hiron Point</td>
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<td>Coxs Bazaar</td>
<td>21°27′N, 91°50′E</td>
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<td>Keling</td>
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<td>Funafuti-B</td>
<td>8°30′S, 179°13′E</td>
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<tr>
<td>Gan</td>
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<td>1°28′N, 103°48′E</td>
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<td>Zanzibar</td>
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<td>Cocos is</td>
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<td>Booby is</td>
<td>10°36′S, 141°55′E</td>
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<td>Miyakejima</td>
<td>34°4′N, 139°29′E</td>
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<td>Nakano s</td>
<td>29°50′N, 129°51′E</td>
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<td>Legaspi</td>
<td>13°9′N, 123°45′E</td>
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<td>Abashiri</td>
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<td>Biaru</td>
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<td>Aburatsu</td>
<td>31°34′N, 131°25′E</td>
<td>14</td>
<td>0.78</td>
<td>Sandakan</td>
<td>5°49′N, 118°4′E</td>
<td>13</td>
<td>0.96</td>
</tr>
</tbody>
</table>
Sea level removing linear trend at Malakal (134.5E, 7.3N)

Sea level removing linear trend at Keling (102.1E, 2.2N)

The high and low sea level events reflect the effects of ENSO in the west tropical Pacific. The strongest event in the studied period is 1997-1998 El Nino which corresponds to a decrease in sea level. Moreover, the AIPO demonstrates consistent interannual signals with observed sea level.
ENOI is used to assimilate SST and SLA. A different method is used to assimilate profiles by assimilating layer thickness observations computed from temperature and salinity observations.

The assimilation method is applied in the Indian ocean and Pacific ocean by the assimilation of SST, SLA and T/S profiles into the HYCOM.

The assimilation experiment shows the signals of variability is strengthened, and the thermocline is enhanced. The assimilation experiment also agrees with the independent observations such as TAO, drifters etc. The results of these comparisons indicate the encouraging performance of data assimilation method.
Thanks for your attention!
New assimilation method for isopycnic model

\[ X_a = X_b^f + P^f H^T (H P^f H^T + R)^{-1} (Y - H X_b^f) \]

Difference between observation and model:

- \( H(X) \rightarrow Y \)
  - Observed operator
  - Model result
  - Observation

\( X=(T,d), Y=(T,S) \rightarrow H(\text{nonlinear}) \)
\( X=(T,d), Y=(T,d) \rightarrow H(\text{linear}) \)

Nonlinear operator may cause serious suboptimal problem  Xie and Zhu, 2010

Fig. 2. Schematic of a simplified HYCOM configuration of two layers. Blue line is the linearly interpolated temperature profile based on the model temperature defined at the middle points of two layers, and red line represents the observed temperature profile. (For interpretation of references to color in this figure legend, the reader is referred to the web version of the article.)

\[
T(z) = H(d_1, d_2, T_1, T_2) = [(2z - d_1)T_2 + (2d_1 + d_2 - 2z)T_1]/(d_1 + d_2).
\]