Development of a coastal monitoring and forecasting system at MRI/JMA

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JMA operational ocean forecast system

**MOVE/MRI.COM-WNP**
- operated since 2008
- western North Pacific model
- 10km resolution
- data assimilation with 3DVAR
- targeting mesoscale phenomena in the open ocean (Kuroshio, Oyashio, mesoscale eddies,...)
- **cannot resolve coastal processes**

Need for coastal system

Typhoon "Sanba" Sep 2012

Coastal trapped waves

Unusual tide in Sep 2011

Iitsukushima shrine

Sea-level information (Hiroshima local meteorological office)

MOVE/MRI.COM-WNP

new system
monitoring and forecasting system of the Japanese coastal seas

storm surge model

storm surge

wind waves

Seiche (Abiki)

tides

mesoscale eddies

wind-driven circulation

thermohaline circulation

Coastal trapped waves

Spatial scale

1000 km
100 km
10 km
1 km
100 m
10 m
1 m

Temporal scale

minute
hour
day
month
year
decade
century

MOVE/MRI.COM-WNP

Unusual tide in Sep 2011

Hiroshima local meteorological office

Japanese coastal seas
Plan for development of coastal systems

Target area:

- **Seto Inland Sea (MOVE/MRI.COM-Seto)**
  - 2km coastal model (MRI.COM-Seto)
  - 4DVAR assimilation model with 10km grid (MOVE-4DVAR)
  - under preparation for operational use at JMA

- **Whole coastal regions of Japan (MOVE/MRI.COM-Jpn)**
  - Model Japan with 2km resolution (MRI.COM-Jpn)
  - 4DVAR assimilation model in the North Pacific

Roadmap:

- 2015- (MOVE/MRI.COM-Seto)
- Several years later (MOVE/MRI.COM-Jpn)
Analysis model (MOVE-4DVAR)
- WNP model (MRI.COM-WNP)
- 10km resolution
- Optimize T and S fields with 4DVAR
- 30 years analysis/reanalysis (1985-2014+)
  (FORA)

Forecast model (MOVE-Seto)
- Seto Inland Sea model (MRI.COM-Seto)
- 2km resolution
- Initialized with 10km analysis fields of MOVE-4DVAR
- high-resolution atmospheric forcing from JMA operational models (MSM, GSM)

This system will be in operation at JMA soon
### Configuration of MRI.COM-Seto

<table>
<thead>
<tr>
<th>Model</th>
<th>MRI Community Ocean Model (MRI.COM) ver. 3.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>coordinates</td>
<td>free surface sigma-z, polar coordinates</td>
</tr>
<tr>
<td>Hori. resolution</td>
<td>$1/33^\circ \times 1/50^\circ$ (~2km)</td>
</tr>
<tr>
<td>Vert. resolution</td>
<td>4-600m (50 layers)</td>
</tr>
<tr>
<td>Tracer advection</td>
<td>Second-order Momentum closure (Prather 1986)</td>
</tr>
<tr>
<td>Hori. mixing</td>
<td>Smagorsinky bi-harmonic</td>
</tr>
<tr>
<td>Vert. mixing</td>
<td>Noh and Kim (1999)</td>
</tr>
<tr>
<td>Tides</td>
<td>Tidal mixing parameterization (Lee et al. 2006)</td>
</tr>
<tr>
<td>Lateral boundaries</td>
<td>MOVE-WNP- 4DVAR (10km)</td>
</tr>
<tr>
<td>Nesting</td>
<td>Off-line one-way nesting</td>
</tr>
<tr>
<td>Atmos. forcing</td>
<td>JMA operational model outputs (GSM + MSM)</td>
</tr>
<tr>
<td>River run-off</td>
<td>Monthly climatology of 28 major rivers</td>
</tr>
<tr>
<td>others</td>
<td>SSS restore to climatology with 29.2day</td>
</tr>
<tr>
<td>Time step</td>
<td>2.5 min</td>
</tr>
</tbody>
</table>

**Background vertical diffusivity**

**River runoff**

1 $\times 10^{-3}$ [cm / s]
Observations used for data assimilation

- **Satellite altimeter (along track)**
  - TOPEX/Poseidon, Jason-1/2
  - ERS-1/2, Envisat, Cryosat-2
  - GFO, SARAL/AltiKa, HY-2

- **Gridded SST**
  - MGDSST (JMA SST product)
    - Merged satellite and in-situ data
    - 0.25deg x 0.25deg

- **In-situ observations (T and S)**
  - Argo
  - Ship
  - Buoy
  - ...

- Density-related observations (T and S)
- Use of velocity data is future subject
Difference between 3DVAR and 4DVAR

**3DVAR**
(Three-dimensional variational method)

- Does not use a numerical model for ocean state estimate
- Estimates ocean state at a fixed time
- Treats observations as if valid at an analysis time (-> F-GAT)

**4DVAR**
(Four-dimensional variational method)

- Utilizes a numerical model
- Optimizes a model trajectory within an assimilation window
- Uses obs at their actual time of measurement
- Easy to assimilate any variables related to prognostic variables
Assimilation cycle

MOVE-4DVAR (10km analysis model)

MOVE-Seto (2km forecast model)

MOVE-4DVAR SST (10km)

MOVE-Seto SST (2km)
Comparison between 3DVAR and 4DVAR analysis fields

(a) Observation
10-Jan-2000
29-Jan-2000
5-Feb-2000

(b) MOVE-4DVAR
10-Jan-2000
29-Jan-2000
5-Feb-2000

(c) MOVE-3DVAR
10-Jan-2000
29-Jan-2000
5-Feb-2000

Sea level at Hachijo-jima

Tide gauge
MOVE-3DVAR
MOVE-4DVAR

Hachijo-jima
Unusual high tide in September 2011

- SLAs exceed 20cm at south coast of Japan in the end of Sep 2011
Unusual high tide in September 2011

- SLAs exceed 20cm at south coast of Japan in the end of Sep 2011
- The new system succeeded in reproducing this event
- The sea-level rise associated with this event was caused by coastal trapped waves induced by a Kuroshio path fluctuation
Model configuration:

- Model Japan (MRI.COM-Jpn)
  - Covers the whole coastal regions of Japan
  - Same numerical model (MRI.COM)
  - Same horizontal resolution (~ 2km)

- Uses up-to-date schemes
  - Explicit tidal forcing (Sakamoto et al. 2013)
  - Improves river runoff using JMA operational NWP products
  - Incorporates sea ice model
  - Introduces $Z^*$-coordinate
  - New turbulence closure (GLS)
  - Online two-way nesting
**Data assimilation:**

- **Improve DA scheme**
  - Extends control variables (velocity, external forcing, ...)
  - Effective method to initialize high-resolution coastal model

- **Use of new observations for assimilation**
  - Velocity observations (HF radars)
  - High-resolution 2D SSH (SWOT, COMPIRA)
  - Coastal sea-level (tide gauge observations)
  - Sea ice concentration (for Sea of Okhotsk)

*Images of sea ice concentration and HF radar system.*
Summary

• Coastal monitoring and forecasting system around the Seto Inland Sea (MOVE/MRI.COM-Seto)
  – Will be in operation at JMA soon
  – Fine resolution coastal model (MRI.COM-Seto)
    • 2km resolution
    • Represents realistic short-term and small-scale processes
  – 4DVAR assimilation scheme (MOVE-4DVAR)
    • Enhances short-term variability compared to 3DVAR
    • Succeeds in reproducing the unusual tide event in September 2011

• Next generation system: MOVE/MRI.COM-Jpn
  – Covers the whole coastal regions of Japan with 2km resolution
  – Use of up-to-date model schemes
  – Use of new observations for data assimilation
Thank you
3DVAR in MOVE/MRI.COM

Multi-variate system: horizontal inhomogeneous Gaussian, vertical T-S EOF. Optimal amplitudes of T-S EOF (y) are calculated by minimizing the cost function (J) with a nonlinear descent scheme “POpULar”. Model insertion: IAU

Analysis Increment is represented by the linear combination of the EOF modes.

Background Constraint

Constraint for T, S observation

\[
x(y) = x_f + S \sum_l w_l U_l \Lambda_l y_l
\]

Amplitudes of EOFs

Constraint for SSH observation

\[
J = \frac{1}{2} \sum_m \sum_l y_{m,l}^T B_l^{-1} y_{m,l} + \frac{1}{2} \left[ Hx(y) - x^0 \right]^T R^{-1} \left[ Hx(y) - x^0 \right]
\]

\[
+ \frac{1}{2} \left[ h(x(y)) - h^0 \right]^T R_h^{-1} \left[ h(x(y)) - h^0 \right] + \alpha(y)
\]

Seek the amplitudes of EOF modes y minimizing the cost function J.

→Analysis increment of T and S will be correlated.

Fujii and Kamachi, 2003a,b,c