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Reproducibility of currents and water masses in the North Pacific subarctic region in MOVE/MRI.COM

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1. Introduction

Kuroshio-Oyashio (K-O) confluence zone:

- Complicated frontal structures.
- Energetic mesoscale eddy activity.

→ Suitable for evaluation of high-resolution DA system (Sec. 3).

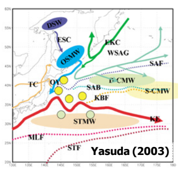


Fig. 1: Schematic illustration of the near-surface current, front and water-mass structure in the K-O confluence zone.

Temperature inversion (T-inv) in the subarctic North Pacific:

- Subsurface T-min and underlying T-max.
- T-min: formed by seasonal cycle of surface cooling & heating.
  → Preserve wintertime atmospheric conditions.
- T-max: warm and saline water transport from K-O region.
  → Heat reservoir.
- Understanding of T-inv is limited to climatological mean state due to lack of observation.

→ DA system would be useful for understanding T-inv variations (Sec.4).

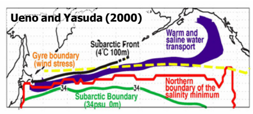


Fig. 2: Distribution of warm and saline cross gyre flow.

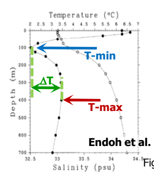


Fig. 3: Annual mean T-S profiles at (50°N, 165°E)

2. Description of MOVE/MRI.COM and experiments

MOVE/MRI.COM-WNP & -NP

MRI.COM (Ishikawa et al. 2005, Tsujino et al. 2006):

MRI community ocean model

- z-coordinate, free-surface model
- Western North Pacific model (WNP): 15°–65°N, 117°-200°E, 1/10° × 1/10°, L54
- North Pacific model (NP): 15°S-65°N, 117°-200°E, 1/2° × 1/2°, L54
- Biharmonic Smagorinsky viscosity + harmonic background viscosity (WNP)
- Mellor and Blumberg (2004) mixed layer model
- One-way nesting (NP → WNP)

MOVE (Usui et al. 2006):

MRI Multivariate Ocean Variational Estimation system

- 3DVAR with vertical coupled T-S EOF modes (Fujii & Kamachi 2003)
- Incremental Analysis Update (Bloom et al. 1996)

Cost function: (background; T-S observation; sea surface height)

$$J(\mathbf{y}) = \frac{1}{2}\sum_m\sum_l \mathbf{y}^T\mathbf{B}_{m,l}^{-1}\mathbf{y} + \frac{1}{2}\mathcal{Q}\left(\frac{\mathbf{Hx(y)}-\mathbf{x}^o}{\sigma_o}\right)^T\mathbf{R}^{-1}\mathcal{Q}\left(\frac{\mathbf{Hx(y)}-\mathbf{x}^o}{\sigma_o}\right) + \frac{1}{2}\mathcal{Q}\left[\frac{\mathcal{H}(\mathbf{x}(\mathbf{y}))-h^o}{\sigma_h}\right]^2 + J_c$$

y: amplitude of T-S EOF modes

$$\mathcal{H}(\mathbf{x}) = \frac{1}{\rho_s}\int_{z_m}^{0}\rho'(T,S,p)dz \quad \text{(observation function for SSH)}$$

$$\mathbf{x}(\mathbf{y}) = \mathbf{x}_f + \mathbf{S}\sum_l w_l\mathbf{U}_l\mathbf{\Lambda}_l\mathbf{y}_l \quad \text{(reconstruction of T-S from } \mathbf{y}\text{)}$$

[$\mathcal{Q}$: A function used for the variational QC; $\mathbf{U}$: A matrix composed of dominant T-S EOFs; $\mathbf{S}$: Standard deviation of T and S; $\mathbf{\Lambda}$: Singular values of the EOFs]

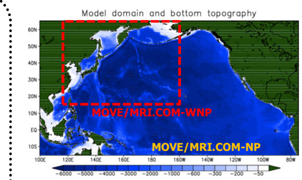


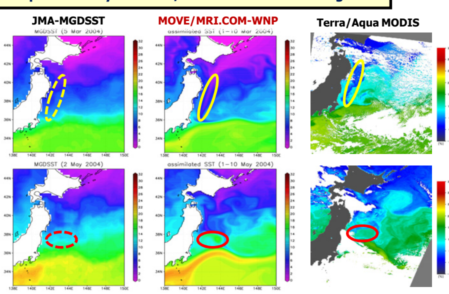
Fig. 4: Model domain and bottom topography.

Assimilation experiment:

- Period:
  - (WNP) Jan 2001 – Dec 2004
  - (NP) Jan 1985 – Dec 2007
- Assimilation window:
  - (WNP) 5 days
  - (NP) 1/3 month (~10days)
- Observation data:
  - SSHA (T/P, Jason-1, ERS, ENVISAT)
  - SST (MGDSST: Japan GHRSST)
  - WOD01, GTSPP
- Forcing: JRA-25/JCDAS (Onogi et al. 2007)

3. Reproducibility in the K-O confluence zone and improvements of the analysis scheme

Reproducibility of MOVE/MRI.COM in the K-O region



Mesoscale variabilities such as Oyashio coastal branch and warm-core eddy are well reproduced.

Fig. 5: Comparison of SST fields with observations.

Some issues of the assimilated field and their improving strategies

Issue-1: Excessively low temperature of Oyashio water

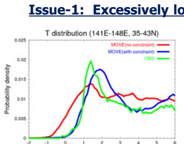


Fig. 6: Temp distribution of Oyashio water at 100m.

Low temperature estimates arise from non-Gaussian temperature distribution of Oyashio water .

→ Adding a constraint to the cost function:

$$J_c = \frac{w}{32}\left[T(\mathbf{x}) - T_c - |T(\mathbf{x}) - T_c|\right]^4$$

$$T_c = 0.5\,^\circ\mathrm{C}, \quad w = 1.0$$

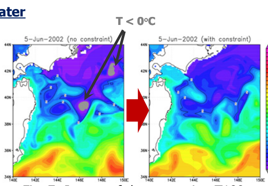


Fig. 7: Impact of the constraint. T100 distributions (left) without and (right) with constraint.

Issue-2: Overestimate of Oyashio area

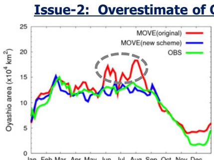


Fig. 8: Time sequence of Oyashio area in 2002 (141-148E, 35-43N).

In summer, MOVE tends to overestimate Oyashio area (T at 100m <5°C).

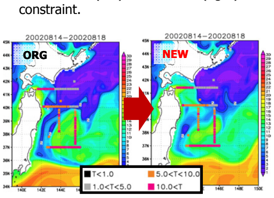


Fig. 9: Impact of the new scheme. T100 distributions are compared with in-situ observations.

→ Flow-dependent B matrix :

$$B_{ij} = \exp\left[-\frac{\Delta x_{ij}^2}{2\sigma_x^2} - \frac{\Delta y_{ij}^2}{2\sigma_y^2}\right] \qquad B_{ij} = \exp\left[-\frac{\Delta x_{ij}^2}{2\sigma_x^2} - \frac{\Delta y_{ij}^2}{2\sigma_y^2} - \frac{\Delta T_{ij}^2}{2\sigma_T^2}\right]$$

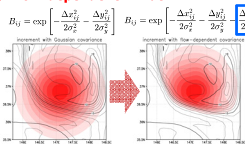


Fig. 10: Increment in single-observation experiment.

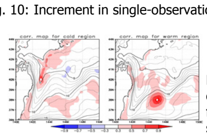


Fig. 11: Corr. map of T100 estimated from model simulation

→ Application of non-Gaussian pdf to the variational QC:

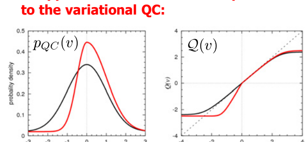


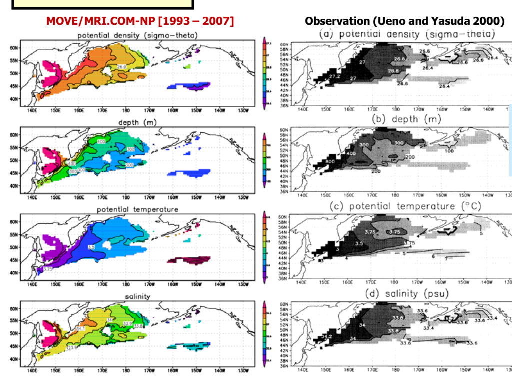
Fig. 12: (left) Obs pdf and (right) Q(v).

$$p_{QC}(y|\mathbf{x}) \propto \exp\left[-\mathcal{Q}(v)^2/2\right]$$

$$v = \frac{y - H(\mathbf{x})}{\sigma^o}$$

4. Temperature inversions in the subarctic North Pacific (SNP)

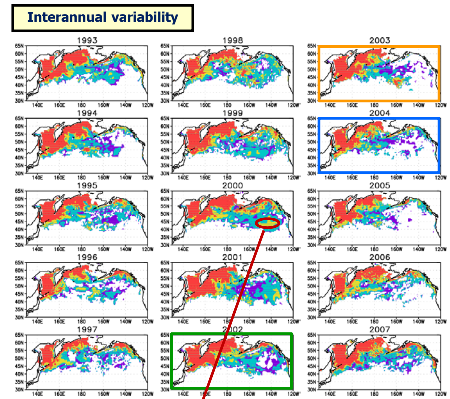
Annual mean field



Mean state of MOVE/MRI.COM is quantitatively well reproduced compared with observation.

Fig. 5: Annual mean T-inv distribution. Potential density, depth, temperature and salinity at T-max depth are compared with observation.

Interannual variability



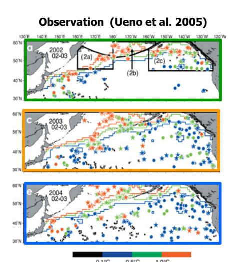


Fig. 5: Interannual variability of wintertime (Jan-Mar) ΔT distribution. Results of MOVE/MRI.COM-NP are compared with observation constructed from Argo float.

- In the eastern SNP, T-inv shows large variability.
- From 1999 to 2001, large T-inv occurs accompanying cold SSTA.
- DA results indicate that horizontal advection is responsible for the cold SSTA formation.

T-inv variation in the eastern SNP

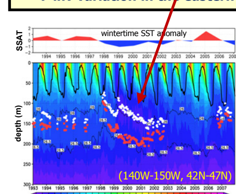


Fig. 5: (Top) wintertime SSTA, (bottom) time sequence of T-inv structure in the eastern SNP.

Mixed Layer Heat Budget:

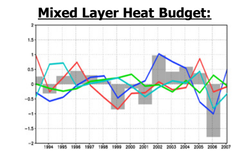


Fig. 5: Heat budget of ML T-anom averaged over 140-150W, 42-47N.

$$\frac{\partial T_m}{\partial t} = \frac{1}{h_m}\left[\frac{Q_t}{\rho C_p} - \int_{-h_m}^{\eta}\left(u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y}\right)dz + \int_{-h_m}^{\eta}\mathscr{D}_H(T)dz - \kappa_v\frac{\partial T}{\partial z}\Big|_{z=-h_m} + \mathscr{E} + \int_{-h_m}^{\eta}\delta T_{inc}dz\right]$$

tendency; Qnet; advection; hor. Diff; vert. diff (BG); entrainment (unknown residual); increment