

APPLICATION OF NONLINEAR CONSTRAINTS IN A VARIATIONAL OCEAN DATA ASSIMILATION SYSTEM MOVE/MRI.COM

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Abstract

Variational data assimilation method can adopt nonlinear constraints for improving representation of target phenomena more realistically. Two kinds of nonlinear constraints, not previously studied in oceanography, have been adopted in a three-dimensional oceanic variational data assimilation system MOVE/MRI.COM. One is the constraint for the variational Quality Control (var-QC) procedure and the other is used to avoid density and temperature inversions.

Estimation of the large heat content anomaly in the upper ocean related to El Niño and La Niña phenomena is improved with the var-QC. For example, it prevents unusual but correct observation data on the thermocline deepening in the 1997/98 El Niño from being ignored. As a result, it improves the temperature field estimation in the eastern equatorial Pacific.

The constraint for avoiding inversions prevents the low salinity layer at the surface and the barrier layer in the eastern equatorial Pacific in the El Niño period from being destroyed by the convective adjustment procedure performed after minimizing the cost function. Incorporating nonlinear constraints in variational analyses is thus a strong candidate for increasing the accuracy of analysis.

1. Description of MOVE/MRI.COM

Assimilation and prediction system: MOVE/MRI.COM-G, -NP, -WNP

MOVE (Fuji & Kamachi, 2003a,b,c; Usui et al., 2006): MRI Multivariate Ocean Variational Estimation system

- 3DVAR with vertical coupled T-S EOF modes (Fuji & Kamachi 2003a,b,c)
- Incremental Analysis Updates (Bloom et al. 1996)

Cost function:

$$J(y) = \frac{1}{2} \sum_{j=1}^n y^T B_j^{-1} y + \frac{1}{2} \sum_{i=1}^m [H(x(y)) - x^i]^T R^{-1} [H(x(y)) - x^i] + \frac{1}{2\sigma^2} \sum_{i=1}^m [H(x(y)) - h^i]^2$$

background T-S profile data
Nonlinear sea surface height Constraint

y: amplitude of T-S EOF modes

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

$$x(y) = x_f + \sum_{i=1}^n u_i U_i A_i y_i \quad (\text{reconstruction of T-S from } y)$$

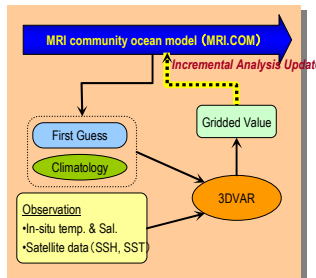


Fig. 1: Analysis flow in the MOVE system.

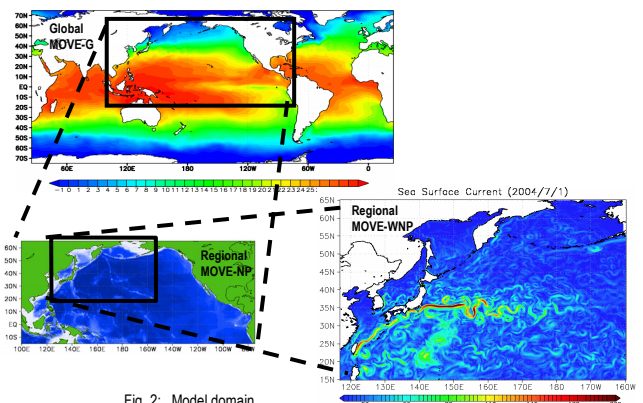
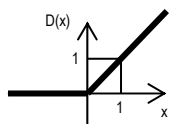


Fig. 2: Model domain

2. Constraint avoiding the density inversion

$$\alpha = \frac{1}{\alpha_1} \sum_p \sum_k [D(\rho_{p,k} - \rho_{p,k-1})]^2$$

α is a constraint avoiding density inversion because it has a large value when $\rho_{k-1} > \rho_k$ is positive.



It is difficult to express the exceptionally deepening of the thermocline by EOF combinations. A false temperature maximum tends to be analyzed above the thermocline, instead. This shortcoming is improved by introducing the constraint above.

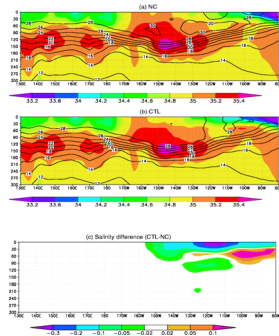


Fig. 3. Temperature (contour) and salinity (color) fields of the section along the equator in November, 1997. (a) using no constraint, (b) using the constraint, (c) difference of salinity field.

3. Variational QC

$$J_o = \frac{1}{2} Q (H(w) - y)^T R^{-1} Q (H(w) - y)$$

Data of exceptional large anomaly in El Niño periods is discarded by conventional 3σ check. Variational QC prevents those data from being discarded because variational QC compares the observation data not with the background value like the conventional QC, but with the analyzed value.

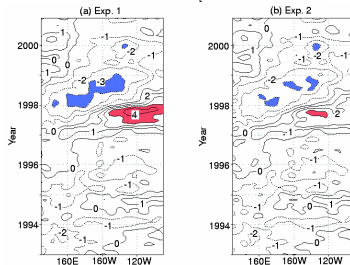
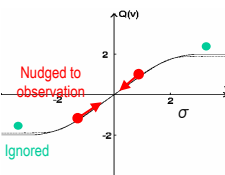


Fig. 4. Longitude and time section of the heat content anomaly at the equator. (a) with variational QC. (b) with the conventional 3σ check.

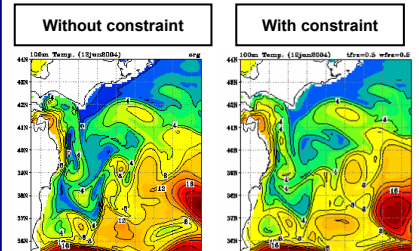
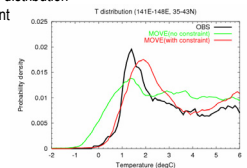
4. Constraint avoiding negative temperature

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

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

Motivation: Oyashio Temperature is too low. Oyashio area is too large.

Confluence zone: complex front and filament structures => T: "non-Gaussian" distribution => nonlinear constraint



Usui et al., 2008

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