Development of Four-Dimenisional Local Ensemble Transform Kalman Filter (4D-LETKF) for the Coastal Ocean

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Abstract

Goal: Building of a robust and efficient data assimilation (DA) system for the U.S. West Coast ocean:

1. routinely provide the analysis and forecast of the ocean state along with their uncertainties
2. easily assimilate unconventional observations and implement additional features
3. be portable/relocatable to other parts of the ocean as the regions of interest may change over time

Choice of primary elements for a robust DA system:

1. Model — ROMS
2. Observations — Remote-sensing & In situ
3. DA method — 4D-LETKF

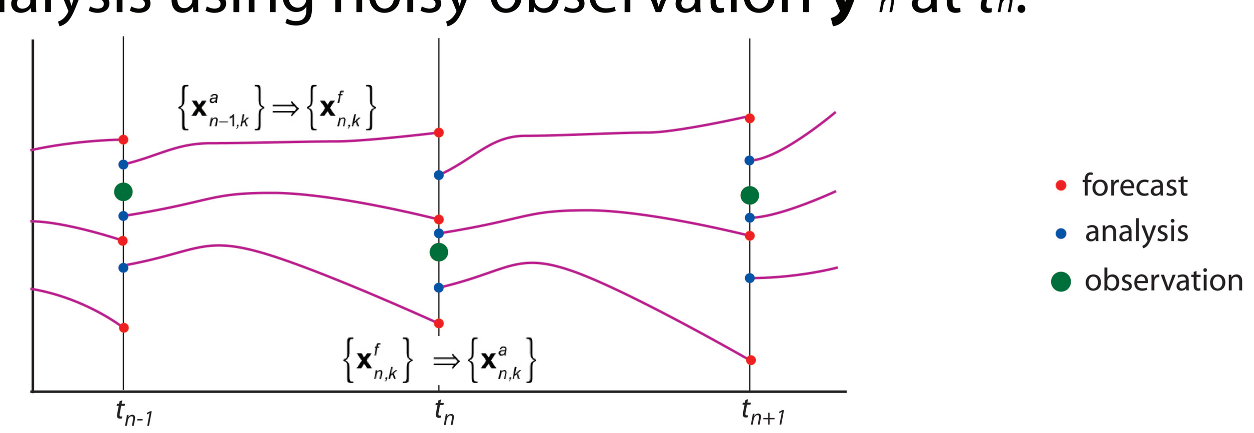
Advantage (a): Model and observation setup.
A 3D-Var DA system has been successfully implemented in ROMS and is working in real-time (Li et al., 2007a).

DA Method 1: Ensemble Kalman Filter (EnKF)

Use of ensemble, $\{\mathbf{x}_{n,k}\}$, $k=1,\ldots,L$:
Probability distribution of the N-dimensional state $\mathbf{x}_n$

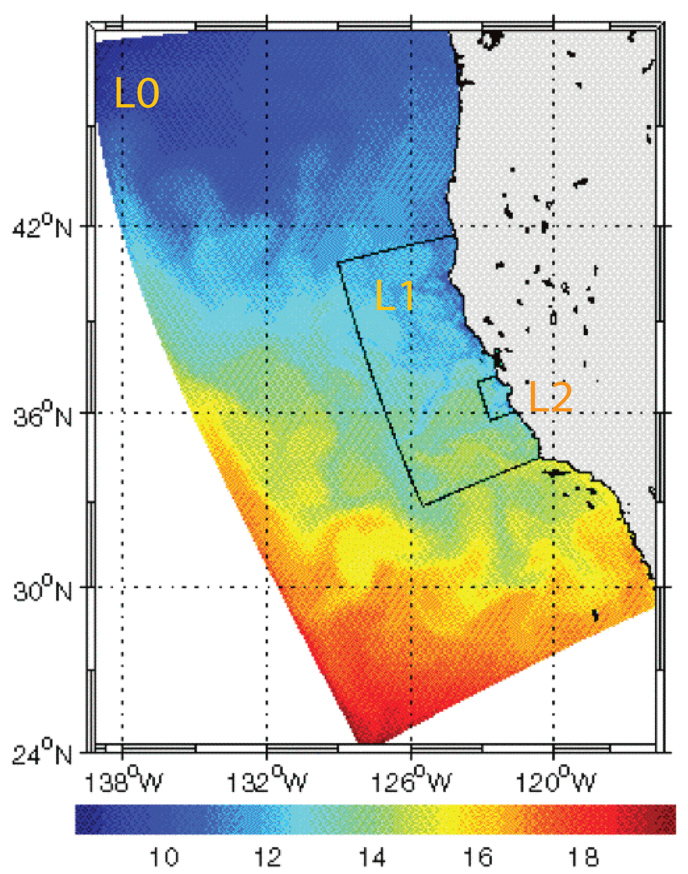
EnKF procedure: Iteration of 2-step cycles

1. Ensemble forecast from t_{n-1} to t_n: $\{\mathbf{x}^a_{n-1,k}\} \Rightarrow \{\mathbf{x}^f_{n,k}\}$
2. Analysis using noisy observation $\mathbf{y}^o_n$ at t_n: $\{\mathbf{x}^f_{n,k}\} \Rightarrow \{\mathbf{x}^a_{n,k}\}$



Advantage (e): Flow-dependent (time-evolving) Information of uncertainties by the ensemble

Model: Regional Ocean Modeling System (ROMS)



State vector $\mathbf{x}_n$ *and dynamics* $\mathbf{m}_{n,n-1}$:

$$\mathbf{x}^T = (\ldots, T_{ijl}, S_{ijl}, u_{ijl}, v_{ijl}, \ldots, \zeta_{ijl} \ldots)^T$$

$$\mathbf{x}_n = \boldsymbol{m}_{n,n-1}(\mathbf{x}_{n-1})$$

Configuration:
Multi-level one-way nesting
L0(15km), L1(5km), L2(1.5km)
Atmospheric forcing by COAMPS

Advantages:
(b) Portability by nesting
(c) Existing short-term predictive skill (Li et al., 2007b)

DA Method 2:
4-D Local Ensemble Tranform Kalman Filter (LETKF)

Unique Features:

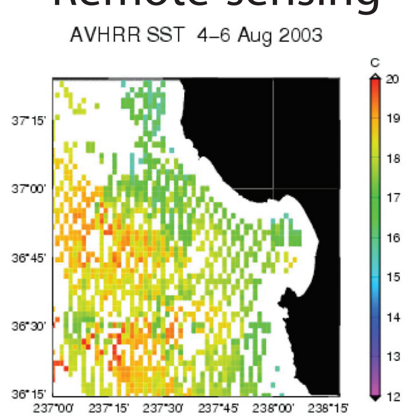
1. Analysis is performed locally at each model grid point, to address the issues common to EnKF methods
   - rank deficiency due to limited ensemble size ($K<<N$)
   - intense algebraic computations
2. Assimilation of asynchronous observations taken at intermediate times during one cycle.

Advantages:
(f) Practical handling of nonlinear, spatiotemporal phenomena by local analysis (Hunt et al., 2007)
(g) Efficiency by parallerization in both forecast and analysis (Hunt et al., 2007)
(g) Accuracy by local and asynchronous analysis, in particular data-poor regions (Szunyogh et al., 2007).
(h) portability by design of computational algorithm

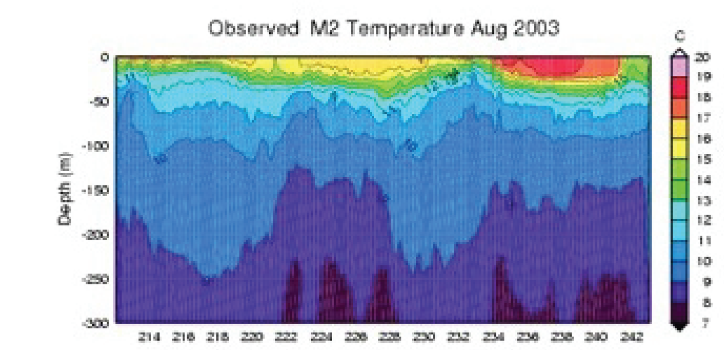
Observations:

Observation vector $\mathbf{y}_n$ *and operator* $\mathbf{h}_n$: $\mathbf{y}_n = \mathbf{h}_n(\mathbf{x}_n)$

Remote-sensing



In situ



Type		Platform	No/day
SST	Remote-sensing	Satellite	O(10^2)-O(10^4)
SSH	Remote-sensing	Satellite	0-O(10^3)
T & S	In situ	Mooring	O(10^2)

Type and number of current routine observations for the ROMS 3D-Var DA system.

Advantage (d): New types and increasing number of coastal ocean observations, partly by the Integrated Ocean Observing System (IOOS)

Concluding Remarks

The ROMS 4D-LETKF system: An ideal DA system by taking full advantage of the state-of-art ocean model and the advanced atmospheric DA method.

Future development: Including

1. feature tracking for eddies and fronts
2. adaptive sampling and observing system design
3. Lagrangian analysis tool for surface and 3D tracer fields

References

Hunt, B.R., E.J. Kostelich, and I. Szunyogh, 2007, Efficient data assimilation for spatiotemporal chaos: A local ensemble transform Kalman filter, Physica D.

Li, Z., Y. Chao, J.C. McWilliams, K. Ide, 2007a&b, A three-dimensional data assimilation scheme for the regional ocean modeling system, JAOT, submitted; A three-dimensional data assimilation scheme for the regional ocean modeling system: Implementation and basic experiments, JGR, accepted.

Szunyogh, I. and co-authors, 2007: A local ensemble transform Kalman filter data assimilation scheme for the NCEP global model, Tellus, accepted.