Nonlinear Ensemble Transform Filter (NETF) for Ocean Assimilation

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Motivation
In nonlinear systems, the analysis moments of the local ensemble transform Kalman filter (LETKF) are biased due to the Gaussian assumption for prior density and observation. The particle filter (PF) performs a non-parametric and Bayesian analysis, but suffers from weight divergence.

Approach: Nonlinear Ensemble Transform Filter (NETF) [2]
- Creates new, equally-weighted analysis ensemble such that its mean and covariance exactly match the Bayesian estimators
- Deterministic square root filter as the ETKF
- Domain localization as in the LETKF
- Outperforms (L)ETKF in Lorenz63/96 tests with small ensembles [2]

NETF Analysis Step: Analogy to the (L)ETKF

Transform forecast ensemble into analysis ensemble with exactly specified mean and covariance:
1. Update mean with weight vector w:
   \[ \bar{x}_a = \bar{x}_f + X_f w \]
2. Update perturbations with transform matrix T:
   \[ X'_a = X'_f T \]
3. Compose final ensemble:
   \[ x_a = \bar{x}_a + X_a \]

→ Identical update mechanism: NETF & ETKF only differ by the explicit entries in T & w!

High-Dimensional Ocean Twin Experiment

Model: NEMO v3.3
- Closed square basin, 0.25°, 5km depth
- Driven by zonal wind
- 74 years spin-up
- DA exp. in year 75

State vector
T, U, V, SSH
(321x81x11 grid)
\[ \text{dim(state)} = 3.3 \times 10^5 \]

Dynamics
- Double gyre circulation
- Central jet
- Mesoscale eddies
- as e.g. in North Atlantic

NETF
- Realistic & challenging assimilation experiment

ETKF
- Generic NETF, no model-dependent changes

Quantitative evaluation
RMSEs (normalized at t=0):
- strong error reduction with time compared to free run
- holds for observed (T, SSH) and hidden variables (U, V)
- filter remains stable

Comparison to LETKF
with CRPS (averaged over T,U,V,SSH)
Considers entire ensemble distributions
- NETF requires a longer spin-up phase than LETKF
- But: better score after convergence

Results and Evaluation [4]

Qualitative evaluation
Snapshots of SSH [m] on day 260:
- NETF reproduces the true circulation
- NETF successfully assimilates the observations

Future work
- More large-scale applications
- Comparison to EWPF
- Extension to nonlin. smoother

Conclusions and Outlook

Conclusions
- Promising nonlinear filter for high-dim. assimilation
- Simple implementation: analog to (L)ETKF
- Works well in Lorenz to ocean models with small ensemble sizes: overcomes curse of dimensionality

Successful development
- Theoretical justification
- Toy models
- Realistic large-scale models

References

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