Temperature and Altimetry Assimilation into a High Resolution OGCM with a Localized Ensemble Kalman Filter

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Outline

- Poseidon OGCM and GMAO coupled forecasting system
- EnKF implementation for Poseidon
- Assimilation experiments
- Impact of T+SSH assimilation on CGCM seasonal hindcast skill
**GMAO CGCM coupled forecasting system**
- **GMAO AGCM**, 2 x 2.5 x L34
- **LSM**: Mosaic (SVAT)
- **OGCM**: Poseidon v4, 1/3 x 5/8 x L27

- Production ODAS: OI of in situ temperature profiles with salinity adjustment
- Experimental ODAS: EnKF

Note: ODAS is run on OGCM prior to coupling to AGCM & LSM

**OGCM**
- Poseidon (Schopf and Loughe, 1995)
- Quasi-isopycnal vertical coordinate
- Prognostic variables are h, t, s, u and v
- Sea surface height (SSH) is diagnostic: \( \eta = \sum \text{buoyancy}(t_i, s_i) h_i \)
- About 30 million prognostic variables at 1/3 x 5/8 x L27 resolution

**CGCM and OGCM**
System-noise modelling
- Model errors: use model EOFs to generate state perturbations
- Forcing errors: add random perturbations to wind stress forcing

Multivariate update
- Multivariate compactly supported covariances
- Update T, S, u & v
- Layer thicknesses (h) adjust between analyses
- Incremental update
- Process SSH and T observations separately

Parallel implementation (message passing: MPI, SHMEM)
- Runs on SGI Altix or HP SC45
- Time/month on 240 Altix CPUs:
  - 8+1 ensemble members: 2.1 hours
  - 16+1 ensemble members: 3.8 hours
  - 32+1 ensemble members: 7 hours

Online bias estimation
- Used in SSH assimilation

Hybrid (3DVAR + ensemble) covariances
- Used in T assimilation

EnKF implementation
a) Standard assimilation

Assimilation alters the model climatology

b) Assimilation with Online bias estimation (OBE)

Estimates of variability (biased model state) and climatological error (bias) are evolved side by side

Online bias estimation
Assimilation experiment

- Assimilate T/P anomalies + TAO & XBT temperature profiles 1/1/2001-12/31/2001
- Online bias estimation in SSH assimilation
- Random forcing from 32 OGCM leading EOFs + wind-stress perturbations
- Compare 9, 17 & 33 member EnKF
- Compare with
  - no-assimilation control
  - Production ODAS (temperature OI + salinity correction)
T OI affects SSH bias even though OI + S(T) doesn't process SSH.

- Control is most biased
- OI partly corrects SSH bias
- EnKF runs have no noticeable SSH bias

Free model run climatology used to reconstruct SSH field from T/P anomalies.

Note the differences in scales!
T assimilation in EnKF runs uses hybrid 3DVAR + EnKF covariances

Note the differences in scales!

Hybrid covariances used in T assimilation with EnKF result in stronger data weights than OI+S(T)
Marginal T Kalman gains for a 1C innovation at two different locations.

Horizontal sections

EnKF 32 - 12/31/01

32 leading EOFs

Zonal sections
Marginal S Kalman gains for a 1σ T innovation at two different locations (units of σ_e).

Horizontal sections

Zonal sections
Marginal T Kalman gain for a unit T innovation at (125W, 0N, 100m)

Steady state: 32 leading EOFs

March 31, 2001
EnKF 9

June 30, 2001
EnKF 17

September 31, 2001
EnKF 33

December 31, 2001

Steady state: 32 leading EOFs
Marginal S Kalman gain for a 1 $\sigma_T$ innovation at (125W, 0N, 100m)

- EnKF9 produces spurious covariance structures
- Apparent consistency between EnKF17 & EnKF33

Steady state: 32 leading EOFs
Impact of assimilation on CGCM hindcast skill

• Old code with assimilation in model layers: 17-member EnKF
• Assimilate T + SSH for February–April of each year of 1993–2002
• Couple OGCM to AGCM & LSM after running ODAS
• 12-month CGCM hindcasts initialized using ocean states from EnKF runs (to save CPU time, CGCM hindcasts have only 5 ensemble member)

• Assess impact of assimilation on SST hindcast skill
• Compare to history of CGCMv1 May-start hindcasts (problematic month)
Niño-3.4 SST

EnKF T+SSH, OBE

NSIPP CGCMv1 tier 1

missed EN

False EN alert

false LN alert
Conclusions

- Online bias correction important when T data & SSH anomalies are assimilated.
- 16+1 and 32+1 EnKF runs have comparable performance.
- EnKF-initialized hindcasts can miss or underestimate El Niño events but result in less false El Niño or La Niña alerts than production forecasts.