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: $\eta = \Sigma_i \text{buoyancy}(t_i, s_i)\, h_i$
- About 30 million prognostic variables at 1/3 x 5/8 x L27 resolution

CGCM and OGCM

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

System-noise modelling

- Model errors: use model EOFs to generate state perturbations
- Forcing errors: add random perturbations to wind stress forcing

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

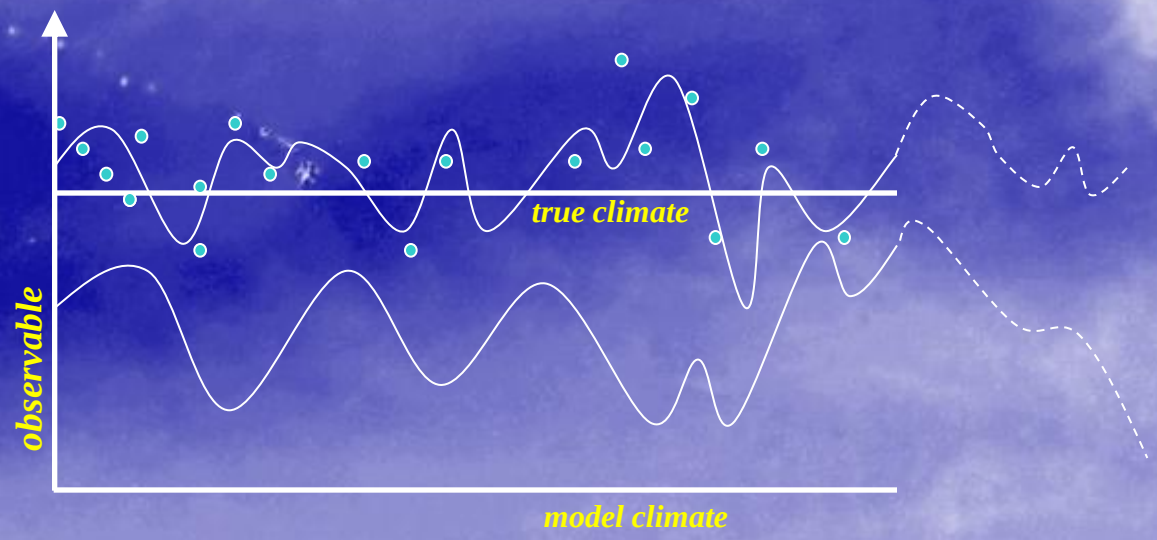
- Used in SSH assimilation

Hybrid (3DVAR + ensemble) covariances

- Used in T assimilation

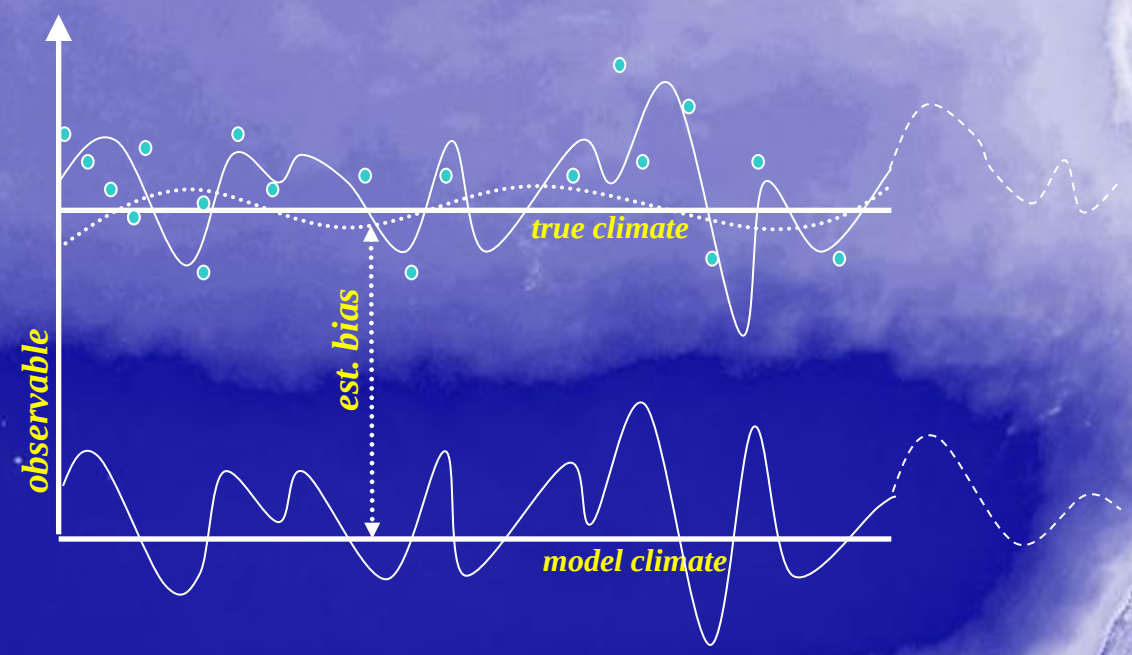
EnKF implementation

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

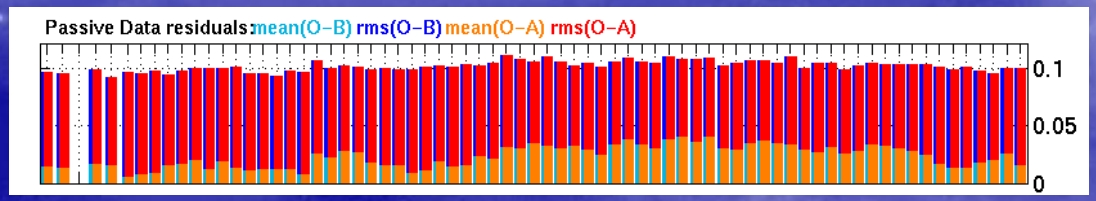
- Assimilate T/P anomalies + TAO & XBT temperature profiles 1/1/2001-12/31/2001
- Online bias estimation in SSH assimilation
- Random forcing from 32 OGCM leading EOFs + wind-stress perturbations
- Compare 9, 17 & 33 member EnKF
- Compare with
    - no-assimilation control
    - Production ODAS (temperature OI + salinity correction)

Experiments

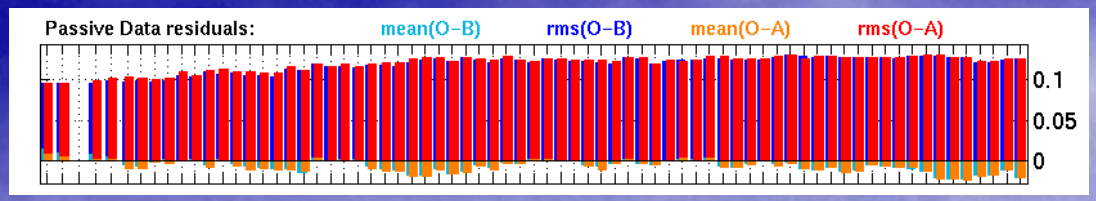
SSH OMF and OMA statistics

mean OMF
RMS OMF
mean OMA
RMS OMA

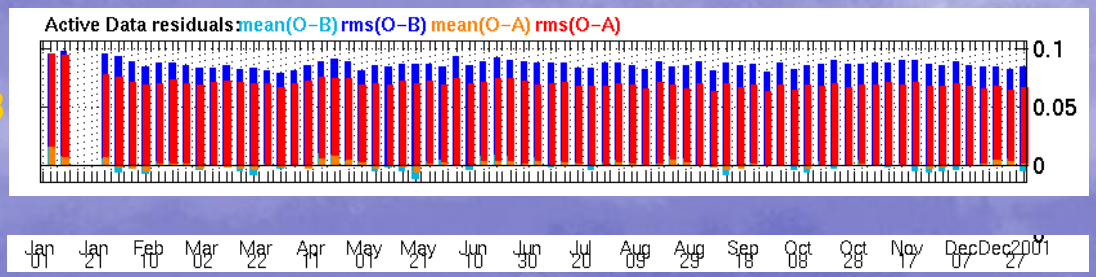
Control



OI+S(T)



EnKF 33



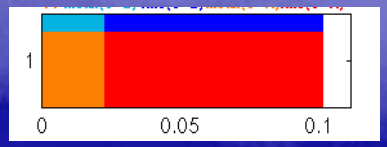
Time series

Note the differences in scales!

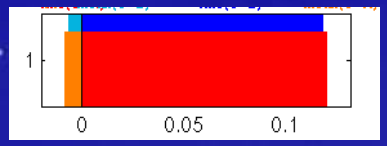
T OI affects SSH bias even though OI + S(T) doesn't process SSH

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

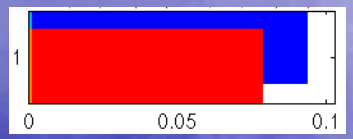
Control



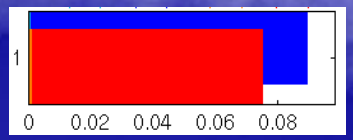
OI+S(T)



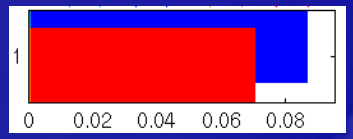
EnKF9



EnKF17



EnKF33



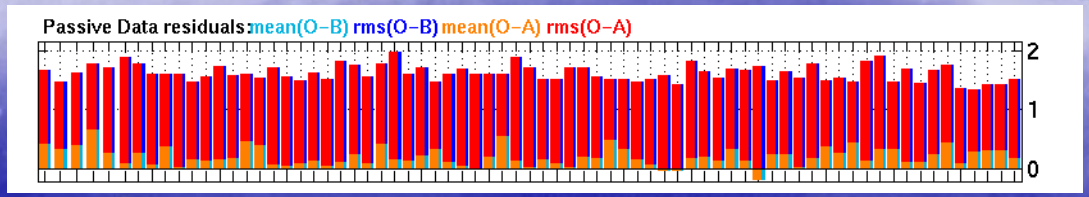
- Control is most biased
- OI partly corrects SSH bias
- EnKF runs have no noticeable SSH bias

Time averages

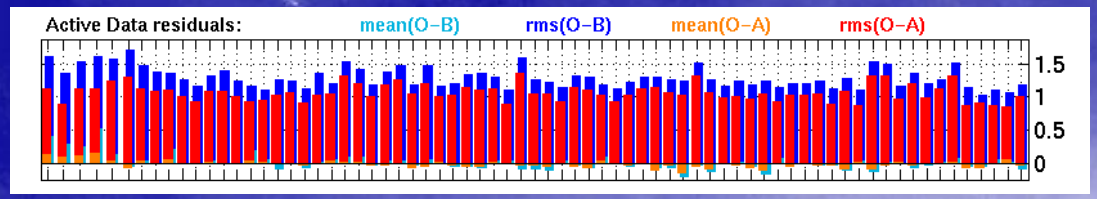
T OMF and OMA statistics

mean OMF
RMS OMF
mean OMA
RMS OMA

Control

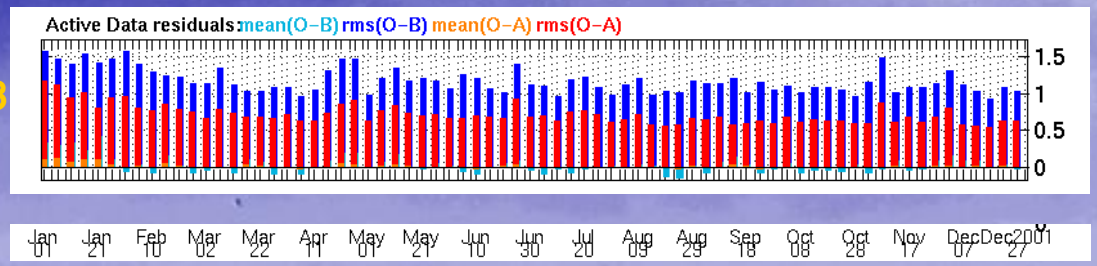


OI+S(T)



Note the differences in scales!

EnKF 33

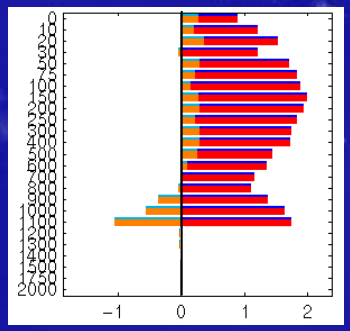


T assimilation in EnKF runs uses hybrid 3DVAR + EnKF covariances

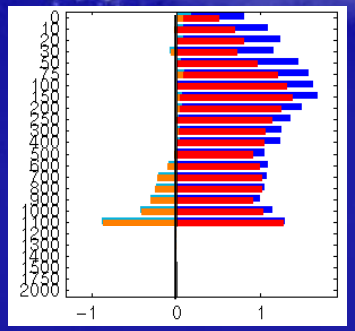
Time series

(Hybrid covariances used in T assimilation with EnKF result in stronger data weights than OI+S(T))

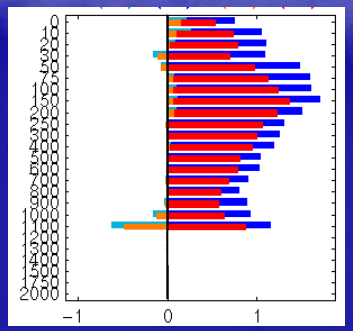
Control



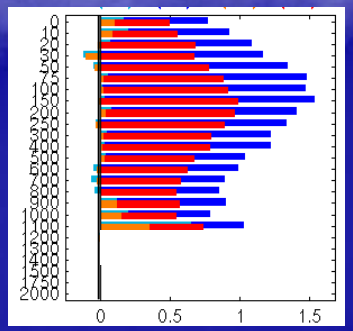
OI+S(T)



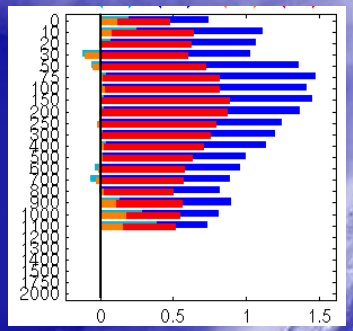
EnKF9



EnKF17

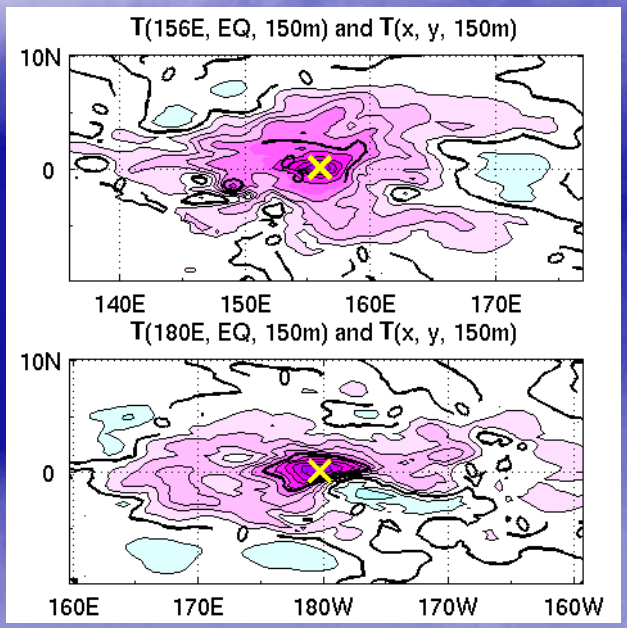


EnKF33

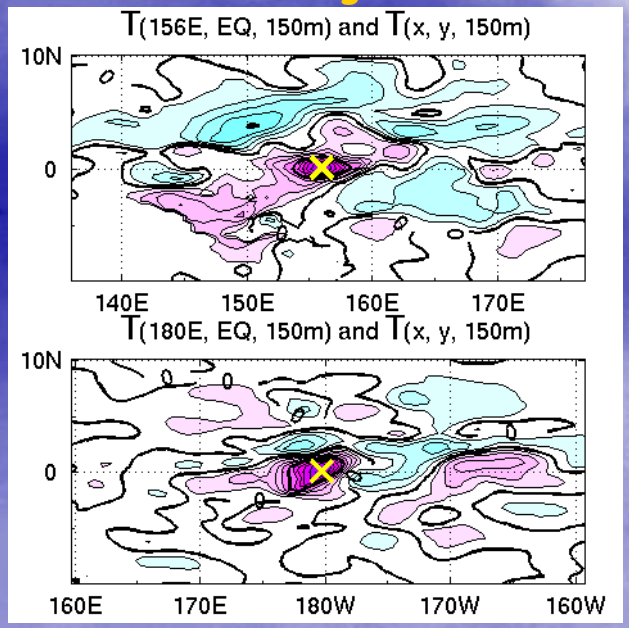


Time averages

EnKF 32 - 12/31/01



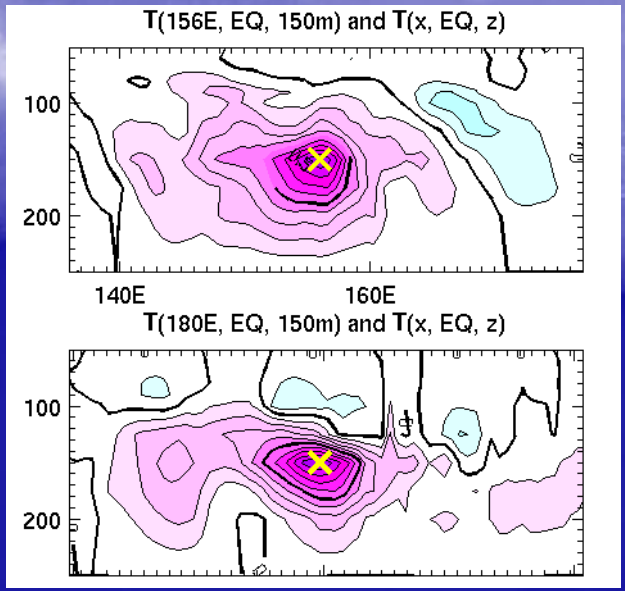
32 leading EOFs



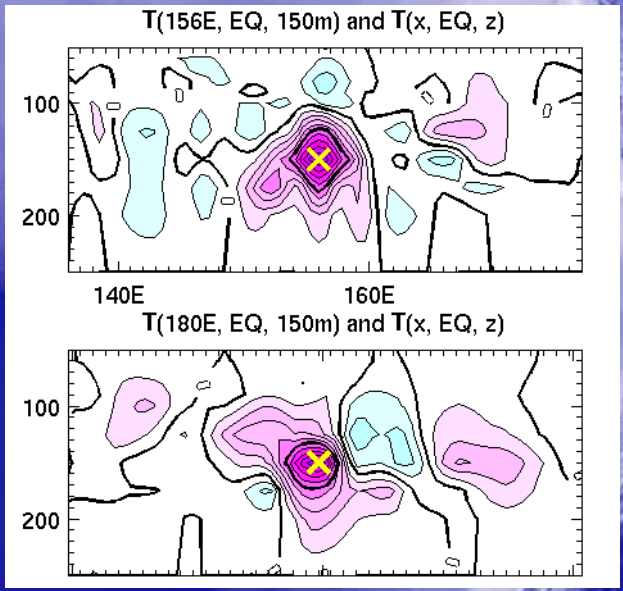
Horizontal sections

Marginal T Kalman gains for a 1C innovation at two different locations

EnKF 32 - 12/31/01

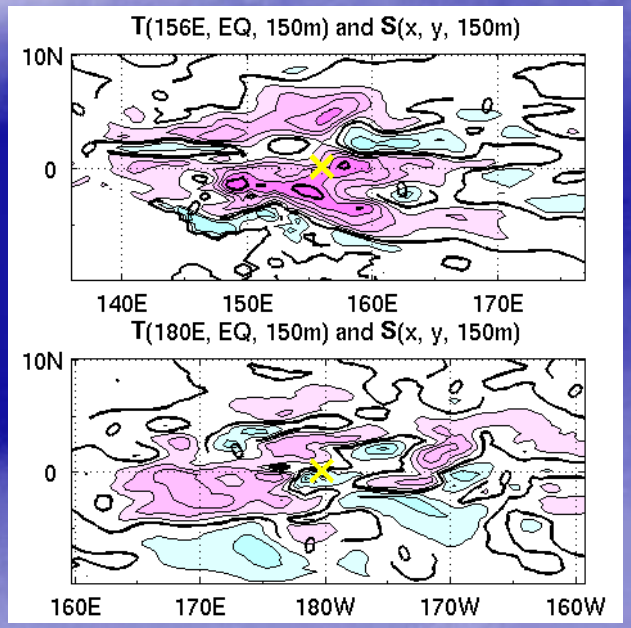


32 leading EOFs

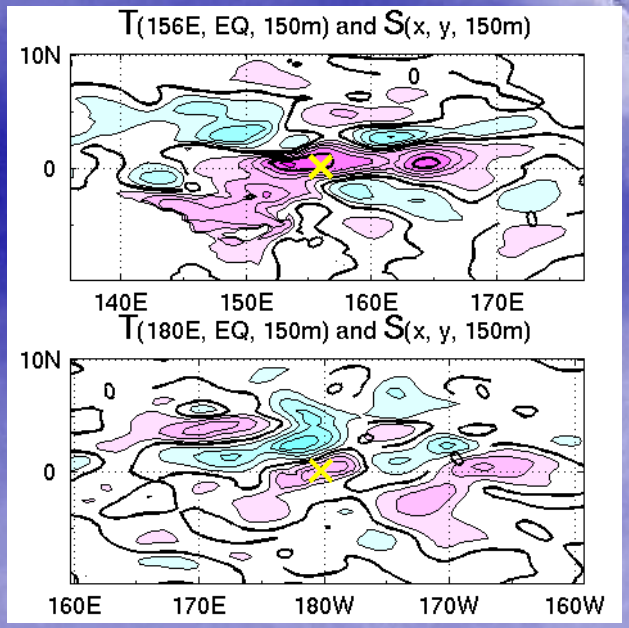


Zonal sections

EnKF 32 - 12/31/01



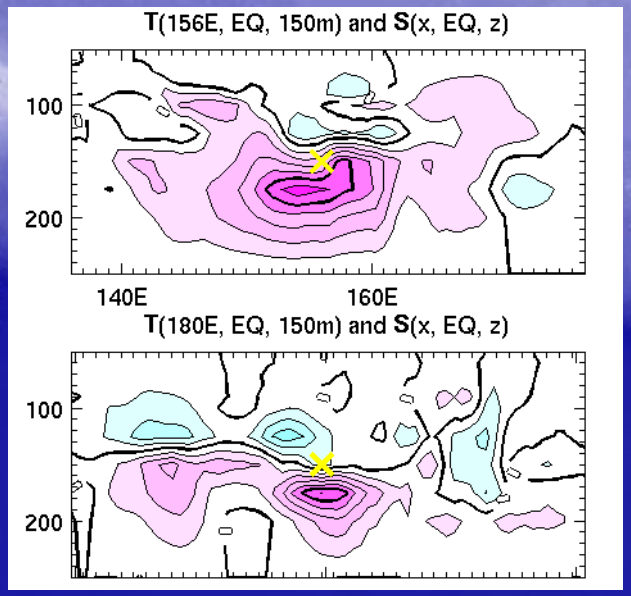
32 leading EOFs



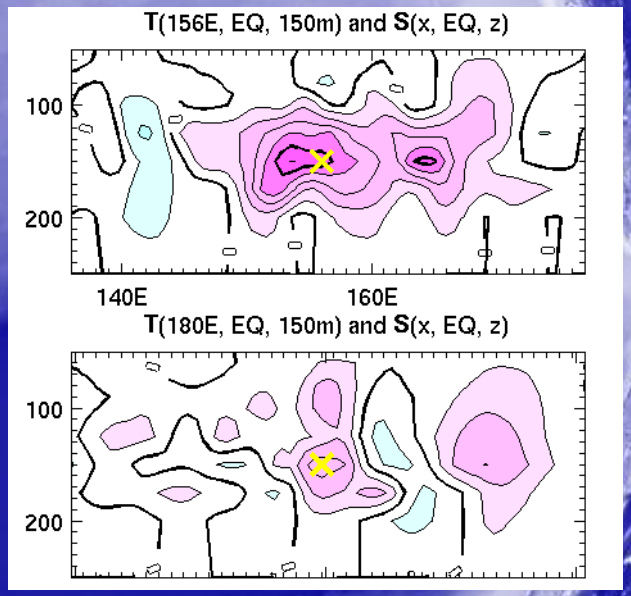
Horizontal sections

Marginal S Kalman gains for a $1\sigma_t$ T innovation at two different locations (units of σ_s)

EnKF 32 - 12/31/01



32 leading EOFs

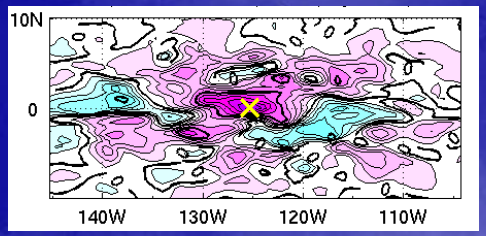


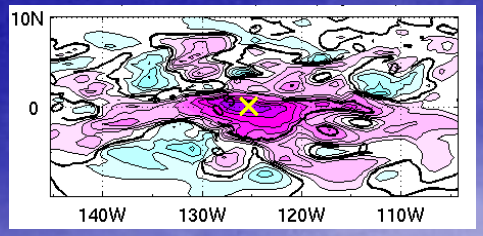
Zonal sections

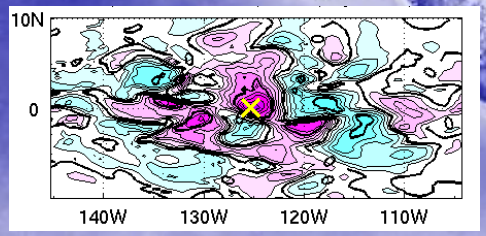
Marginal T Kalman gain for a unit T innovation at (125W, 0N, 100m)

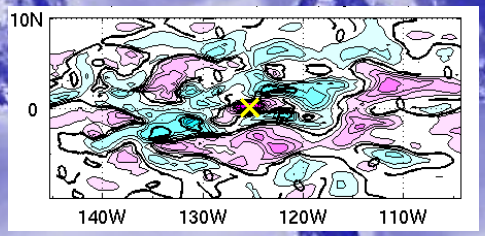
March 31, 2001 | June 30, 2001 | September 31, 2001 | December 31, 2001

EnKF 9

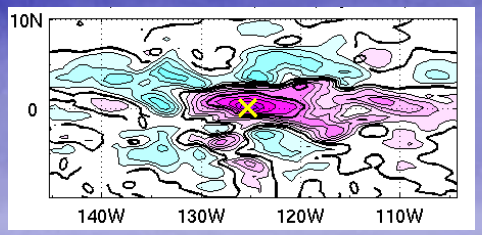


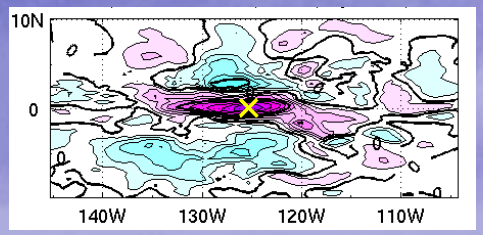


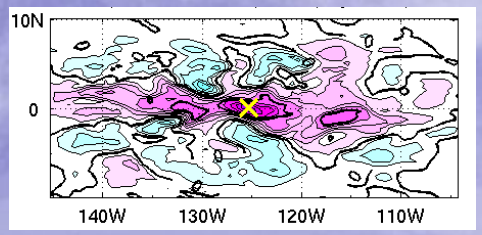


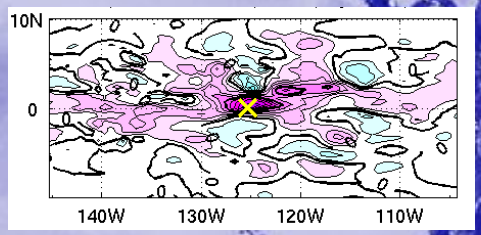


EnKF 17

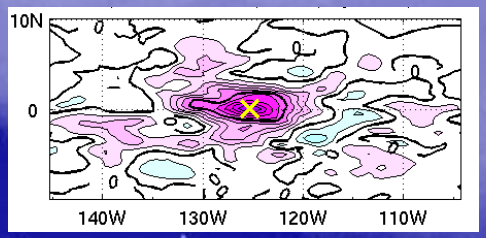


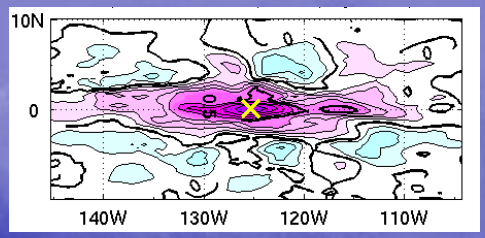


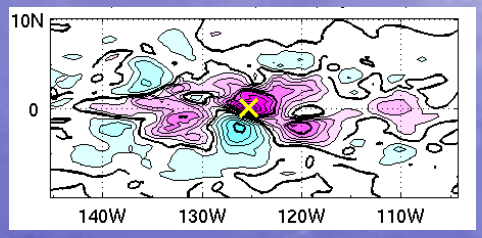


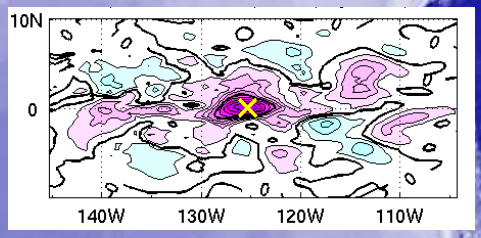


EnKF 33

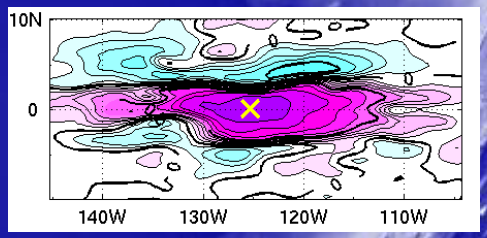




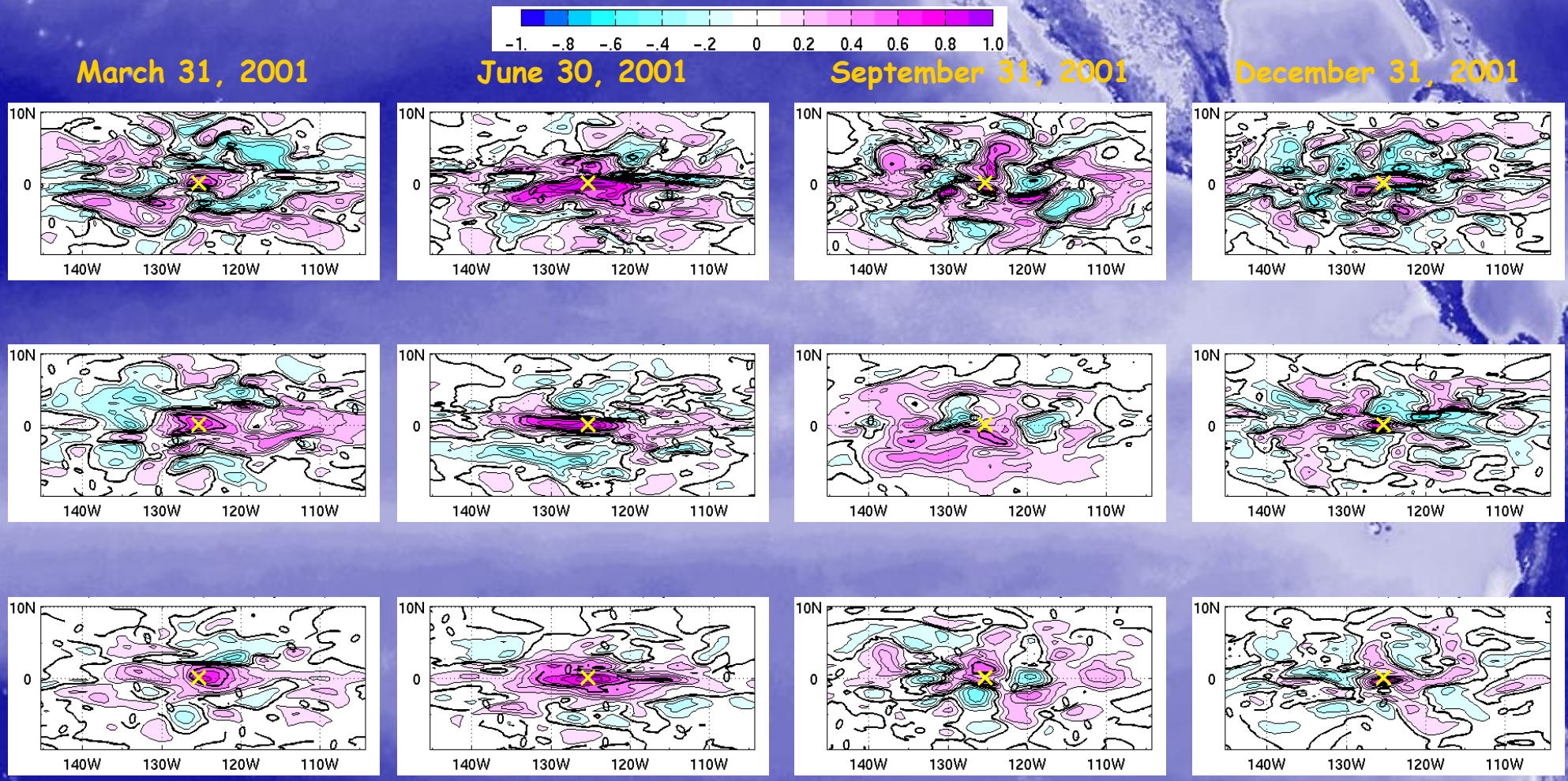




Steady state: 32 leading EOFs

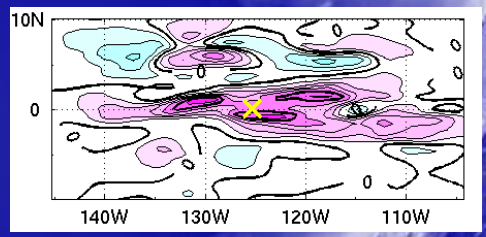


Marginal S Kalman gain for a 1 σ_t T innovation at (125W, 0N, 100m)



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

Steady state: 32 leading EOFs

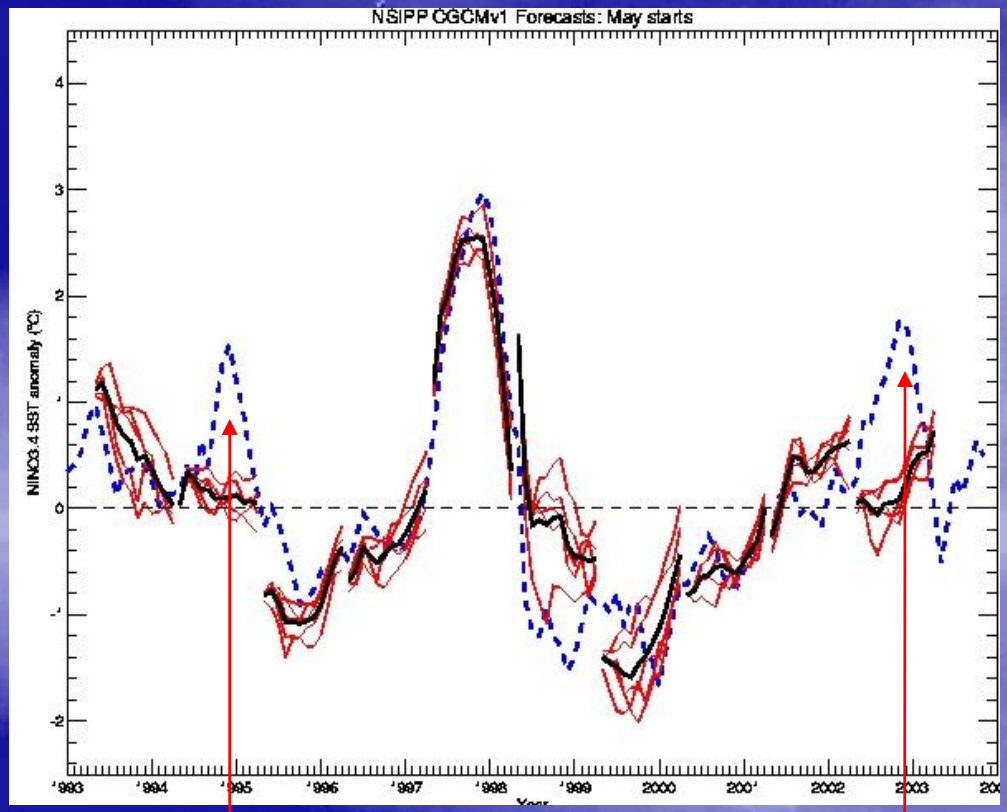


Impact of assimilation on CGCM hindcast skill

- 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)

EnKF T+SSH, OBE

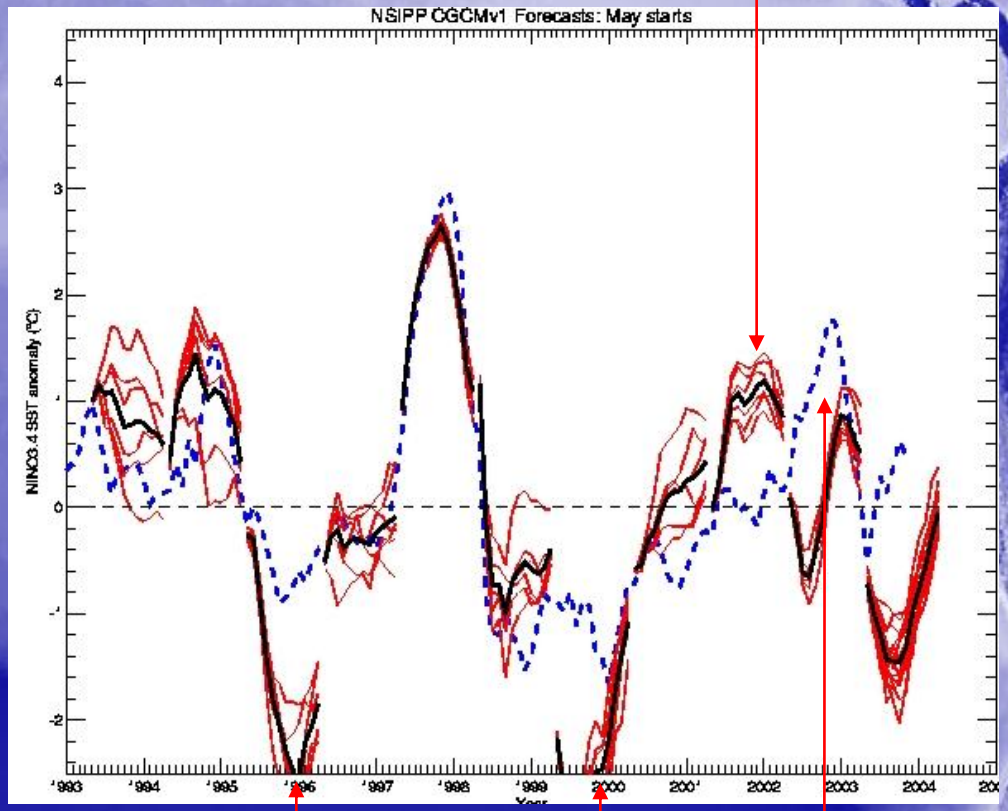


missed EN

missed EN

NSIPP CGCMv1 tier 1

False EN alert



missed EN

false LN alert

false LN alert

Niño-3.4 SST

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