



Coupled Model Initialization and ENSO Prediction

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OUTLINE

- Review ocean initialization
- GFDL Seasonal/Interannual forecasting system
- Coupled Model Assimilation - Ensemble Kalman Filter (EnKF)
- Retrospective forecasts - comparison between 3Dvar and EnKF



Where could advances in ENSO prediction come from?

- Model Improvements - reducing systematic errors
- Constraining Initial Conditions
 - Particularly important in ocean because the memory of ENSO resides there.
 - The importance of ocean subsurface data in making ENSO predictions has been demonstrated in a number of studies.
 - Is the best ocean analysis the best initialization?
- How should we choose the ensemble perturbations?
Presently most models only take into account the uncertainty in atmos. ic



ODA

- There are many assimilation schemes : 3D-Var, 4D-Var, EKF, and many variants.
- Basically a minimization of a cost function comprising of two terms: an observation term (J_o), which measures the misfit between obs and model and a background term (J_b), which measures the misfit of the unknown model state to the background state.
- Data may include: SST, SSH,TAO, XBT, ARGO etc.



Coupling Shock

- Initialization schemes could all suffer from the inconsistencies between the interaction of the model and initial conditions.(eg. The model winds along the eq. do not support the assimilation thermocline slope)
- In order to mitigate coupling shock coupled model initialization schemes have been developed.



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GFDL CM2 Coupled Model Components

- Ocean Model - MOM4-SIS – ocean-ice (Griffies et al 2004)
- ODA – 3Dvar assimilation (Rosati, 1995) and EnKF
<http://data1.gfdl.noaa.gov/nomads/forms/assimilation.html>
- AM2 / LM2 – atmosphere / land (Anderson et al., 2004)
FV Dynamical core (S.J. Lin 2004) – AM2.1
2.5° lon X 2.0° lat X 24 vertical levels



Initialization for SI Prediction GFDL AM2 and CM2

Atmosphere

NCEP R2 T62L28 for mass and momentum

(Ensemble members chosen 12 hr apart) + AMIP moisture + CM2
SST anomalies CM2.1, fully coupled GCM – 10 member ensemble, 1 year
predictions, 1980->2005+
I.C. = Jan1 ... Dec1 (1980->2005)

Land

AMIP

Off-line LM2 + "obs" precip

Ocean

ODA - 3Dvar/EnKF

Perfect Model

Use one of the ensemble members as the truth and compare to the
remaining nine members





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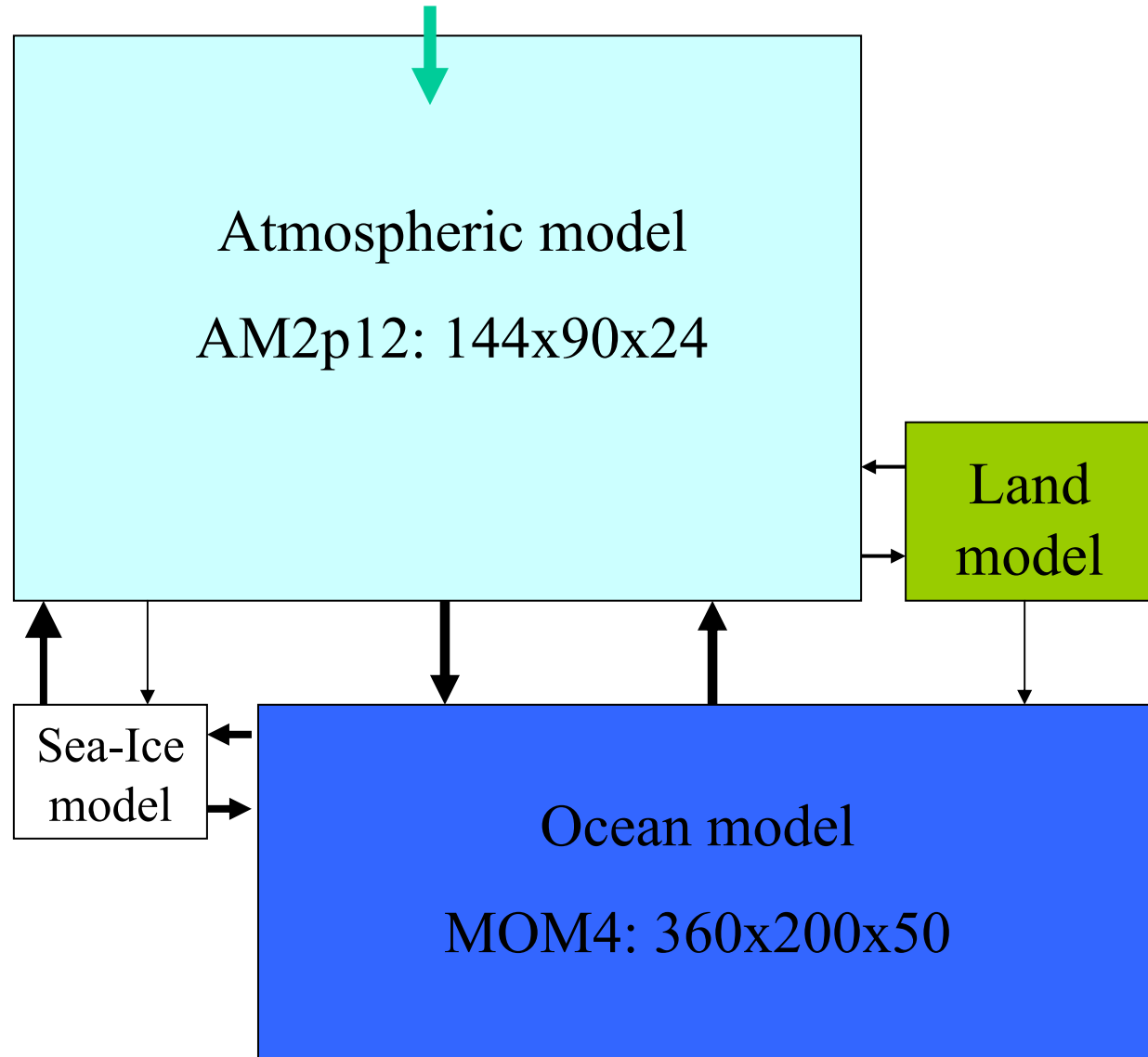
Ensemble Kalman Filter coupled data assimilation system

- Perfect model study framework
 - A model simulation as target
 - Real-time oceanic observing network samples oceanic states
 - Gridded (reanalysis) atmospheric variables sample atmospheric states
- Multi-variate analysis scheme
 - Maintenance of the T-S relationship in Oceanic Data Assimilation (ODA)
 - Maintenance of geostrophic balance in Atmospheric Data Assimilation (ADA)
- Analysis of oceanic states using 20th century ocean observational network
 - ENSO variability
- Impact of ODA's initialization on ENSO forecasts
 - Vertical structure of forecasted NINO3, NINO3.4 and NINO4 temperature
 - Forecast skill in NINO3, NINO3.4 and NINO4
- Potential Impact of CDA's initialization on ENSO forecasts
 - Case study for a strong ENSO warm event
 - Forecast skill in NINO3, NINO3.4 and NINO4



CDA System: GFDL Coupled Climate Model

green-house-gas + natural aerosol radiative forcing



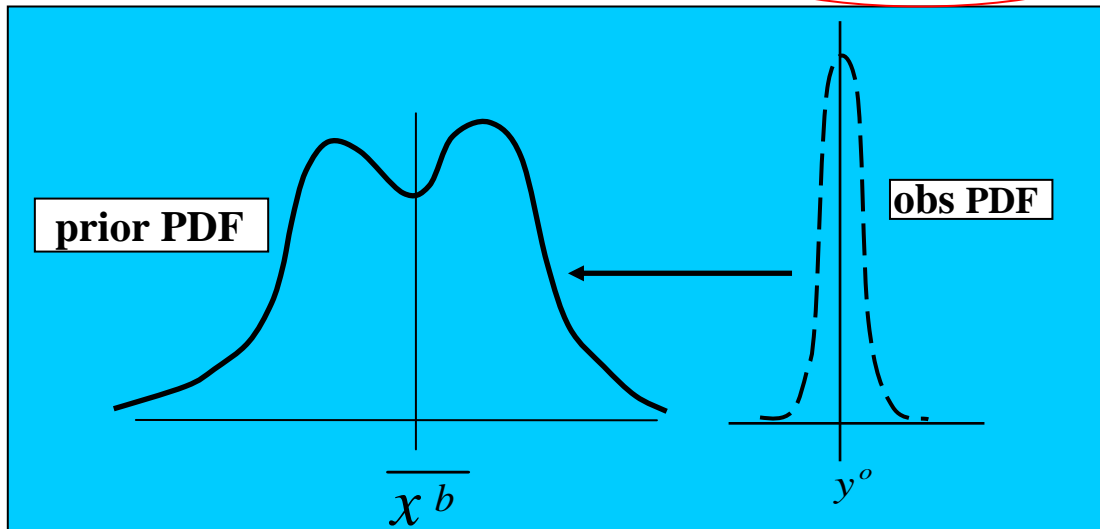


CDA System: Filtering Algorithm

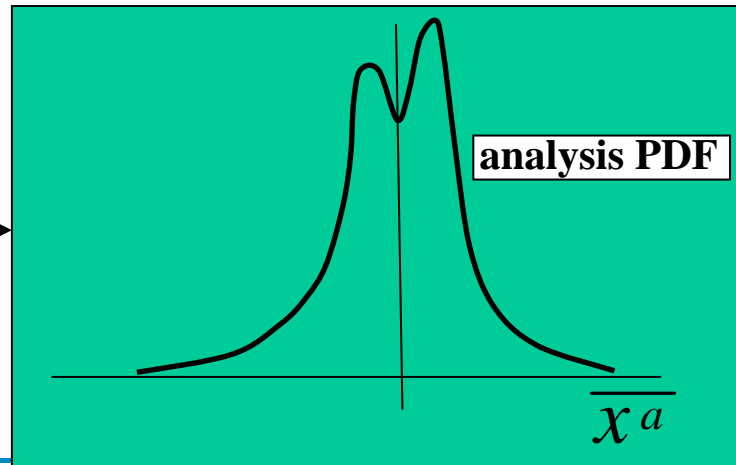
Deterministic (being modeled) Uncertain (stochastic)

6 4 4 7 4 4 8 6 4 7 4 8

$$d\mathbf{x}_t / dt = f(\mathbf{x}_t, t) + \mathbf{G}(\mathbf{x}_t, t) \mathbf{w}_t$$



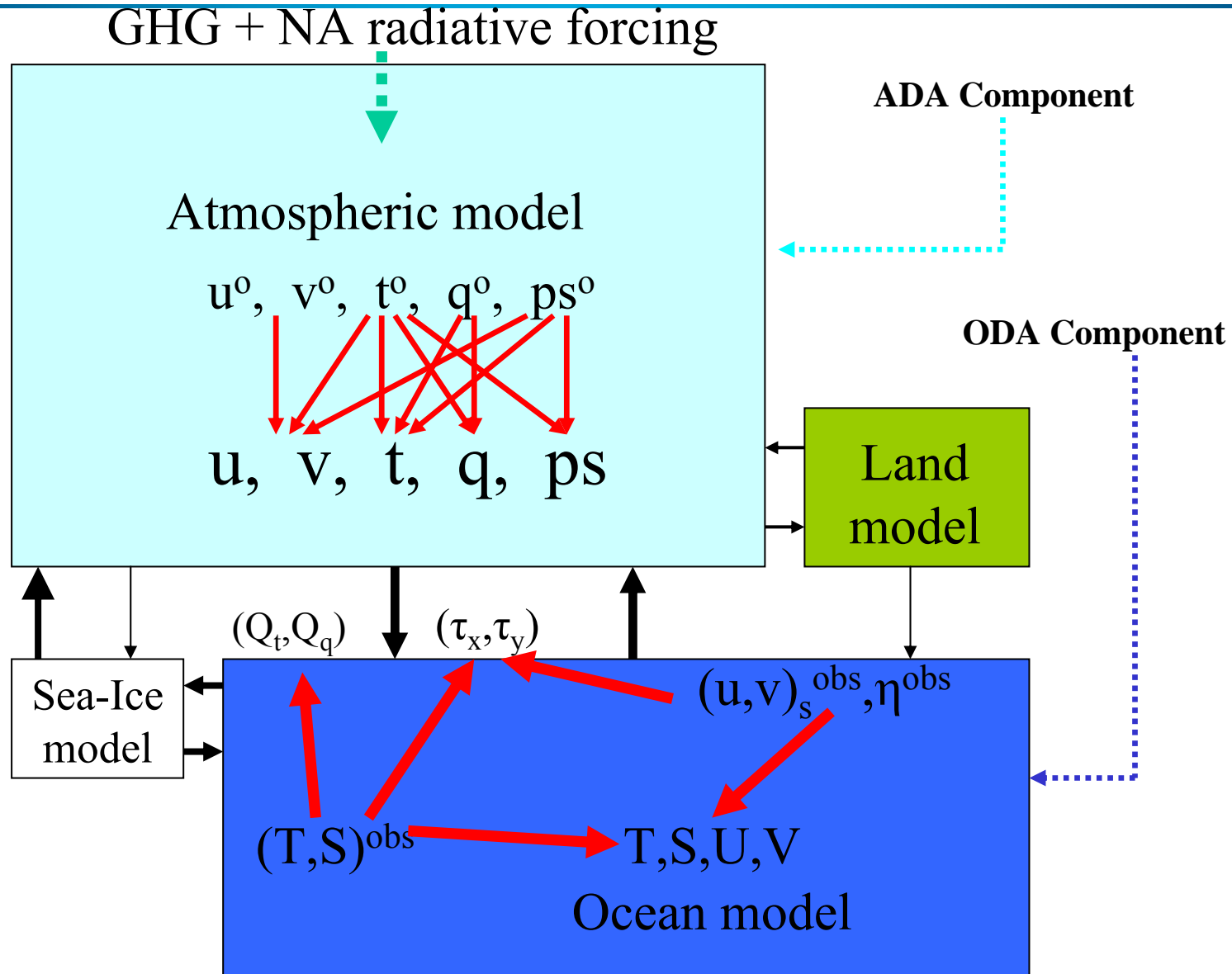
**Data
Assimilation
(Filtering)**



- ✓ Atmospheric internal variability
- ✓ Ocean internal variability (model does not resolve)



CDA System: Multi-Variate Analysis Scheme





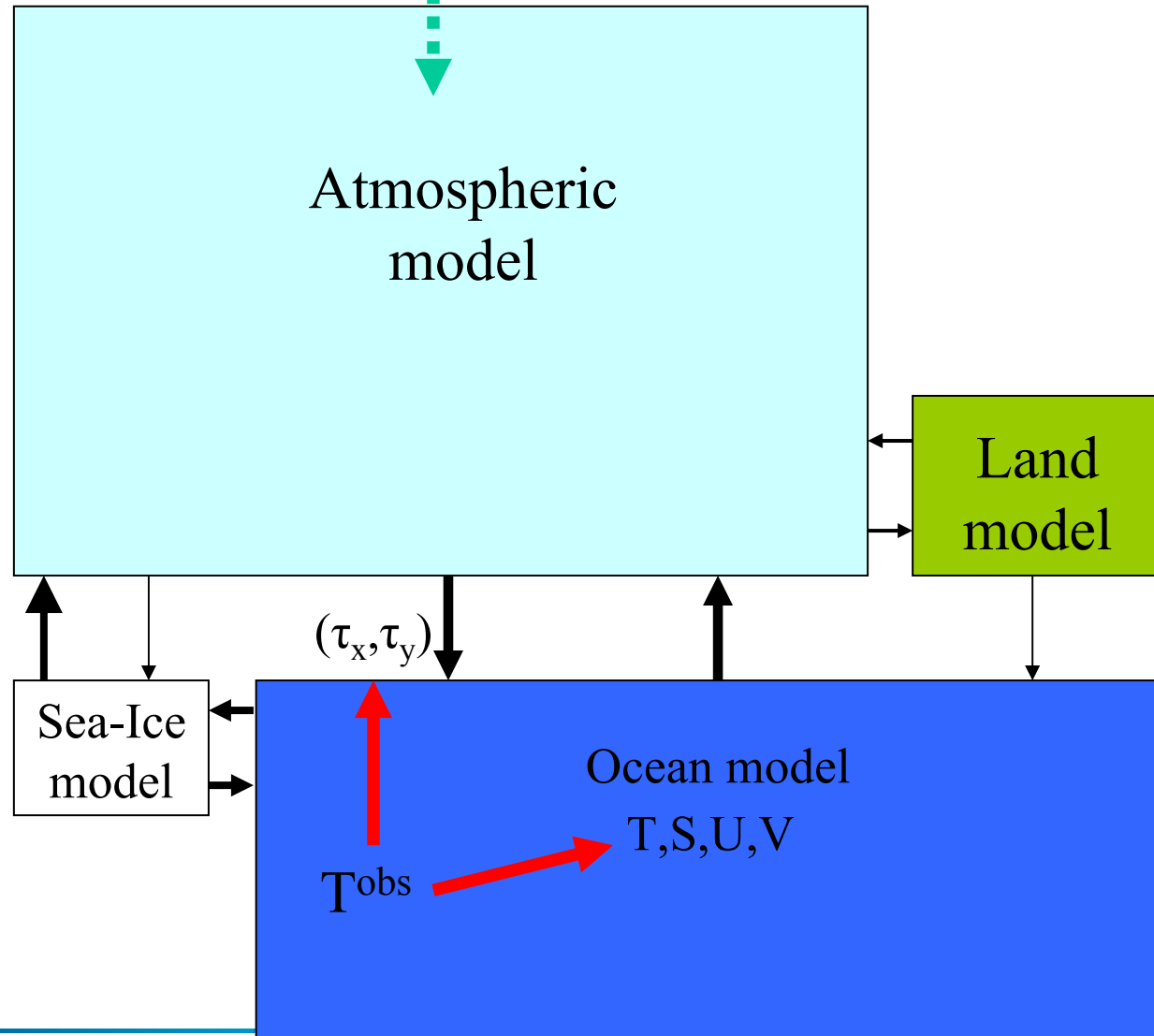
Analysis of Climate States in Perfect Model Study: Assim Configuration

- Idealized twin experiments:
 - Truth: 20th Century climate simulation forced by time-varying green-house-gas radiation (IPCC historical run)
 - Observations: Projecting the IPCC historical run temperature onto 20th century ocean temperature observational network (XBT, CDT, MBT, TAO, ...), plus an $N(0,0.5)$ white noise
- Assimilation Model: CM2.1 control run
- Initialize the model from arbitrary initial conditions (75 years ago, for instance)



Analysis of Climate States in Perfect Model Study: Oceanic Assim Scheme

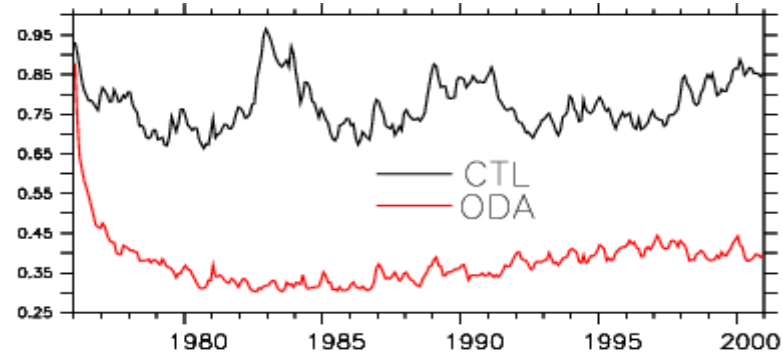
1860 GHG and NA radiative forcing



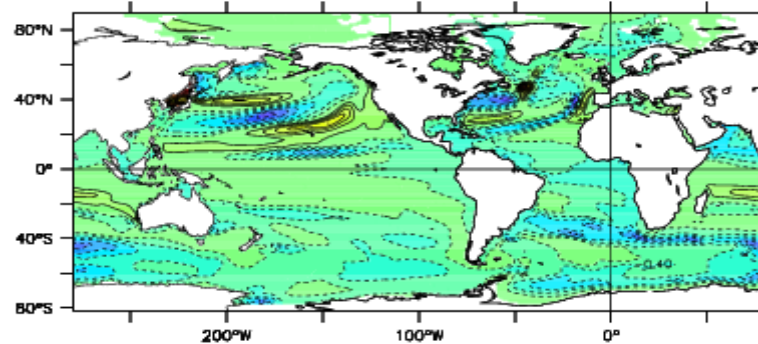


Analysis of Oceanic States : Oceanic Temp Errors

Temp errors
over top 500m

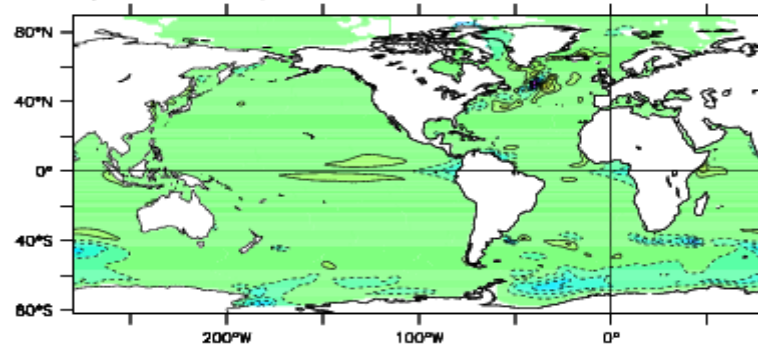


b) CTL temp errors



CTL Mean Errors

c) ODA temp errors

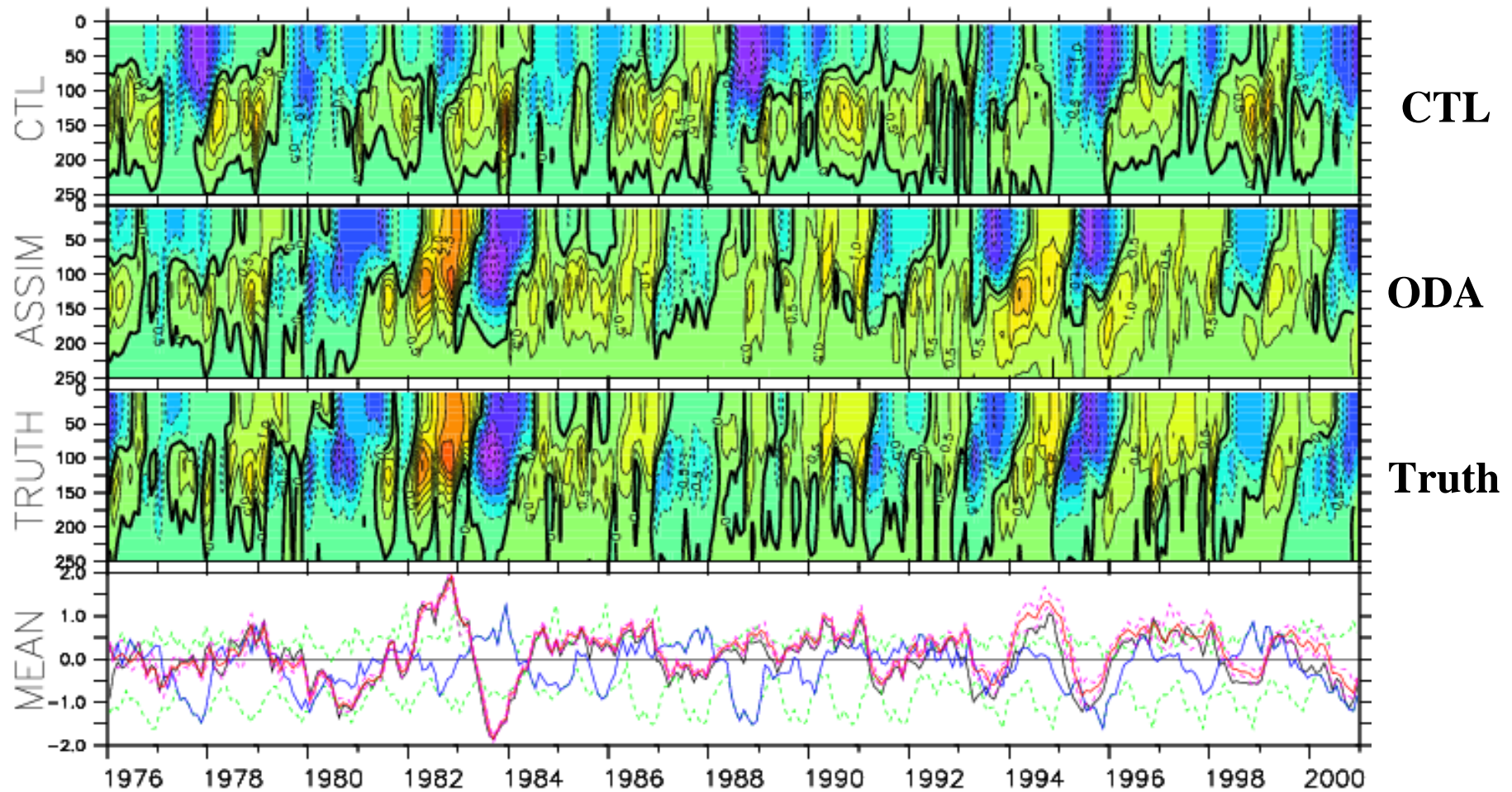


ODA Mean Errors



Analysis of Oceanic States : ENSO variability

NINO3.4 temperature



Truth

— ODA

- - - ODA spread bounds

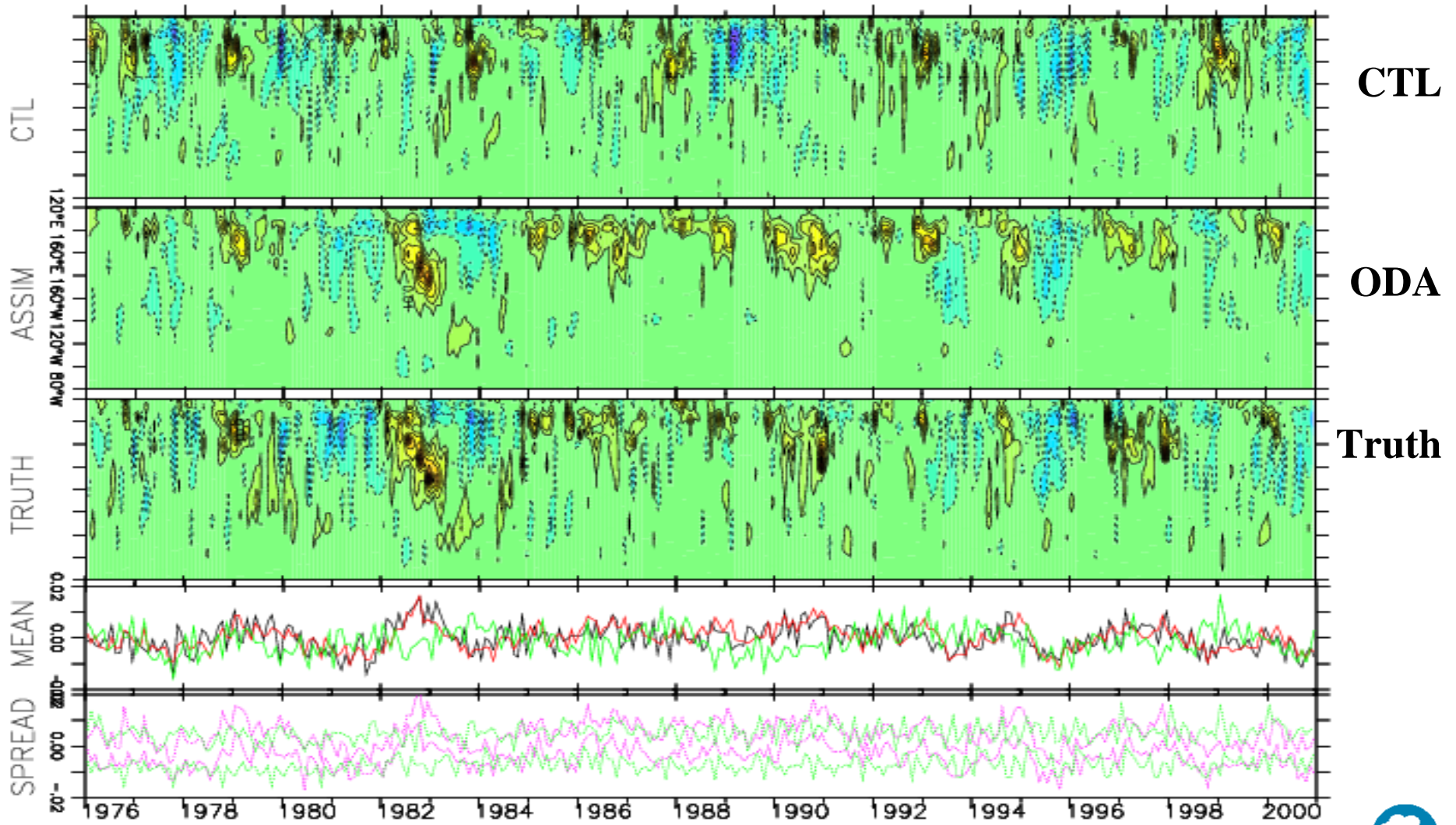
— CTL

- - - CTL spread bounds





Analysis of Oceanic States : ENSO variability: τ_x at tropical Pacific (5S-5N mean)

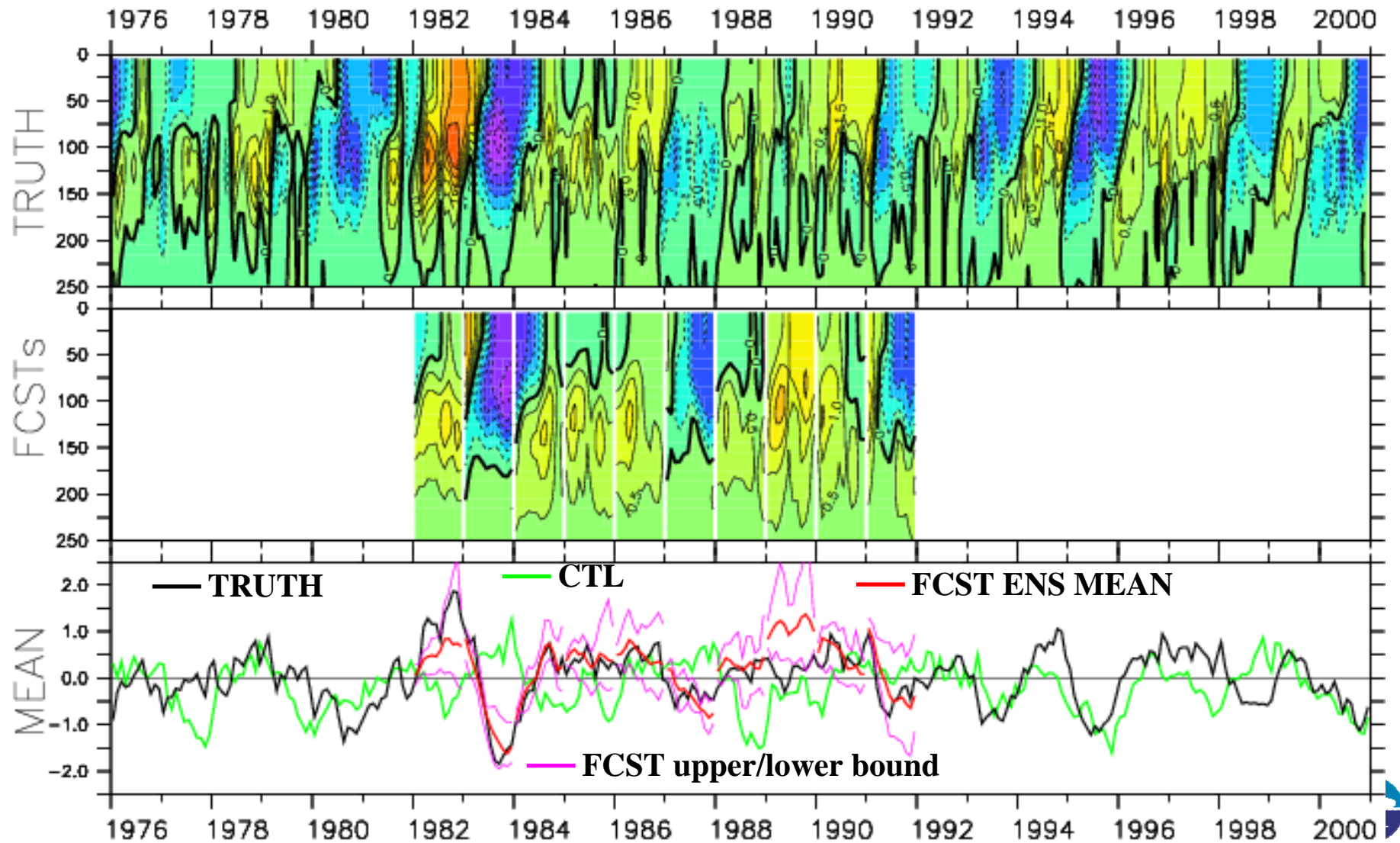


truth — ODA — CTL - - - ODA spread bounds - - - CTL spread bounds





Impact of ODA's Initialization on ENSO forecasts: Nino3.4 temperature anomaly



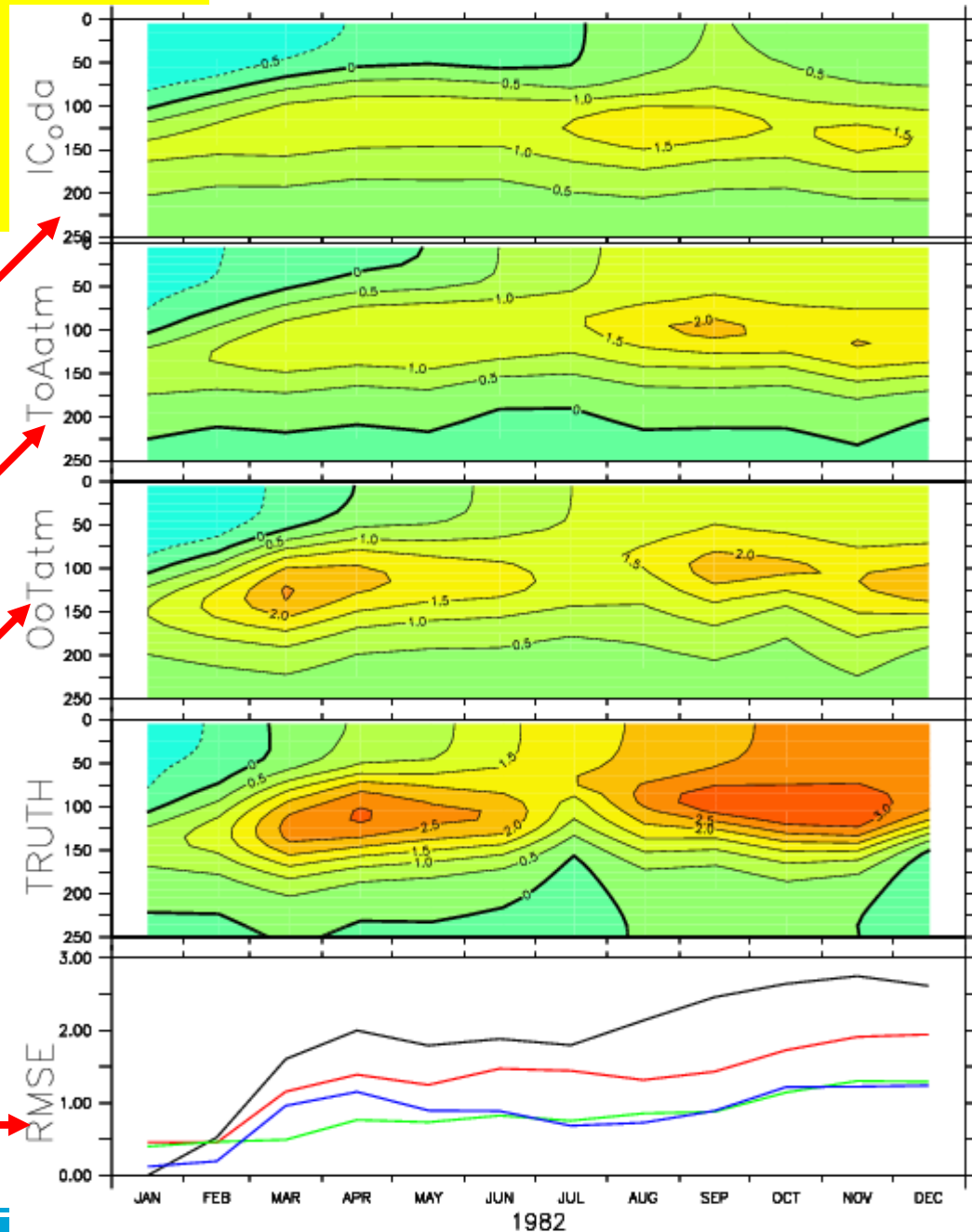
Impact of CDA's ICs on ENSO forecasts: A case study: 1982

NINO3.4 temperature

Initialize the coupled model from:

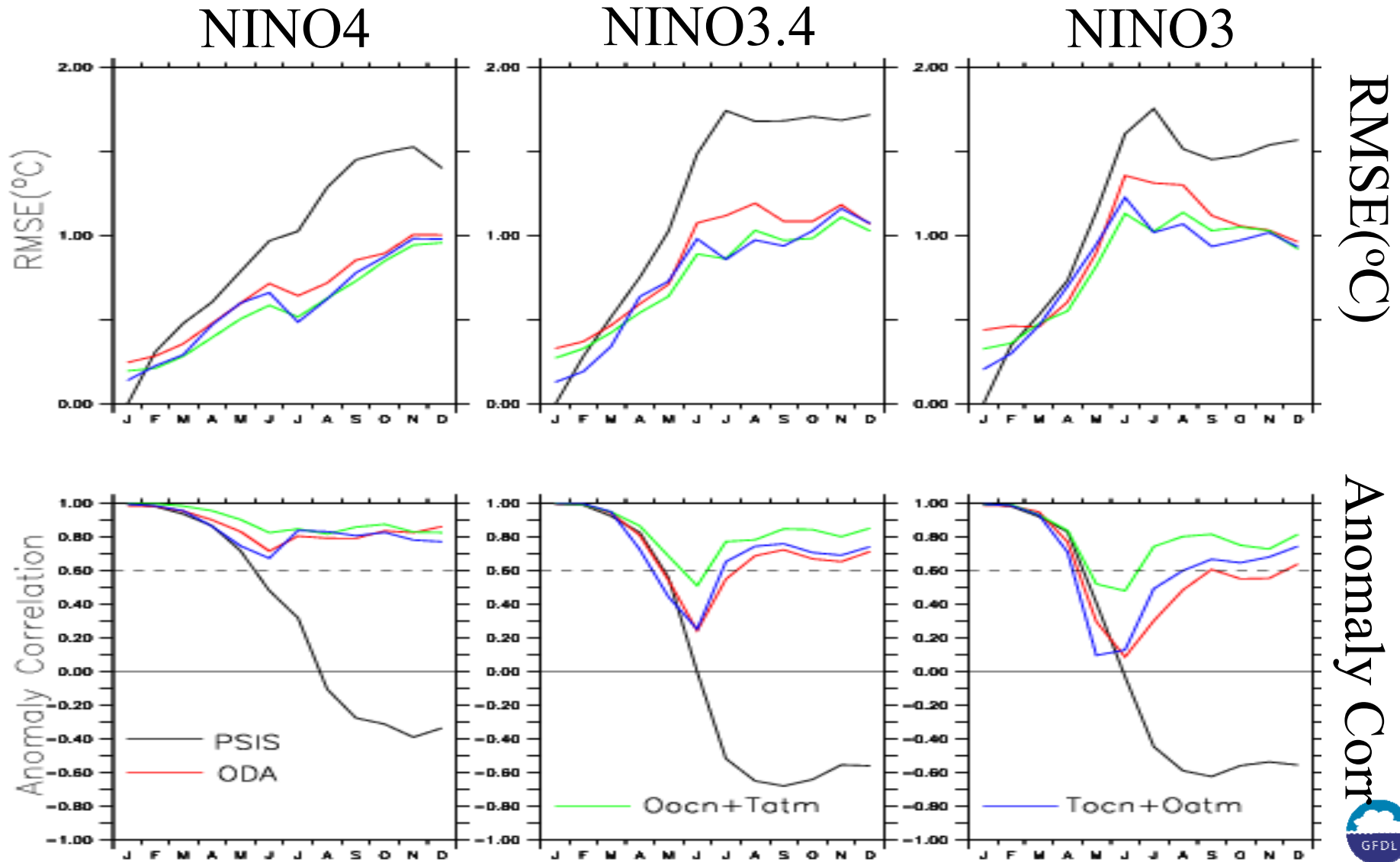
- ODA atmos and ocean
- Perfect ocean and ODA atmos
- Perfect atmos and ODA ocean
- Persistent forecast

RMSEs of 4 forecasts





Potential Impact of CDA's Initialization on ENSO forecasts: SST's forecast skills



RMSE(°C)

Anomaly Corr





Summary for ENSO forecast experiments

- The ensemble mean of forecasts initialized from ODA can capture the warming/cooling trend with weaker amplitude for warming events within one-year forecast
- Skills of forecasts initialized from ODA are much higher than persistent forecasts in the second half year
- Forecast spread initialized from ODA's ICs increases very rapidly
- Perfect atmospheric ICs with ODA's oceanic ICs produce the best ENSO forecast skill
- Accurate atmospheric ICs are very important for ENSO forecasts while oceanic initial conditions govern larger timescale signal



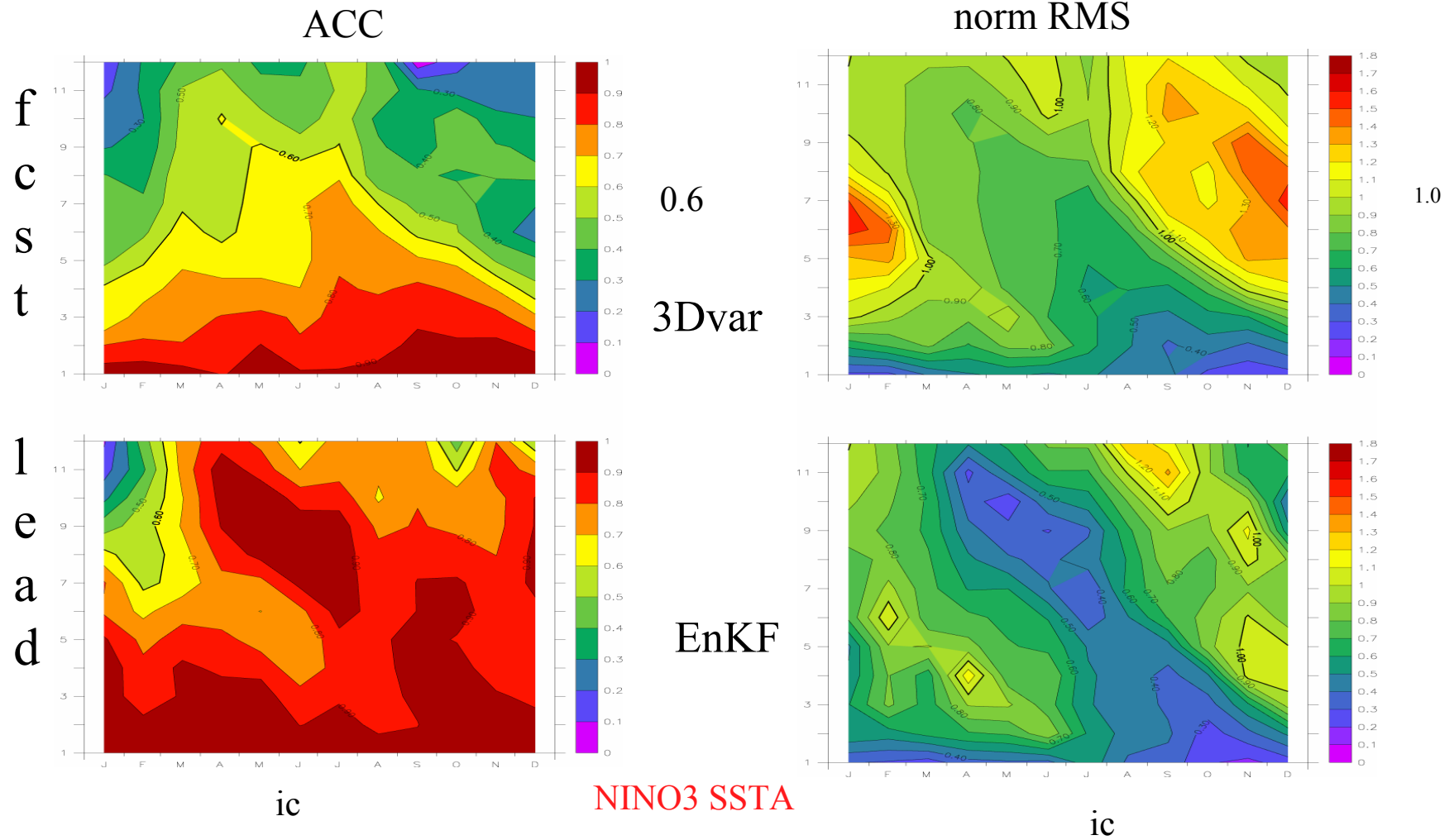
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NINO3 SSTA Forecast error

ODA verify ens members 1-10 against Reynolds SST

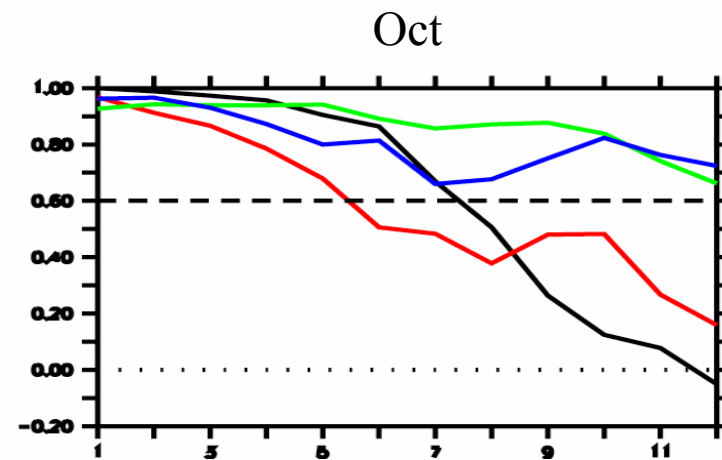
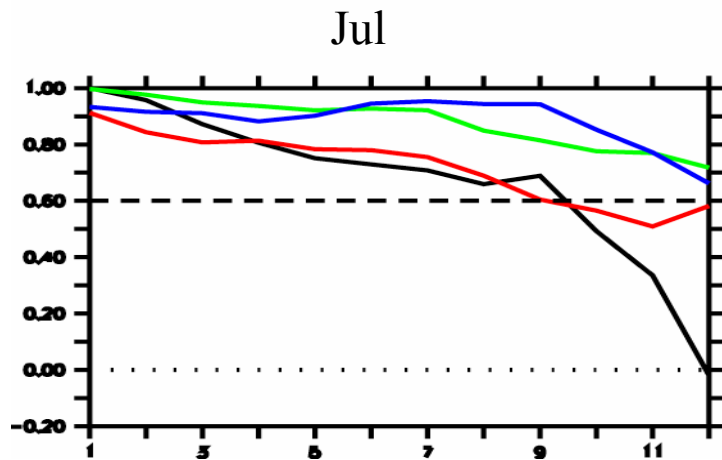
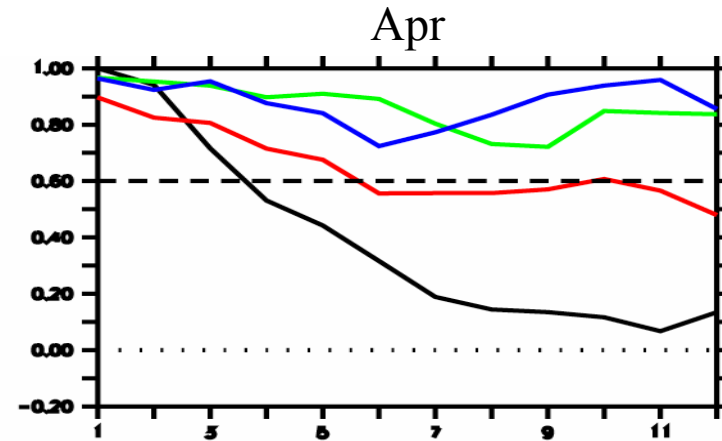
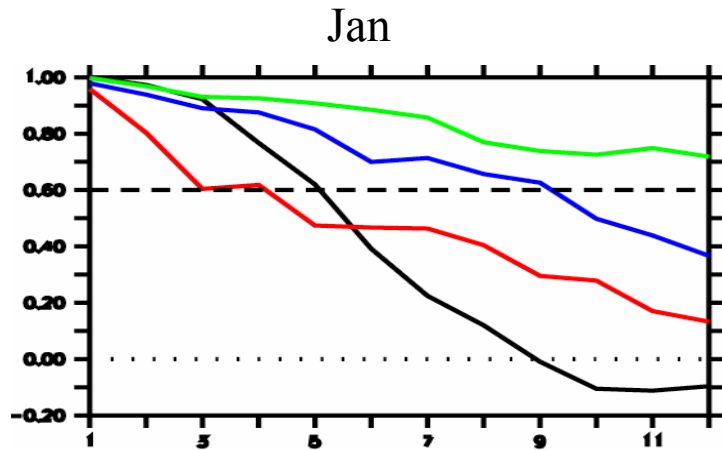


Note considerable improvement at all leads with EnKF!





ACC NINO3 SST



lead

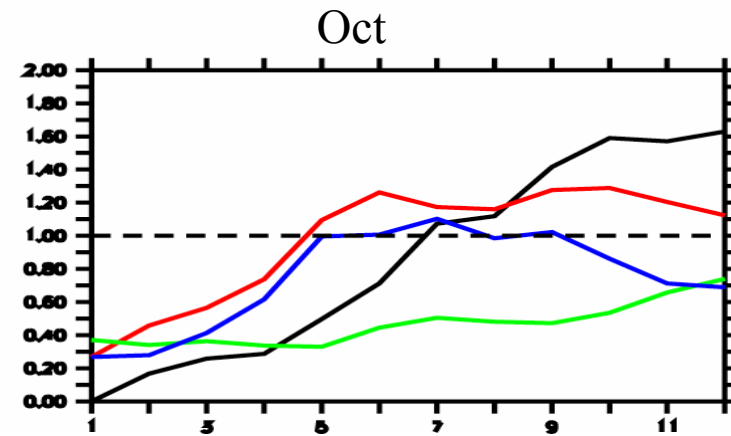
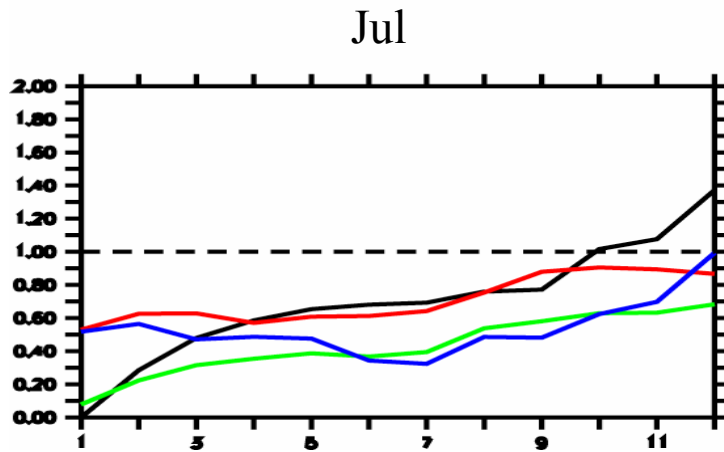
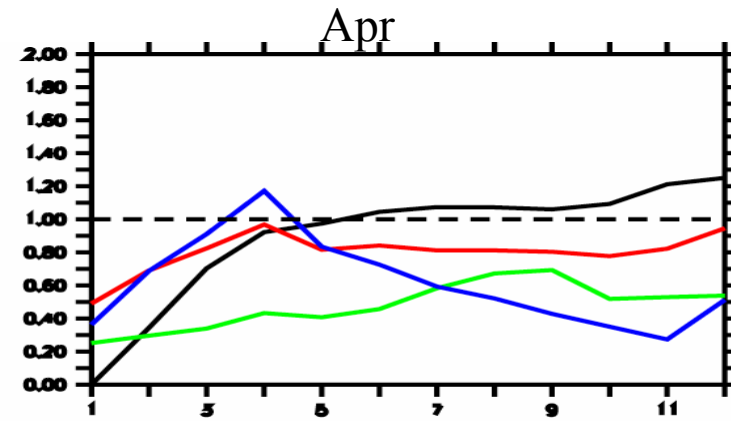
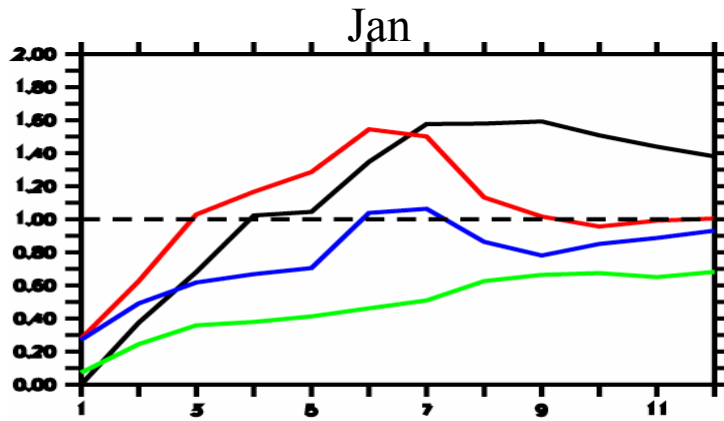
lead

— persis — pm — 3Dvar — EnKF





NORM RMS NINO3 SST



lead

lead

— persis — pm — 3Dvar — EnKF





Summary of Coupled Assimilation System

- Why does the EnKF show such a marked improvement?
 - GFDL's CDA system estimates a temporally-evolving **joint-distribution** of climate states under observational data constraint, with:
 - Multi-variate analysis scheme maintaining physical balances among state variables
 - T-S relationship in ODA
 - Geostrophic balance in ADA
 - Ensemble filter maintaining properties of high order moments of error statistics (nonlinear evolution of errors) mostly



Long Term Efforts ...

- Improve forecast (SI, decadal/multi-decadal) by improving initialization
- Observing system evaluation/design
- Model evaluation/verification for improving modeling
- Model parameter estimation



GFDL's Ensemble Data Assimilation System Using Multi- Coupled Climate Models

