GFDL S/I PREDICTION ACTIVITIES

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How do we improve S/I forecast skill?

- Coupled Model Development
- ODA Development
- Initialization
- Ensemble Methods
  - Size ?
  - How to represent the uncertainty ?
- MM Approaches

Where could advances in ENSO prediction come from?

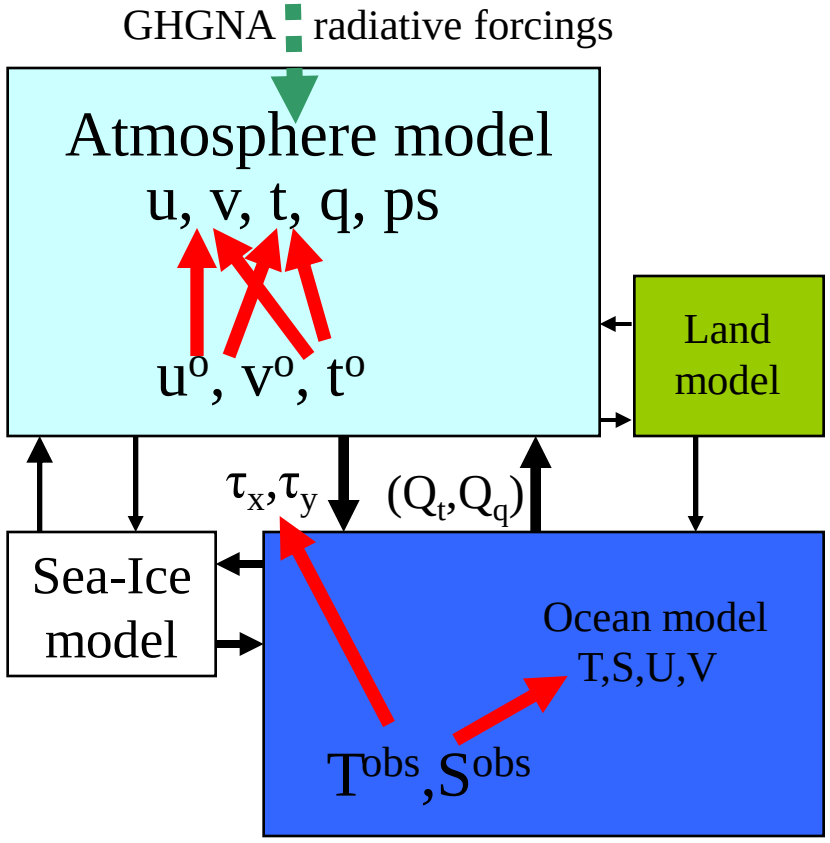
- Model Improvements - reducing systematic errors
- Constraining Initial Conditions
  - Particularly important in ocean because the memory of ENSO resides there.
  - The importance of ocean subsurface data in making ENSO predictions has been demonstrated in a number of studies.
  - Is the best ocean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

Ensemble Coupled Data Assimilation

- Core activity for Seasonal-Decadal Prediction
- Pioneering effort in fully coupled model data assimilation
- Ocean Analysis kept current and available from GFDL web site.
- Participate in CLIVAR/GSOP intercomparisons

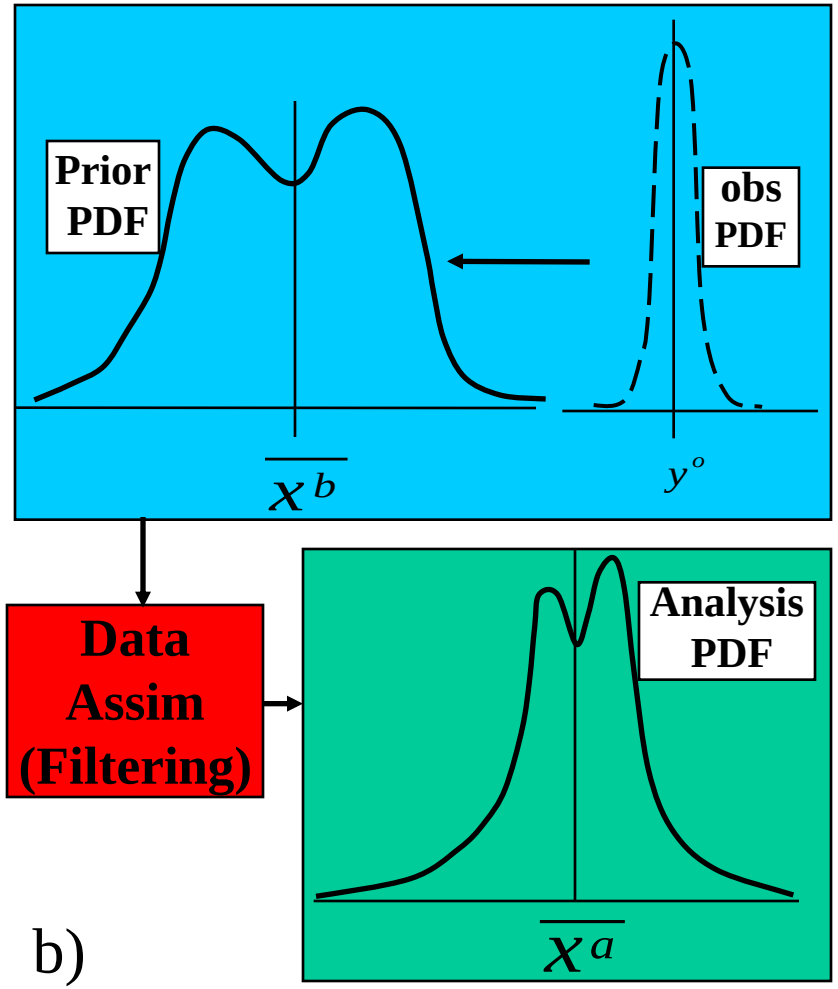
Ensemble Coupled Data Assimilation

Multi-variate coupled analysis Scheme



a)

ECDA System: Ensemble Kalman Filtering Algorithm



b)

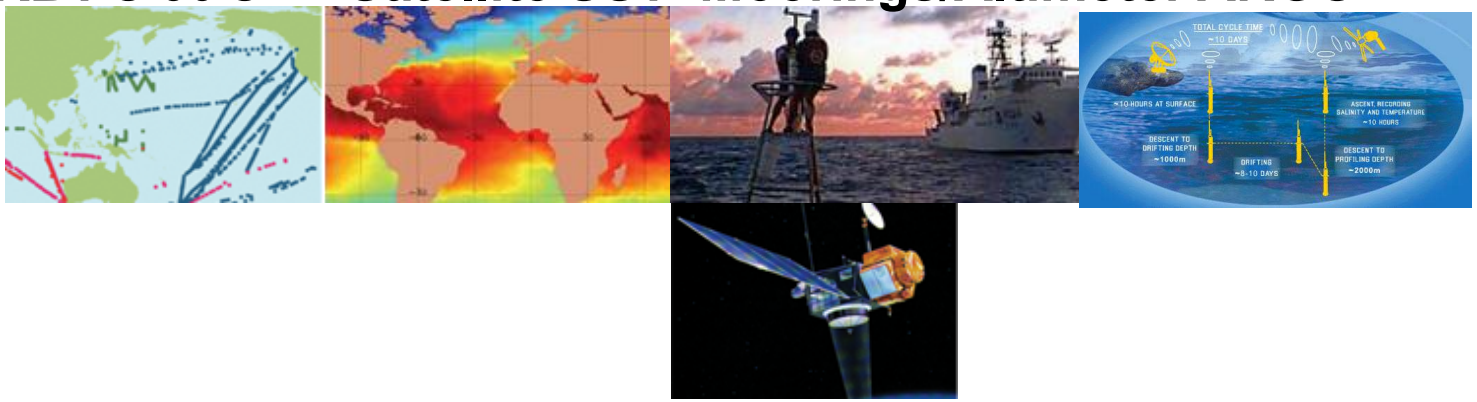
Why ECDA for climate studies?

- A Ensemble Coupled Data Assimilation system estimates a temporally-evolving ***joint-distribution*** (***Joint-PDF***) of climate states under observational data constraint, with:
  - Multi-variate analysis scheme maintaining physical balances among state variables mostly
    - 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
- Optimal ensemble initialization given data and model dynamics:
  - All coupled components are adjusted by data through exchanged fluxes
  - ECDA produces a balanced state that avoids initialization shock and this leads to increased skill.

Ocean observations assimilated

1982 1993 2001

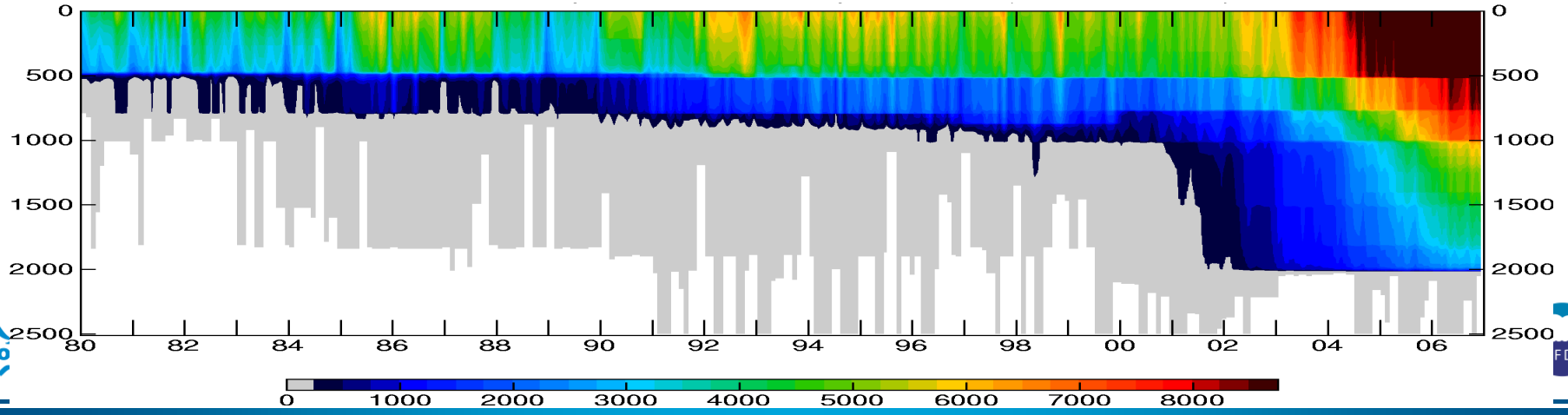
XBT's 60's Satellite SST Moorings/Altimeter ARGO



The ocean observing system has slowly been building up…

Its non-stationary nature is a challenge for the estimation of decadal variability

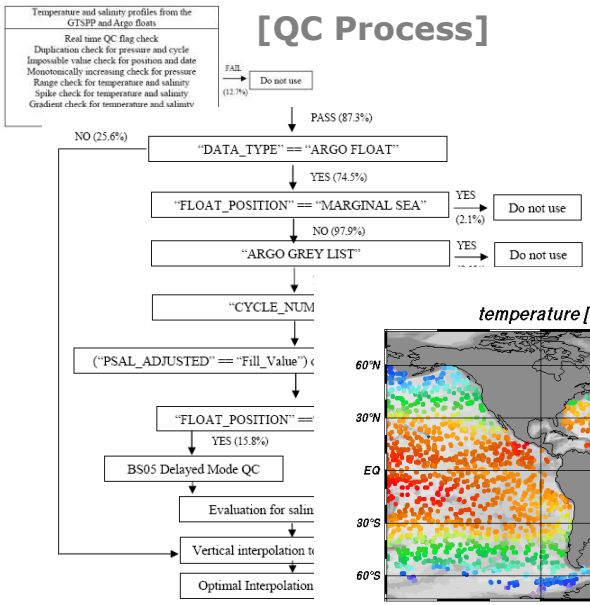
Number of Temperature Observations per Month as a Function of Depth

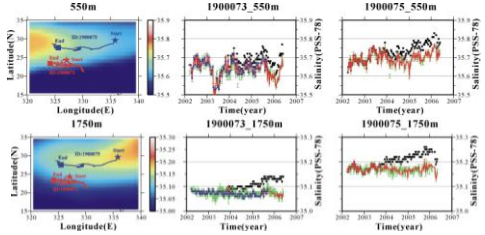


GFDL Argo DB [monthly update]

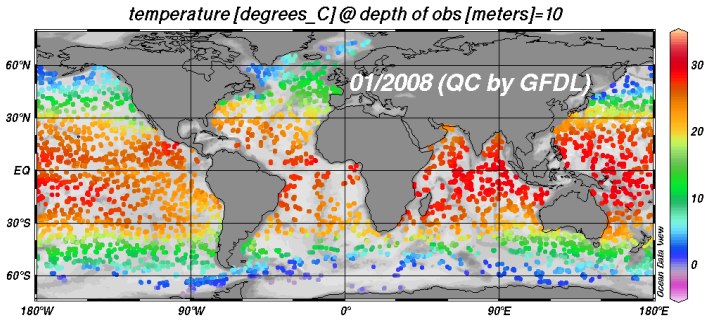
Step 1: Data Mirroring System (Identified Argo + GTSPP)

Step 2: Quality Control System (Real Time + Delayed Mode)

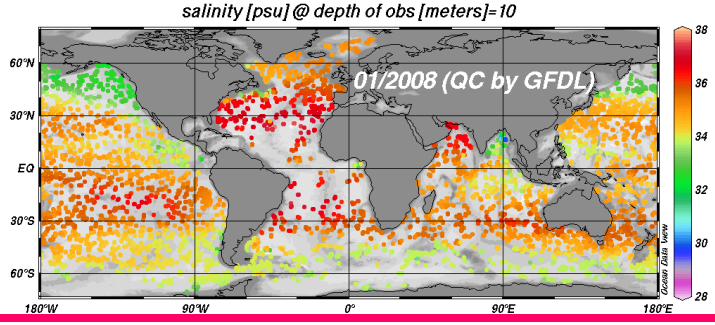




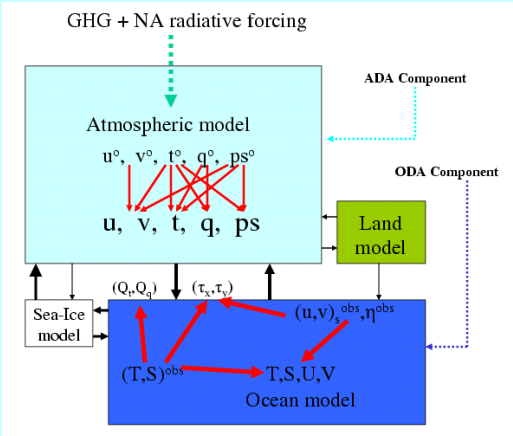
[DMQC result]



[GFDL Argo DB]

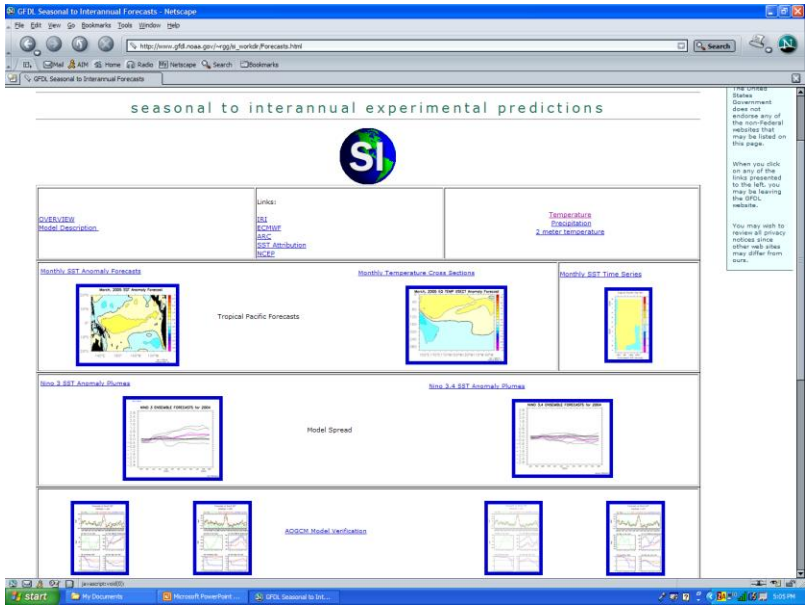


Step 3: Coupled Data Assimilation System



Predicted B.C. - Tier 1

- Tier - 1 forecasts with CM2
  - CM2 same coupled model as our IPCC runs
  - All forecasts available on web site
  - Real time experimental forecasts
  - Retrospective one year forecasts from 1979-2009, 10 ensemble members initialized from every month (3600yrs) using CM2.1 model
  - Participate in MME predictions for NCEP/CTB, IRI, APCC, COLA



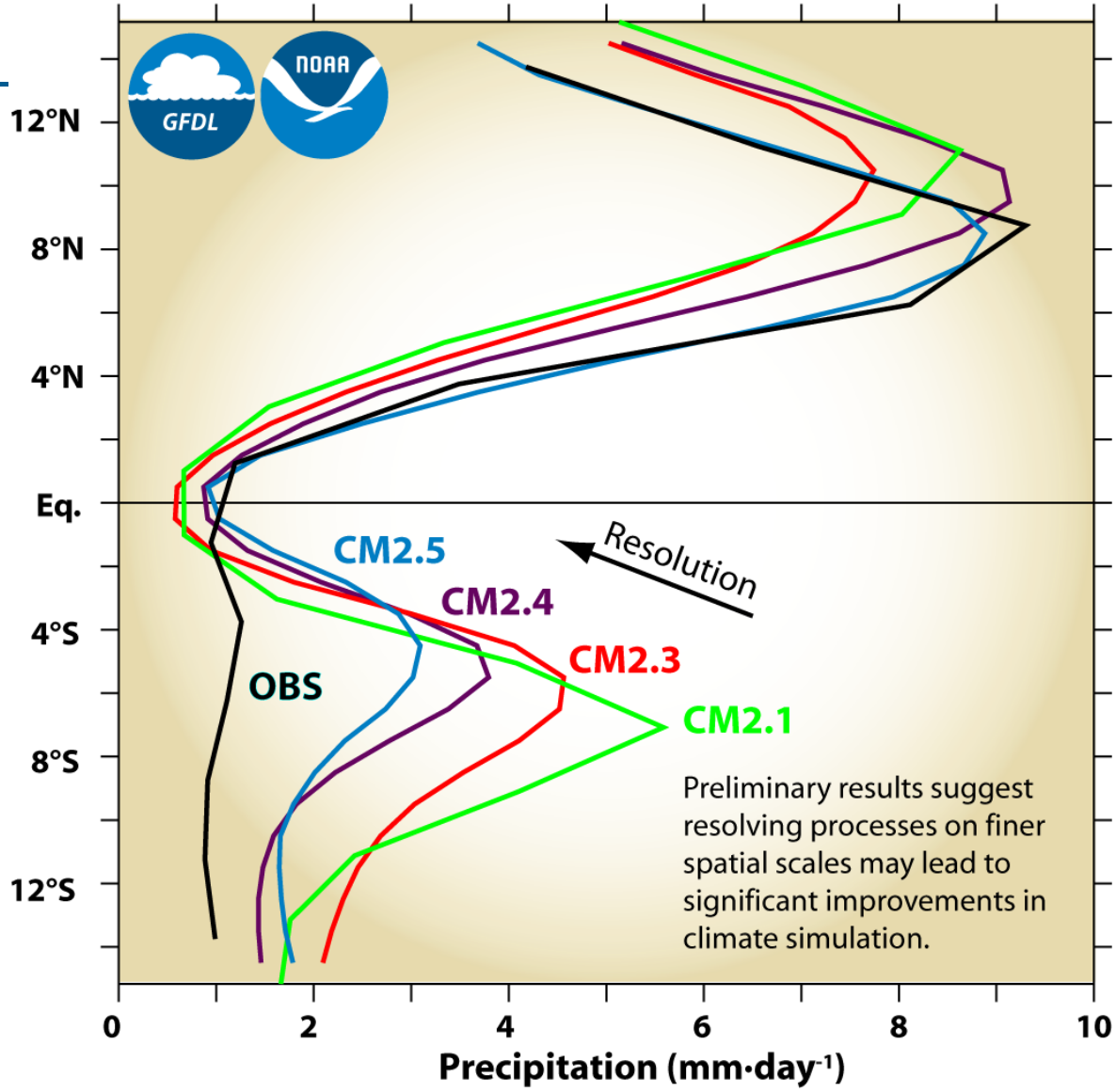
Prescribed B.C.

- Tier – 2 forecasts AM2
  - Routine seasonal forecasts for IRI
  - Retrospective forecasts for APCC
- SST - Attribution
  - Using AM2 (latest atmos. model) run 10 member ensemble 1950 – present
  - Ensembles updated every month
  - Collaborate with operational centers CPC, IRI
- Land prescribed – sensitivity to soil moisture
  - Predicting itself – predictability
  - Initialization – forecasts
  - GLACE

Ongoing Development Efforts

- Develop and implement CM2.5 Hi-Res coupled model for seasonal prediction
- Develop ECDA using CM2.5 as assimilation model
- Improve forecast (SI, decadal/multi-decadal) by improving initialization
- Ocean Observing system evaluation/design
- Produce Ocean Analysis for model evaluation/validation
- Model parameter estimation using ECDA
- Produce forecasts (SI, decadal) from ECDA initialization
- Participate in NMME efforts

GFDL Coupled Model East Pacific Precipitation (150°W-90°W)



Observed rainfall

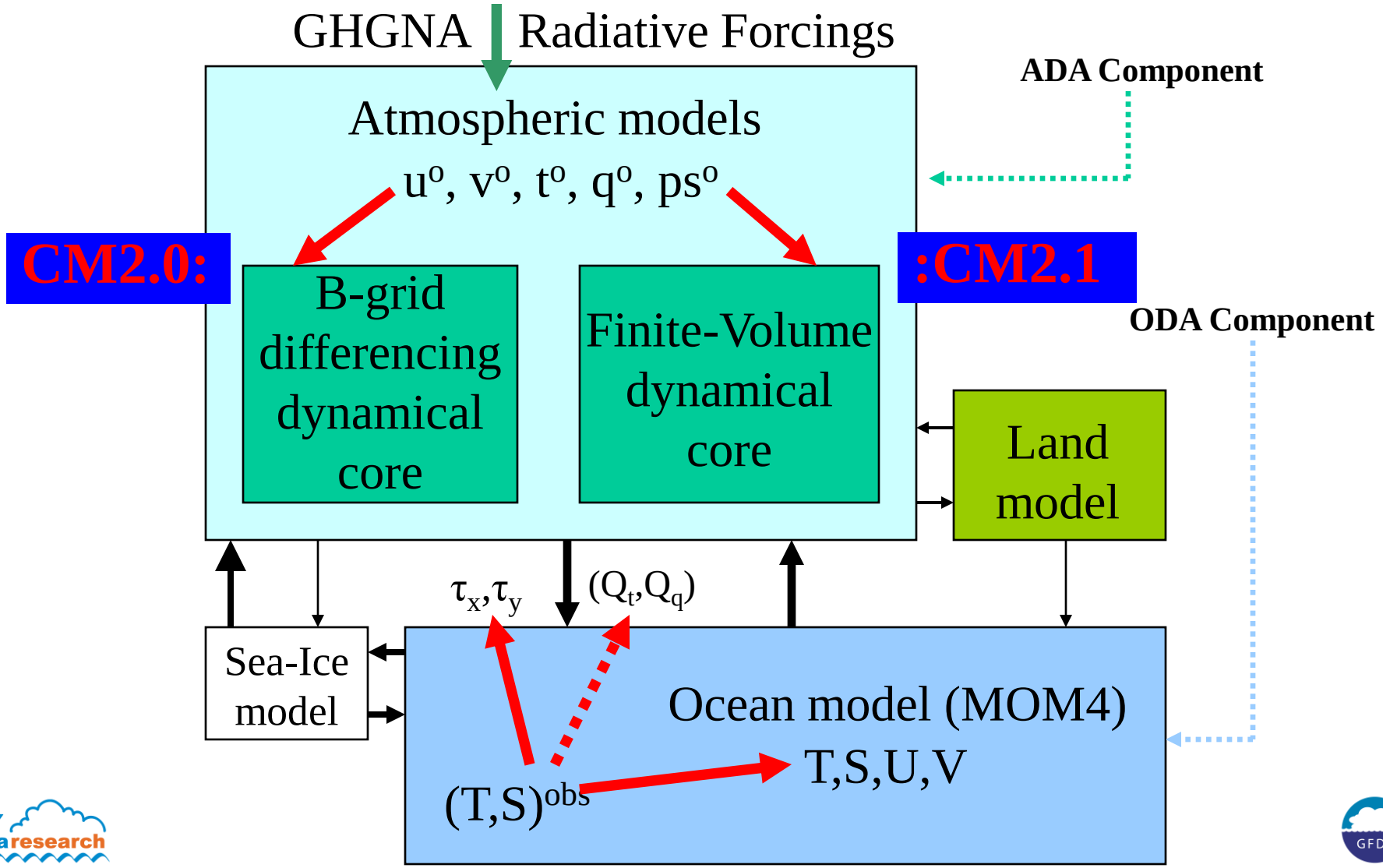
GFDL CM2.1
- 2° Atmosphere
- 1° Ocean

GFDL CM2.3
- 1° Atmosphere
- 1° Ocean

GFDL CM2.4
- 1° Atmosphere
- 1/4° Ocean

GFDL CM2.5
- 1/2° Atmosphere
- 1/4° Ocean

A Multi-Model Ensemble Data Assimilation System at GFDL



Experimental Long-lead Seasonal Hurricane Forecasts

•Gabriel A. Vecchi[1], Ming Zhao[1,2], Hui Wang[3,4], Gabriele Villarini[5,6], Arun Kumar[3], Anthony Rosati[1], Isaac Held[1], Richard Gudgel[1]

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4. Wyle Information Systems, McLean, Virginia, USA
5. Department of Civil and Environmental Engineering, Princeton University, Princeton, New Jersey, USA
6. Willis Research Network, London UK

Goal:

Use understanding and tools developed for exploring the link of climate change and hurricanes to push window of North Atlantic seasonal hurricane forecasts to winter, with skill and quantified uncertainty

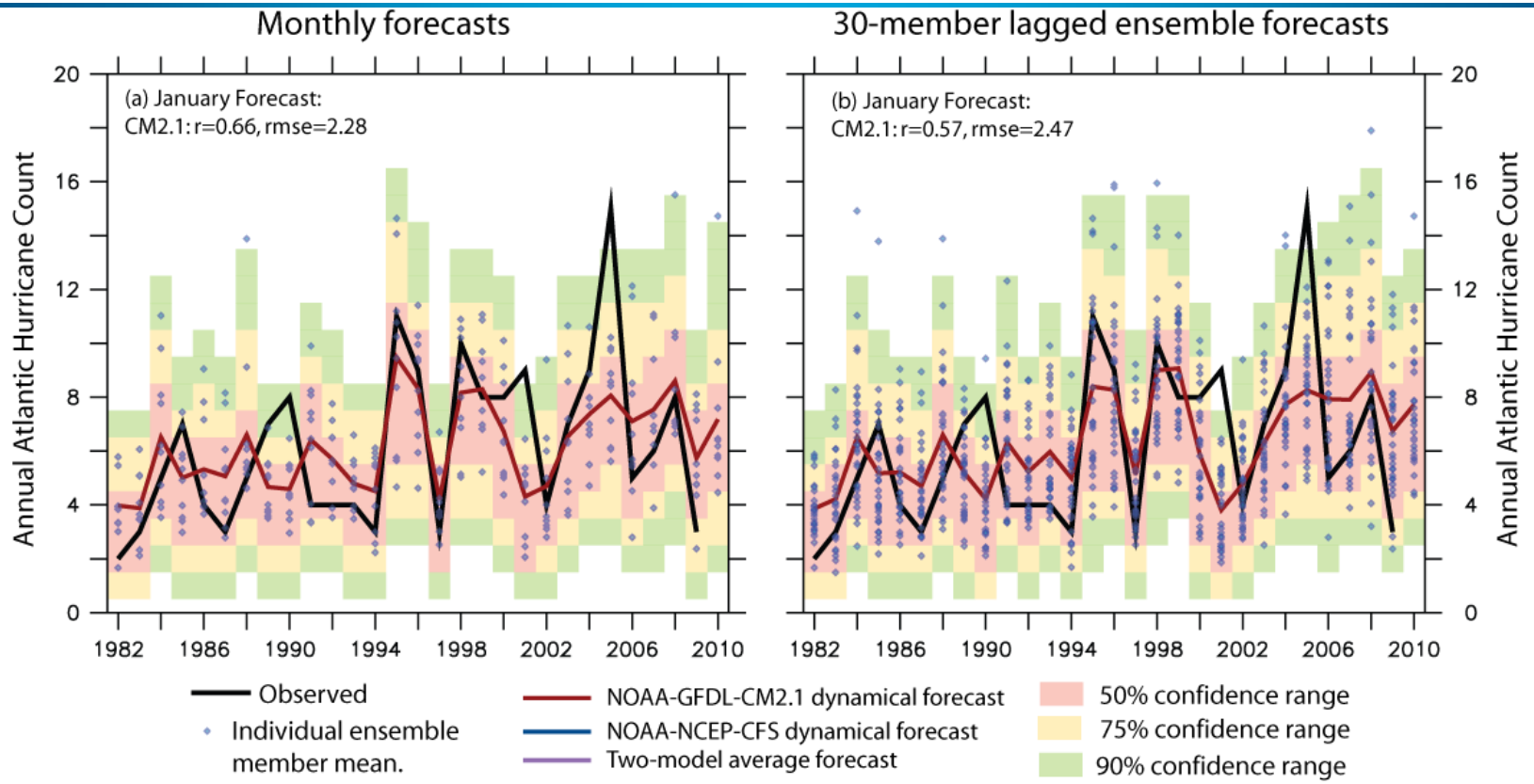
Seasonal Hurricane Frequency Forecast Scheme

- Build a statistical emulator of AGCM (HiRAM-C180), using two predictors:
  - SST_{MDR} (SST anomaly 80°W-20°W, 10°N-25°N)
  - SST_{TROP} (SST anomaly 30°S-30°N)
- Use S-I forecast models to predict two indices
- Convolve PDF of SST forecasts with PDF from statistical model.

Explore Two Systems to Forecast the SST Indices

- GFDL-CM2.1 Experimental Forecast System:
  - Ensemble Kalman Filter initialization of GFDL-CM2.1 - Zhang et al (2007), Delworth et al (2006)
  - 12-month retrospective and forward forecasts
  - Basis of GFDL's efforts to understand decadal predictability
- NCEP-CFS Operational S-I Forecast System:
  - GFS atmosphere and MOM3 ocean, initialized to NCEP (atm/land) and GODAS (ocn) - Saha et al (2006)
  - Nine-month retrospective and actual forecasts
  - Used operationally at NCEP

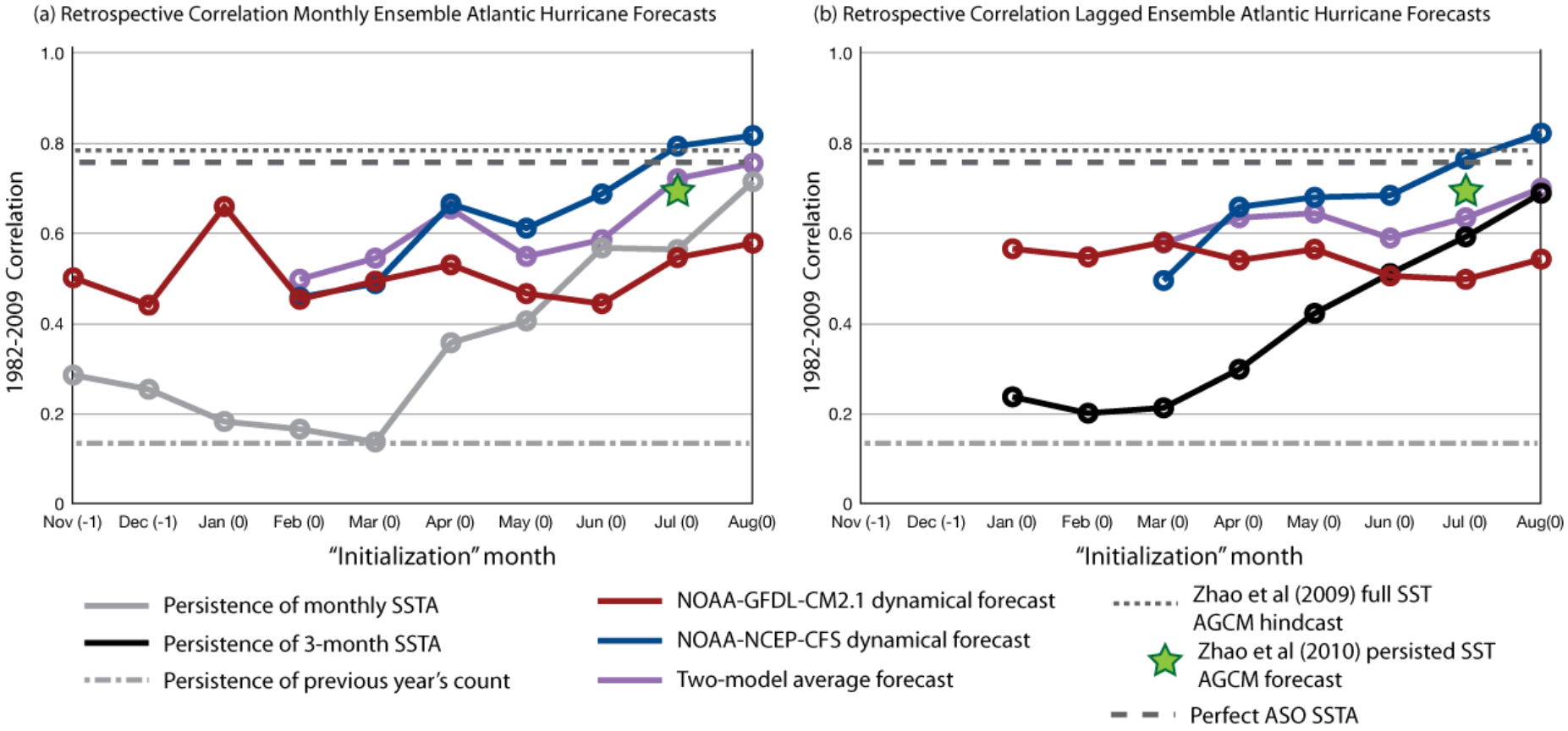
Apply Statistical Hurricane Frequency Model to CM2.1 Retrospective Forecasts of January SST



$$p(C=k) = \int_{-\infty}^{\infty} p(C=k \mid \text{relSSTA}=x) \cdot p(\text{relSSTA} = x)\, dx$$

- p(relSSTA=x) from CM2.1 ensemble
  - Vecchi *et al.* (2011, MWR, in press)

Hybrid (Statistical-Dynamical) Forecast System Exhibits Potential for Multi-season Lead Forecasts

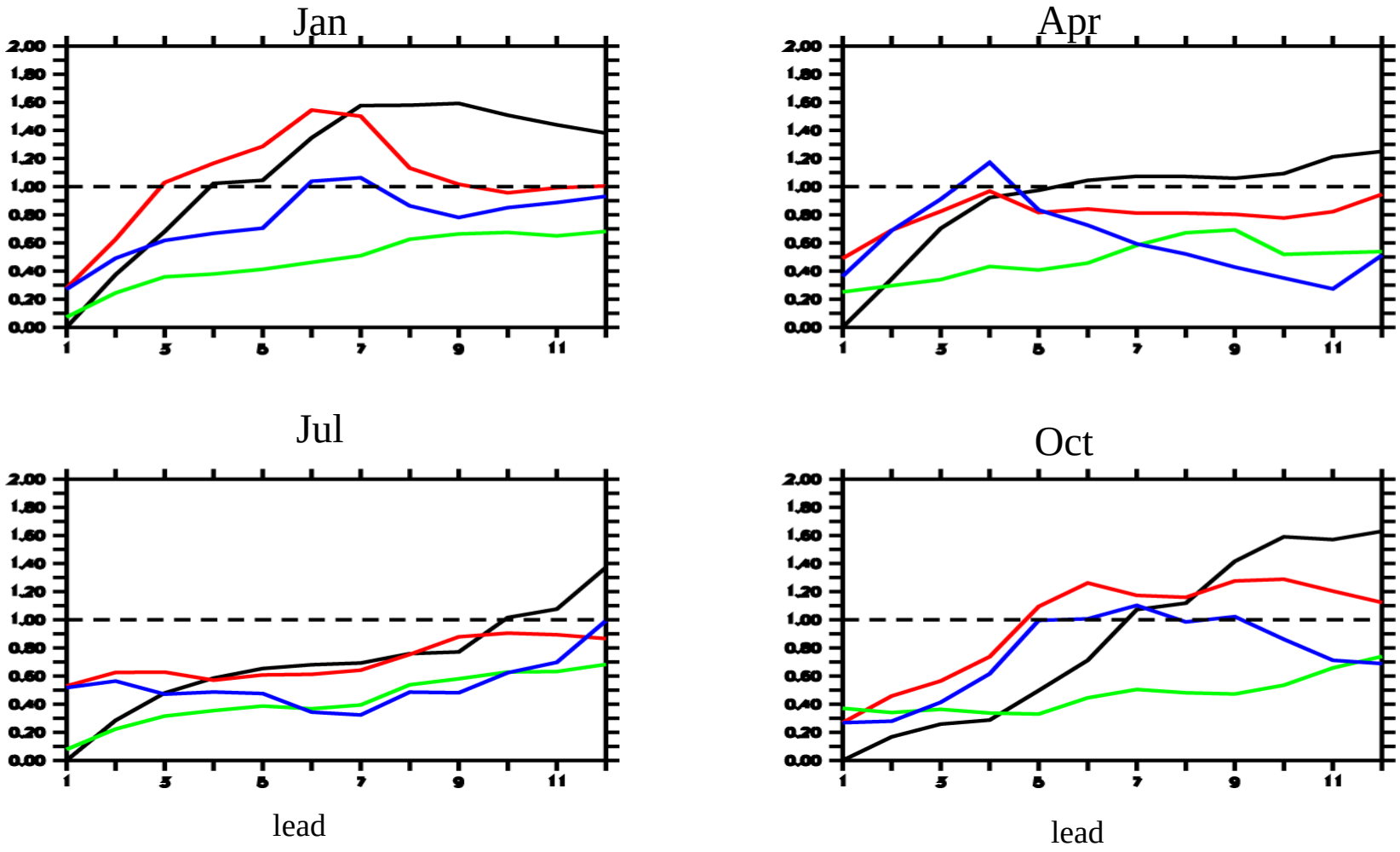


- Vecchi *et al.* (2011, MWR in press)

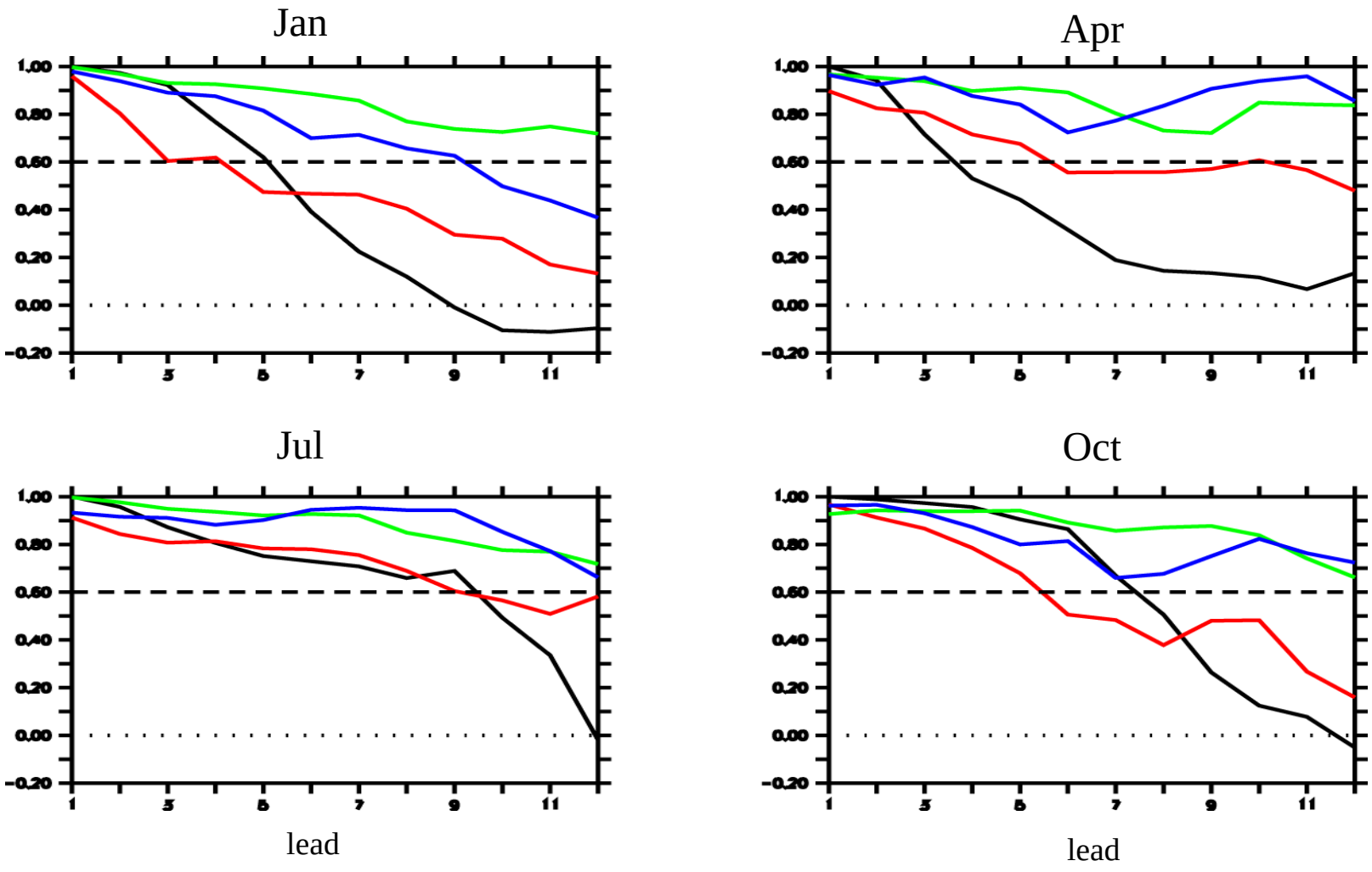
Ongoing Work
(collaboration including members of GFDL – Rosati and Vecchi – and NCEP/CPC – Hui Wang and Arun Kumar)

- Continue evaluation of forecast system through seasons.
- Evaluate new versions of models and initialization schemes (preliminary results mixed, e.g., CFS2 appears to perform worse than CFS1 on hurricanes)
- Work towards understanding differences between CFS and GFDL systems.
- Assess potential decadal predictability (preliminary results indicate potential, but too few degrees of freedom to be confident)
- Expand MME to include other GCMs
- Explore multi-statistical model MME (blend Wang et al (2009) and Vecchi et al (2011))

NORM RMS NINO3 SST



ACC NINO3 SST



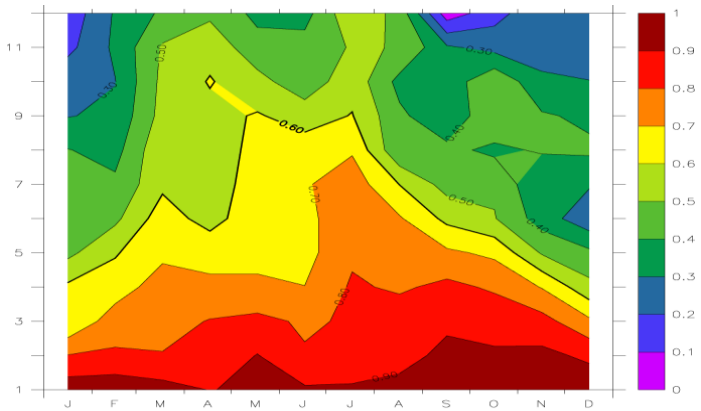
NINO3 SSTA Forecast error

ODA verify ens members 1-10 against Reynolds SST

ACC

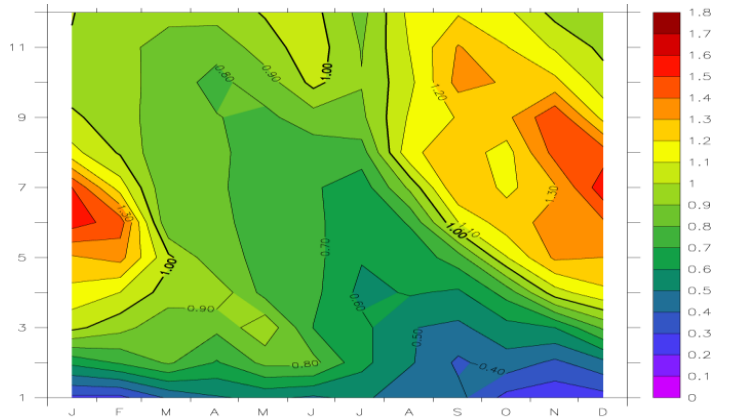
norm RMS

fcst



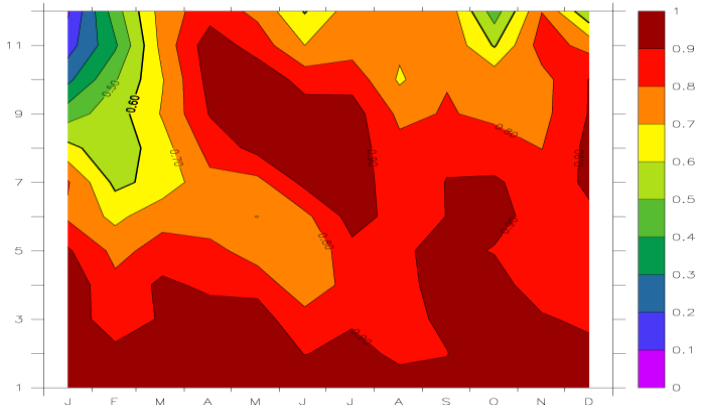
0.6

3Dvar

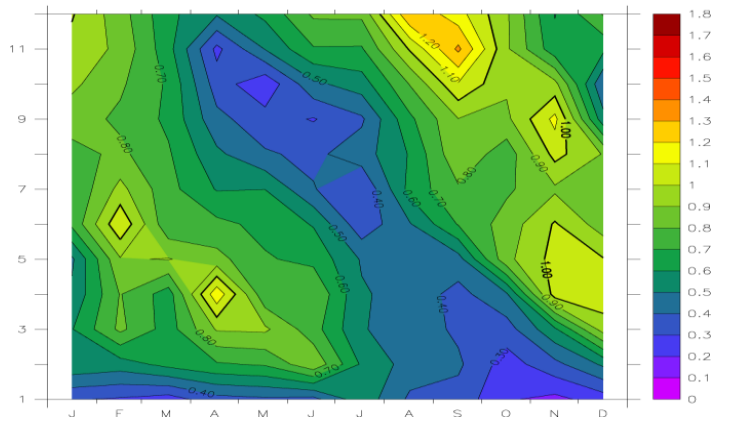


1.0

lead



EnKF



ic

NINO3 SSTA

ic

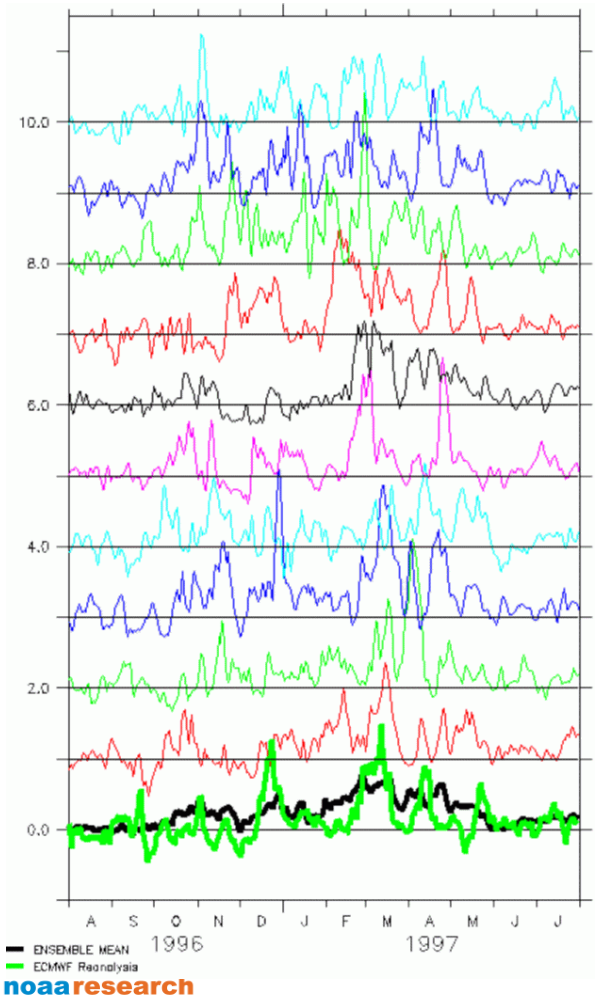
Note considerable improvement at all leads with EnKF!

ODA RESEARCH

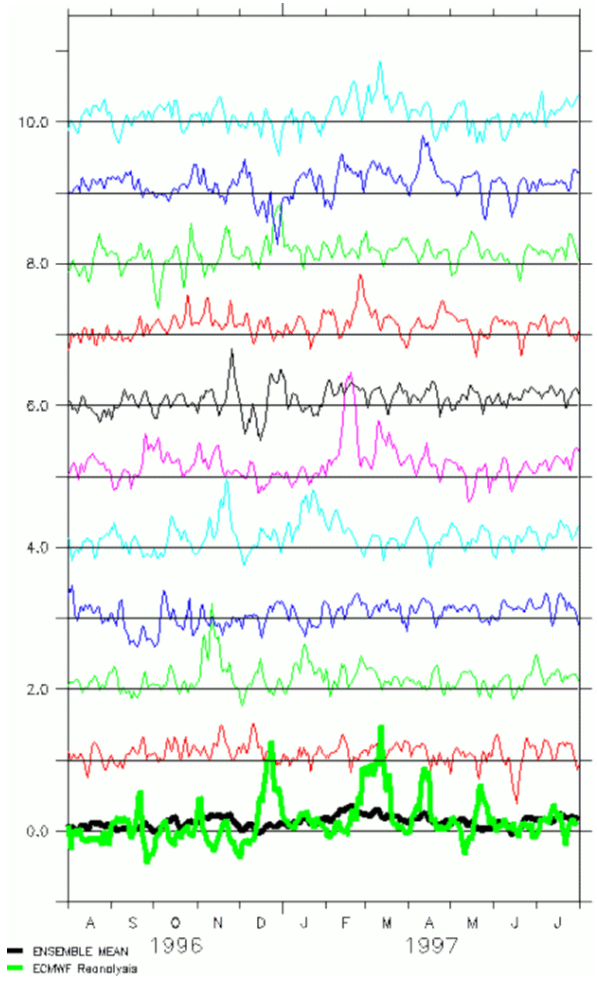
- **3D-variational method** – used in operational S/I prediction for over a decade. A minimum variance estimate using a constant prior covariance matrix,unchanged in time.Stationary filter.
- **4D-variational**-A minimum variance estimate by minimizing a distance between model trajectory and obs using adjoint to derive the gradient under model's constraint. Linear filter. (ECCO, JPL, Harvard)
- **Ensemble filtering** - accounts for the nonlinear time evolution of covariance matrix

Daily western Pacific zonal stresses, from 10 AMIP runs

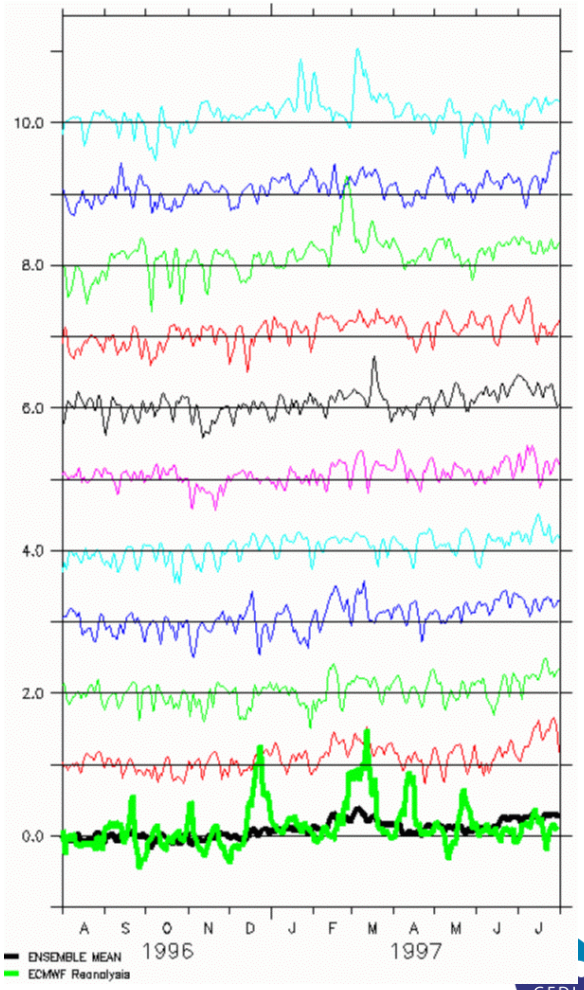
Obs SST forcing



Warm East Indian



Cool West Pacific



noaaresearch

GFDL

Motivation for Ocean Data Assimilation

- ODA produces consistent ocean states serving as initial conditions for model forecasts (S/I, Dec/Cen)
- The reconstructed time series of ocean states with a 3D structure aids further understanding of the dynamical and physical mechanisms of ocean evolution
- Ocean analysis for model simulation or forecast verification
- Restoring SST may only change the top layer structure, instead of building up the vertical thermal structure
- Forcing errors (wind stress, heat flux, water flux)
- Model errors

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 a coupled model initialization scheme (ECDA) has been developed.

GFDL's CM2.x Coupled Climate Models: Efforts in Support of the IPCC AR4 & the US CCSP

In 2004, following several years of intensive development efforts, a new family of GFDL climate models (the CM2.x family) was first used to conduct climate research.

The CM2.x models are being applied to decadal-to-centennial time scale issues (including IPCC-style multi-century control experiments, climate of the 20th century runs, & climate change projections), as well as to seasonal-to-interannual problems, such as El Niño research and forecasts.