Progress in the Development of Subseasonal Ensemble Forecast techniques

CTB Proposal: "Development of Subseasonal Ensemble Forecast Techniques"

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Goals of Proposed Work

Develop and Test Initialization Techniques that focus on Improving the Prediction of Subseasonal Times Scales with a Focus on the MJO, and Implement those at EMC

- Adapt and Test Breeding Approach Used at NASA for Seasonal Prediction to Subseasonal Time scales
- Adapt and Test the EMC Ensemble Transform (ET) Technique within current EMC Systems (CFS, GEFS)
- Carry out Coordinated (NASA and EMC) Experimentation to Evaluate Approaches
- Develop an ESMF-compatible coupled model at NCEP using the GEOS-5 coupled model as a prototype, and implement the “best” initialization approach

Experimental Framework (NASA)

- Model
  - early version of GEOS-5 AGCM coupled to MOM4 Ocean

- Initial Conditions
  - atmosphere and land: MERRA
  - ocean: replay of MERRA with Coupled GEOS-5 model

- Examine Two Perturbation strategies
  - Breeding and Empirical Singular Vectors (**Yoo-Geun Ham**)
  - Control consists of either 1-day LAF or random perturbations with large-scale spatial structure

GEOS-5 Coupled Model Replay System

AGCM

- Finite-volume dynamical core (S.J. Lin)
- Moist physics (J. Bacmeister, S. Moorthi and M. Suarez)
- Physics integrated under the Earth System Modeling Framework (**ESMF**)
- Generalized vertical coord to 0.01 hPa
- Catchment land surface model (R. Koster)
- Prescribed aerosols (P. Colarco)
- Interactive ozone
- Prescribed SST, sea-ice

CGCM

- GFDL ocean model (MOM4)
- A replay of the atmospheric data analysis in the CGCM.
- Has the potential to substantially reduce initialization shocks

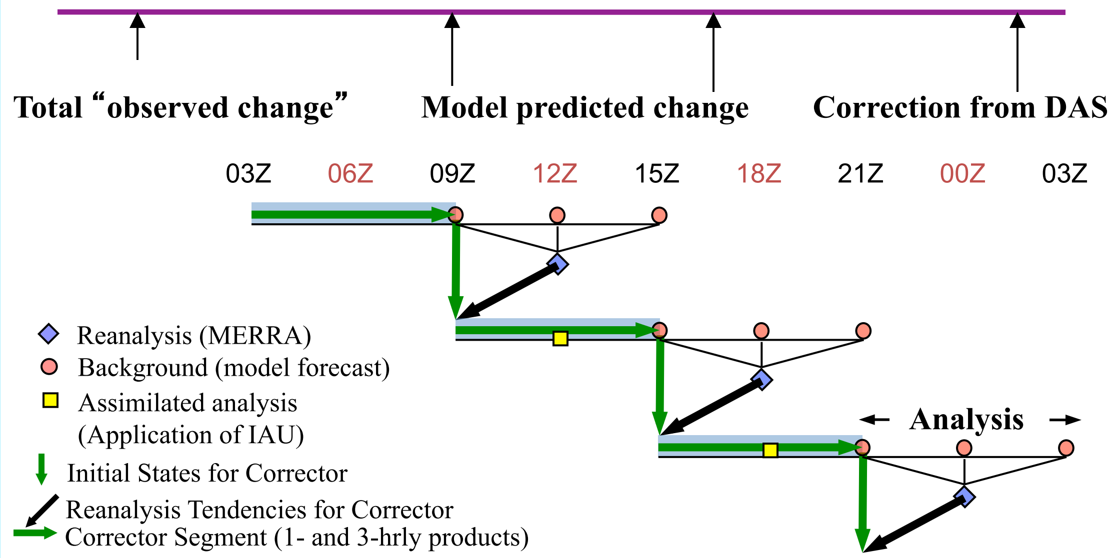
Replay

- Apply Incremental Analysis Increments (IAU) to reduce shock of data insertion (Bloom et al.)
- IAU gradually forces the model integration throughout the 6 hour analysis period

Reanalysis

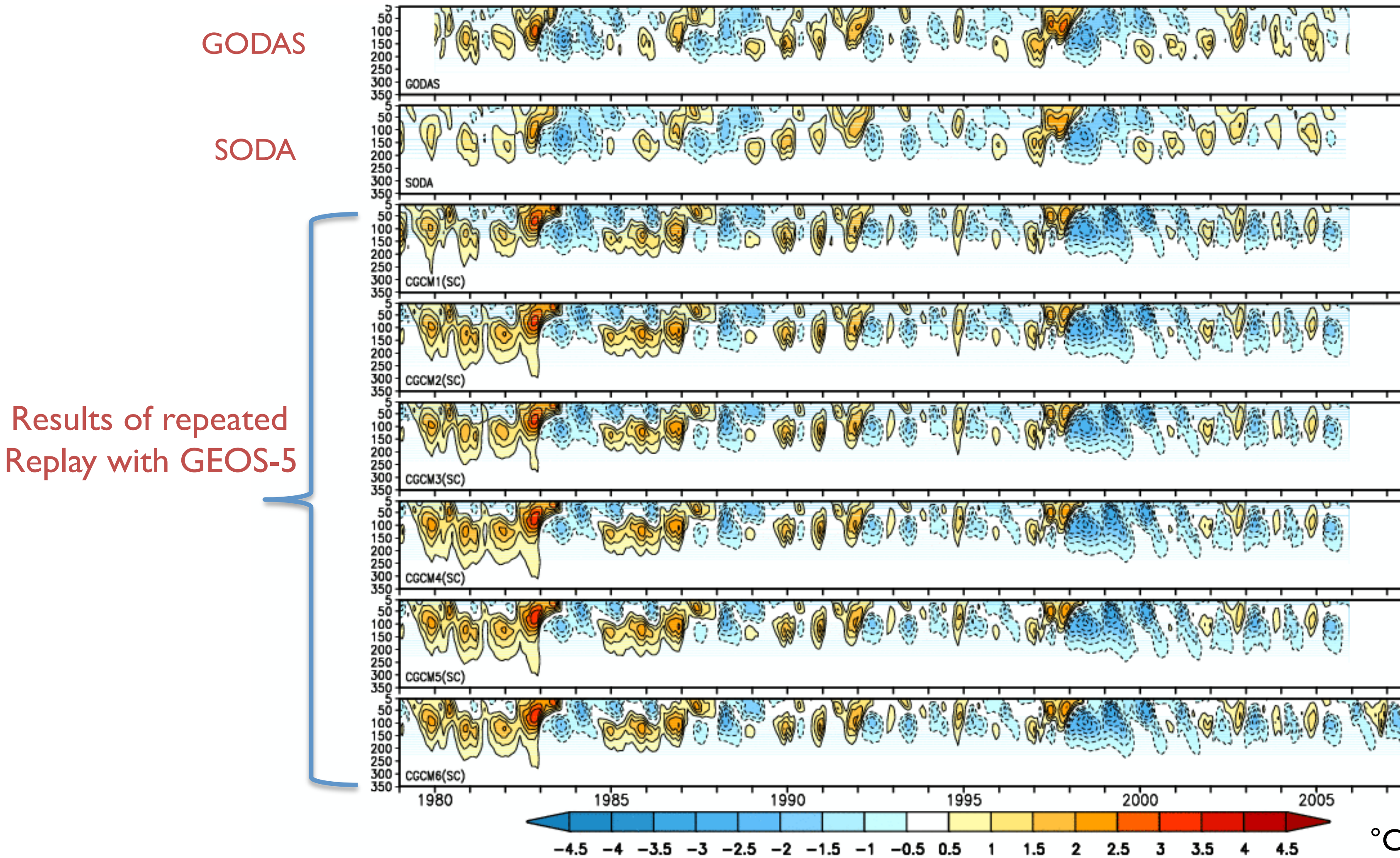
- MERRA
- NCEP, JRA-25, ERA

$$\left(\frac{\partial q^n}{\partial t}\right)_{total} = dynamics(adiabatic) + physics(diabatic) + \Delta q$$



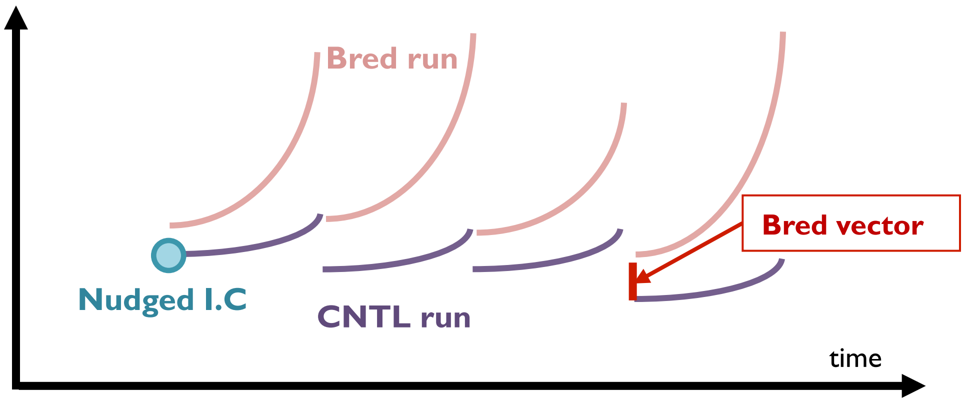
Subsurface Ocean Temperature Anomalies

(5S-5N, 130E-80W)



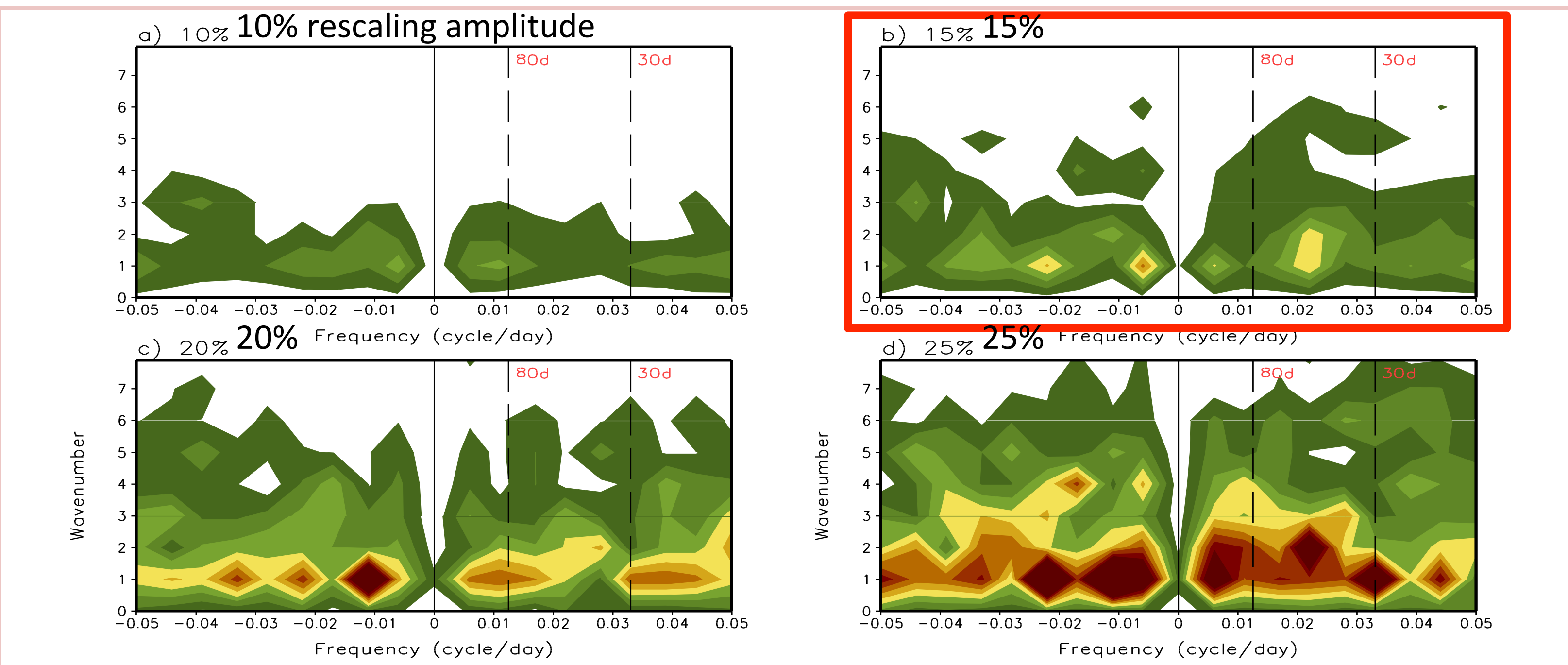
Breeding Experiments

Following:
Chikamoto et. al. 2007
Yang et al. 2009



* Rescaling magnitude :
Based on natural variability of VP200 over 40-180E, 20S-20N

Space-Time Power Spectrum (2 day rescaling)



Forecast skill of bi-variate RMM index - BV

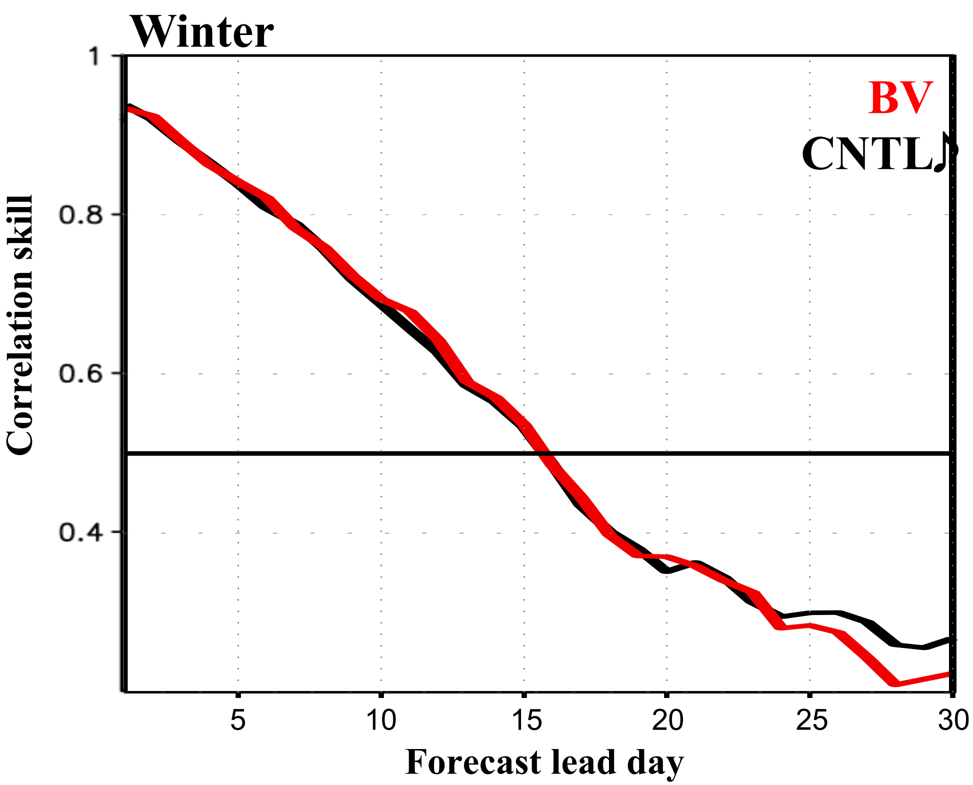
$$\text{Cor of RMM index } (\tau) = \frac{\left[\sum_{i=1}^{N} a_{1i}(t)\cdot b_{1i}(t) + a_{2i}(t)\cdot b_{2i}(t)\right]}{\sqrt{\sum_{i=1}^{N}[a^2_{1i}(t)+a^2_{2i}(t)]}\cdot\sqrt{\sum_{i=1}^{N}[b^2_{1i}(t)+b^2_{2i}(t)]}}$$

$a_{1i}(t), a_{2i}(t)$: observed RMM1,2 at day t

$b_{1i}(t), b_{2i}(t)$: simulated RMM1,2 at day t

τ: Forecast lead day

N : Number of forecasts



	Red	Black
Ensemble perturbation	BV (2dy 15%)	LAF (1-day)
Observation	MERRA	
Initialized method	MERRA replay with coupled GCM	
Ensemble member	2	
Model	GEOS5 CGCM	
Prediction period	1992.11.1-1996.04.30 (Total : 180 cases)	

Empirical Singular Vector (ESV)

1. Define initial (X) & final (Y) variables with forecast data

(1) Select optimal time : 10 days → Time-lag between X & Y : 10 days

(2) Initial variable (X) : U850,U200,VP200 at initial time

Final variable (Y) : U850,U200,VP200 at 10-day after

(3) Calculate anomaly

- Subtract daily climatology & previous 120 day mean
- Divide by standard deviation of each variables

(4) X : PC time series of EOF 5 modes of initial variable

Y : PC time series of combined EOF 2modes of final variable

2. Formulate the Empirical Operator (L)

Linear inverse modeling (L_{linear})

$$Y = L \cdot X$$

$$L = YX^{T}(XX^{T})^{-1}$$

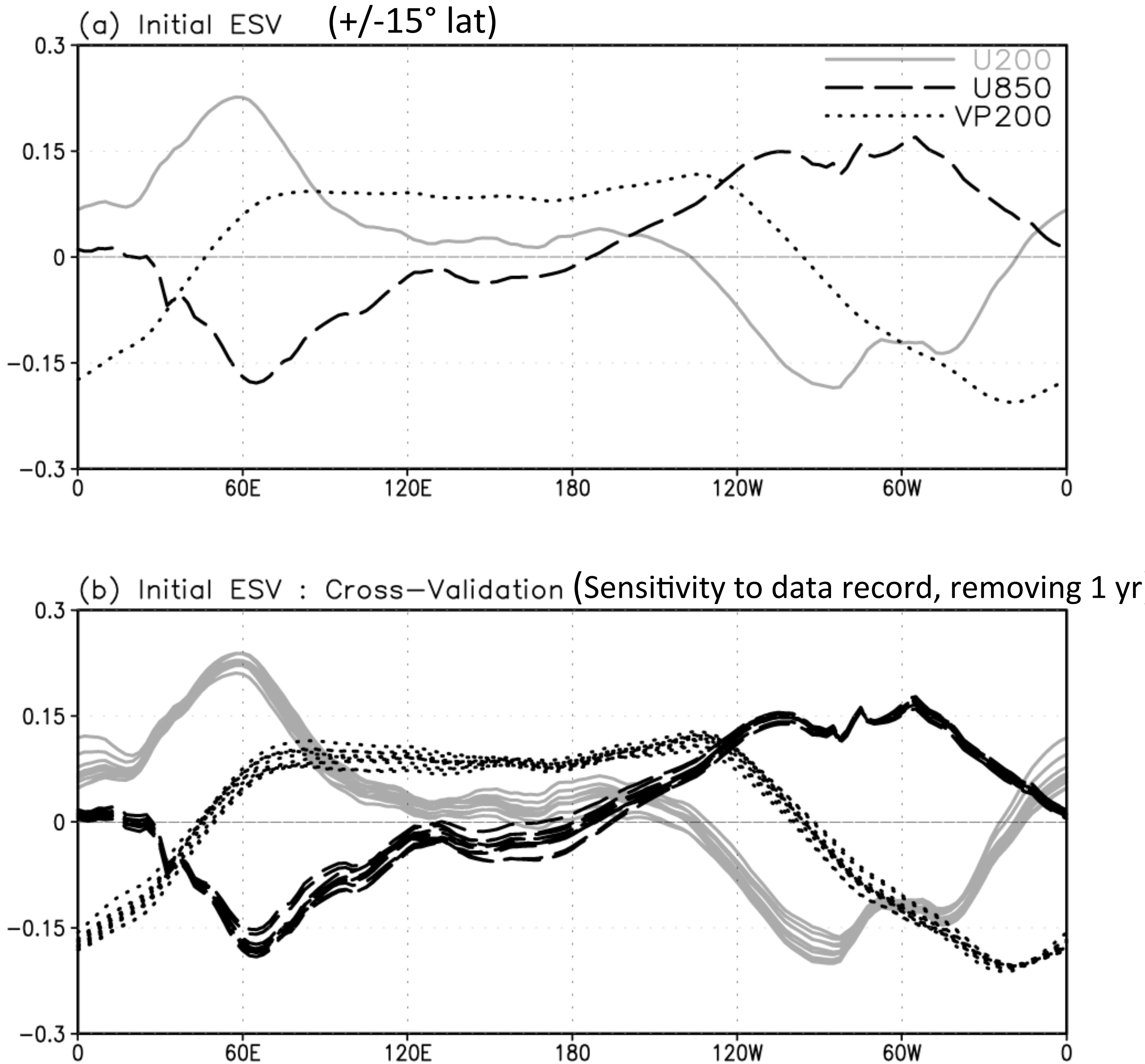
3. Find fast growing perturbation using SVD

$$L_{linear} = USV^{T}$$

Fast growing perturbations :

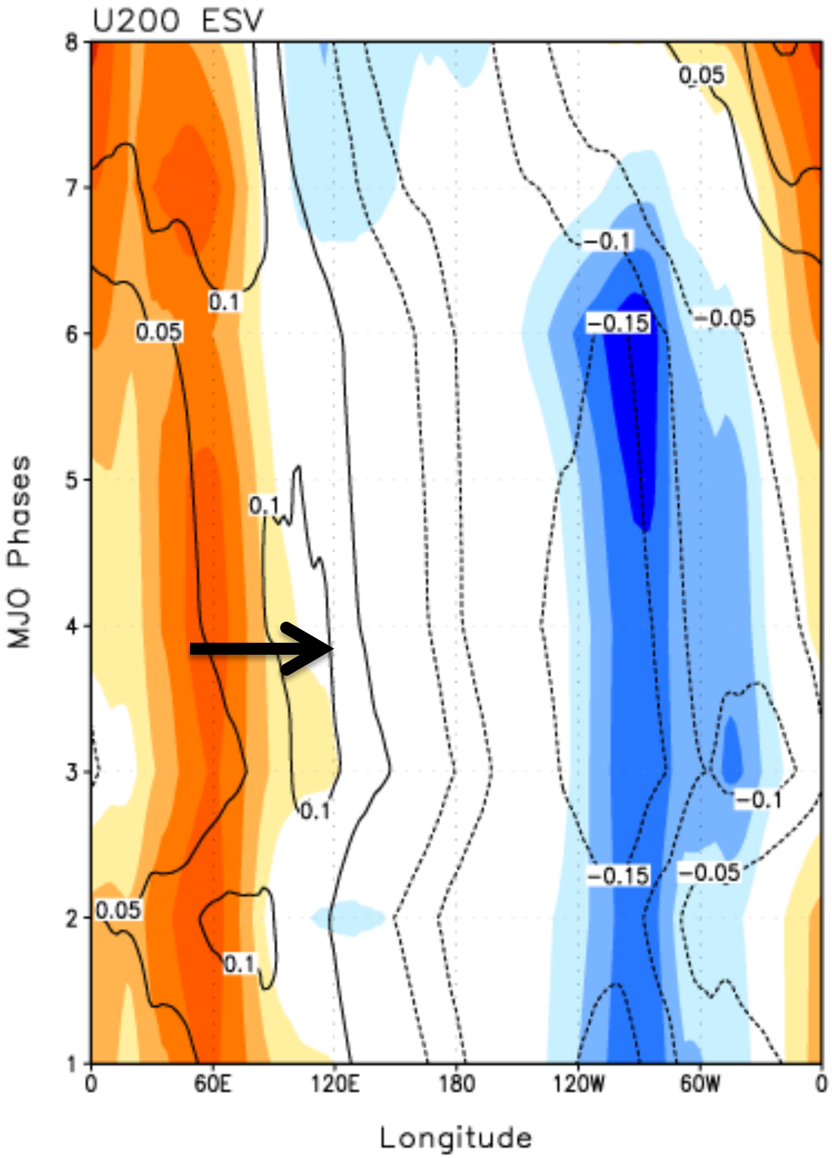
→ Right singular vectors whose singular value is maxima

MJO
Phase 4



(a) Initial ESV
(+/-15° lat)
U200
U850
VP200
0.3
0.15
0
−0.15
−0.3
0
60E
120E
180
120W
60W
0
(b) Initial ESV : Cross−Validation
(Sensitivity to data record, removing 1 yr)
0.3
0.15
0
−0.15
−0.3
0
60E
120E
180
120W
60W
0

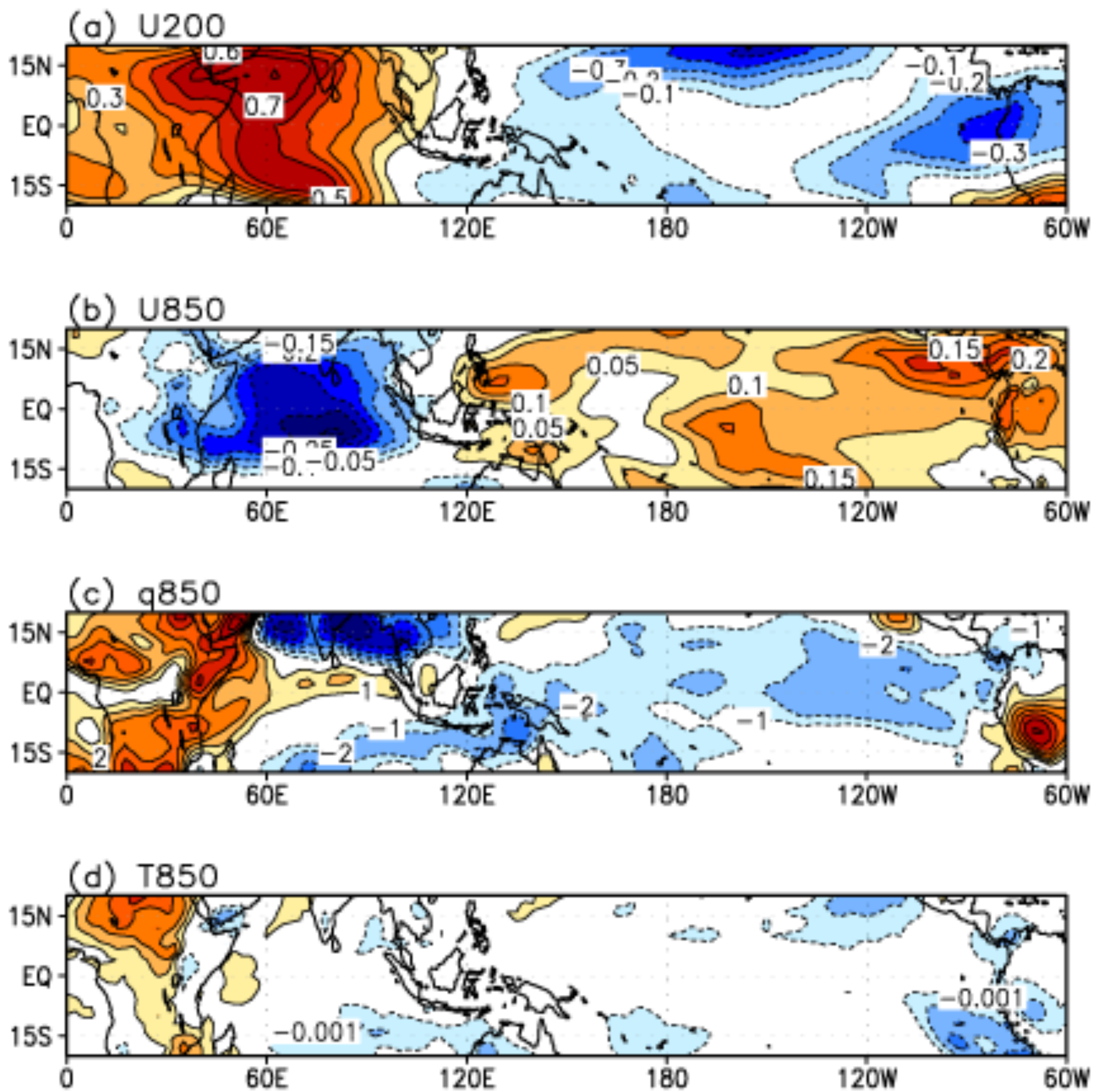
ESV of U200 over equator



Shading : Initial
Contour : Final (10 days after)

ESV mode : Eastward propagating signal over Indian Ocean

Empirical Singular Vector at phase 4



Forecast skill of bi-variate RMM index

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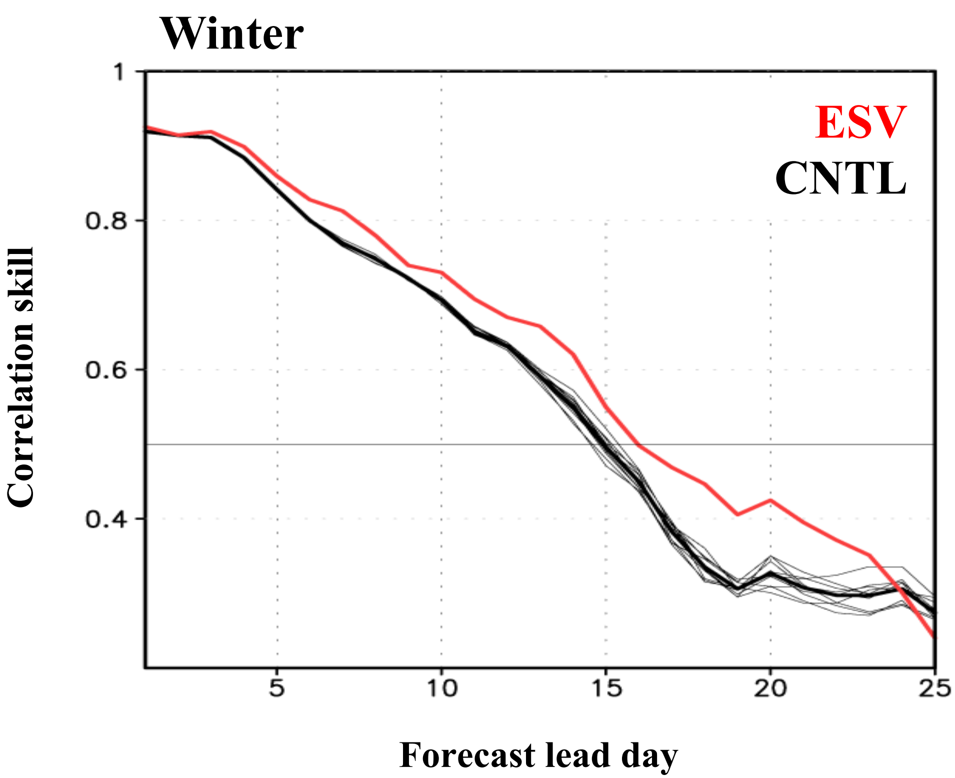
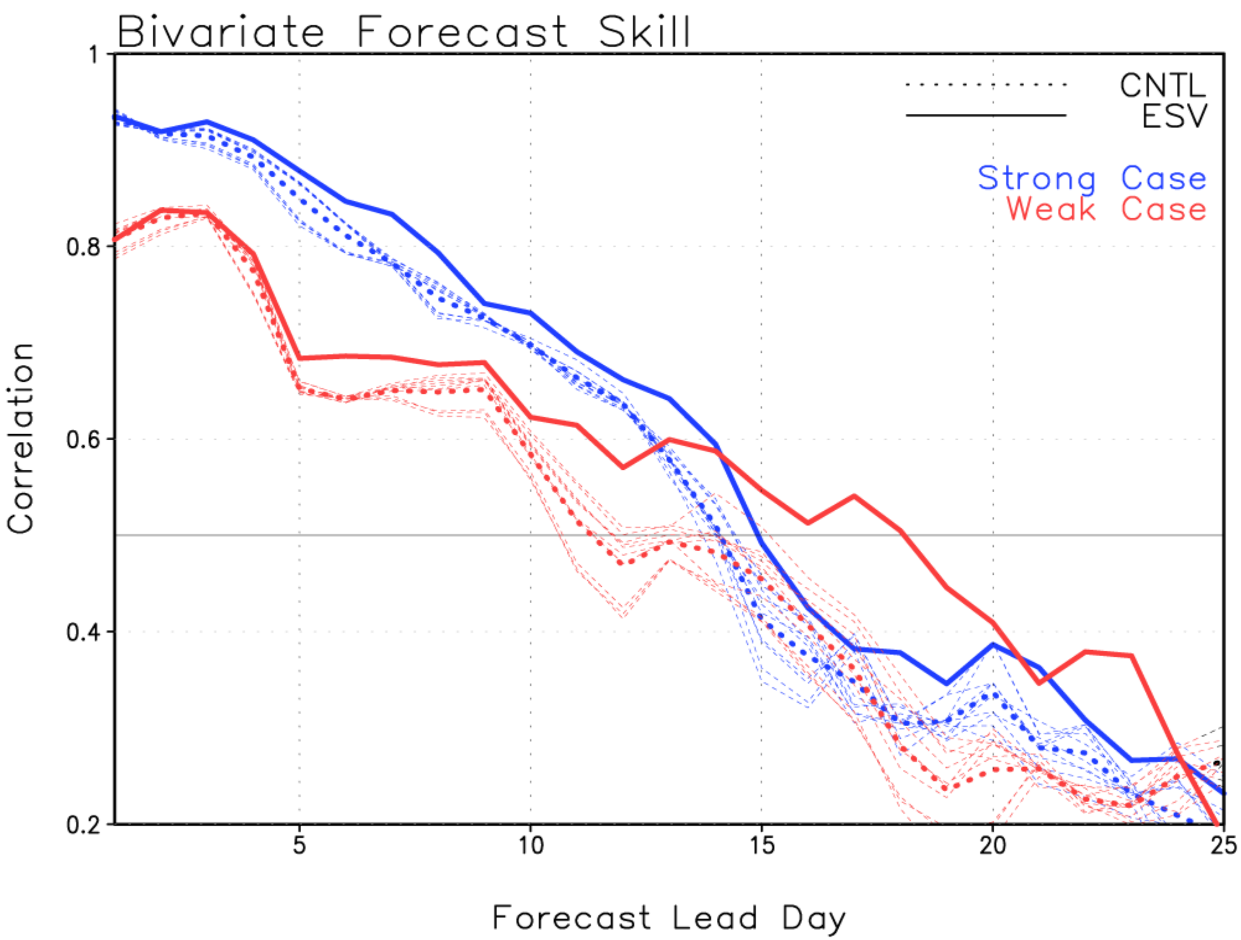


	Red	Black
Ensemble perturba tion	ESV	Random Per t.
Observation	MERRA	
Initialized method	MERRA replay with coupled GCM	
Ensemble member	2	
Model	GEOS5 CGCM	
Prediction period	1990.1.1-2000.04.30 (Total : 180 cases)	

ESV shows systematic improvement in MJO prediction

Forecast skill of bi-variate RMM index

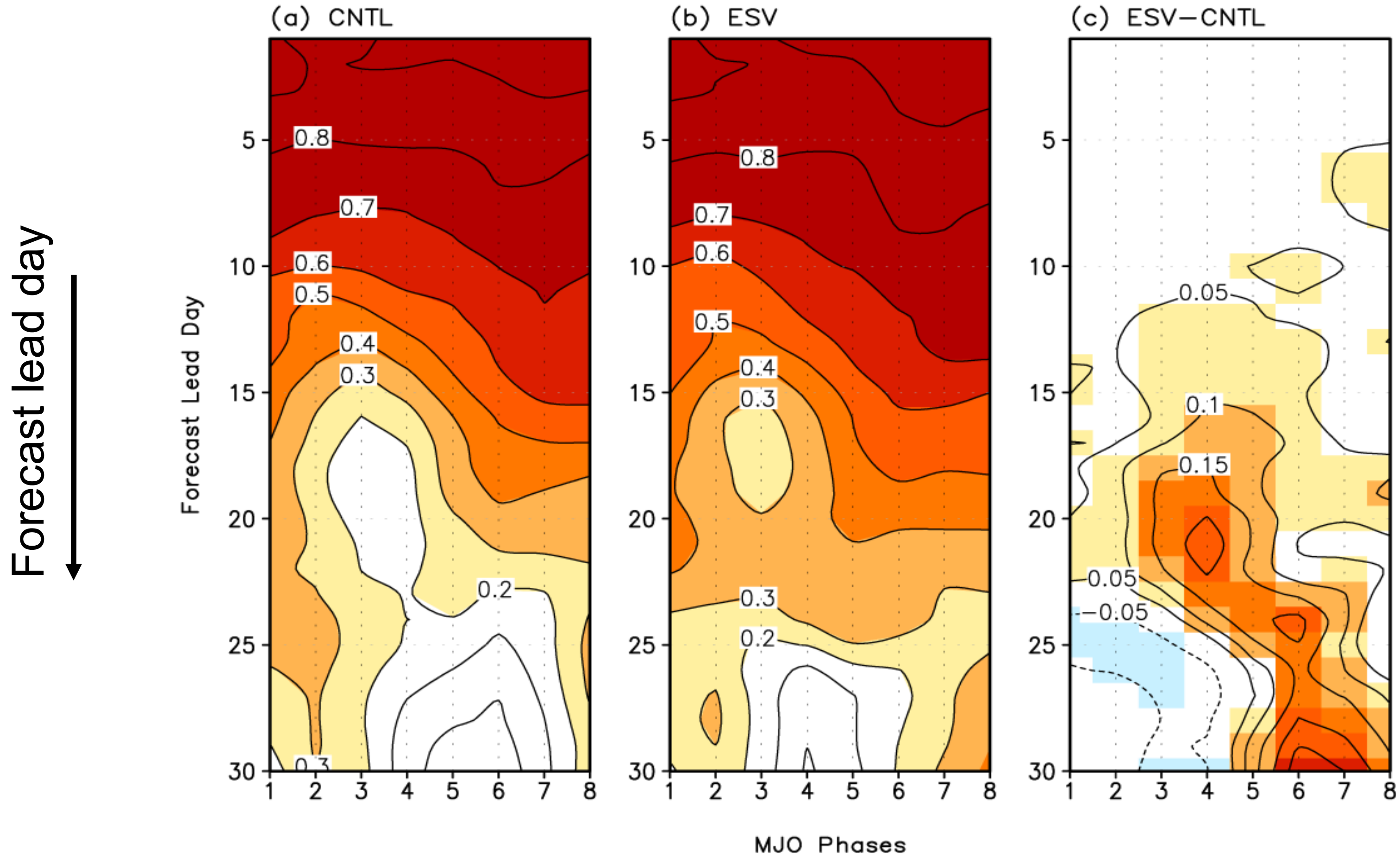


Strong case : RMM magnitude > 1

Weak case : 1 > RMM magnitude

ESV shows robust improvement for weak MJO cases

ESV Correlation skill : phase dependency



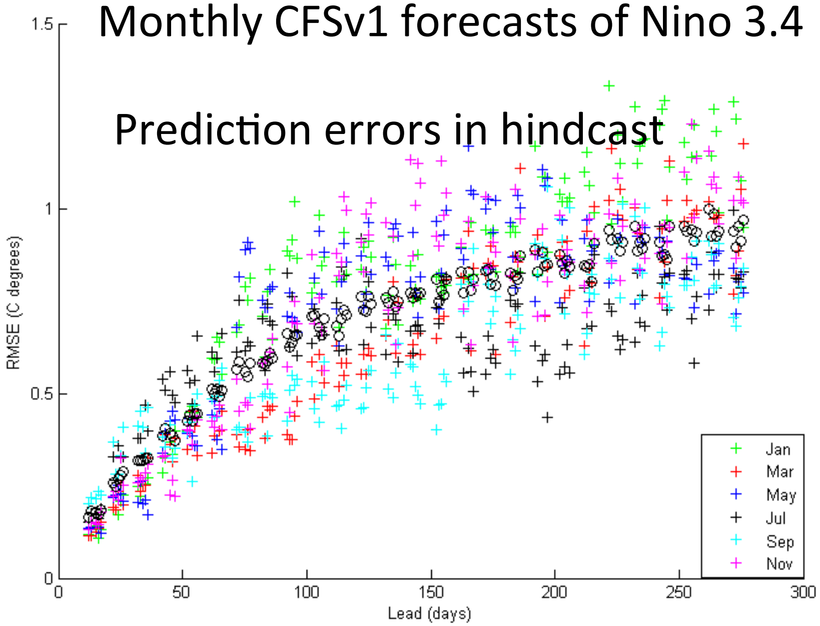
Correlation skill improvement of ESV prediction exists over unpredictable phase (phase 4-8)

Activities at EMC under this project

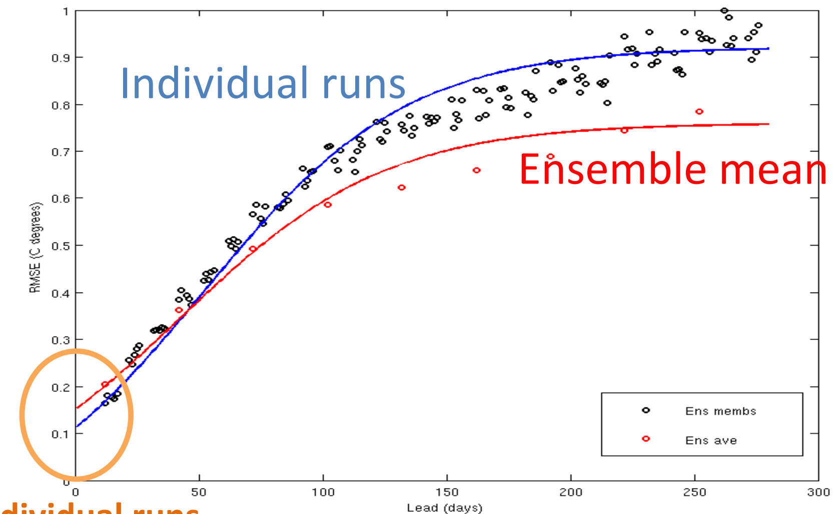
- Performance evaluation of the lagged versus the "all at once" ensemble generation approach
- Developing of a new strategy for analysis error estimation to improve ensemble perturbations
- Several attempts to compile and run an ESMF-based coupled model
- The lack of suitable coupled model to perform ET experiments led to i) the use of old CFSv1 as a testing model, and ii) carrying out and assess the performance of GEFS on extended ranges (out to 35 days)

Ensemble generation approaches: Lagged versus “all at once”

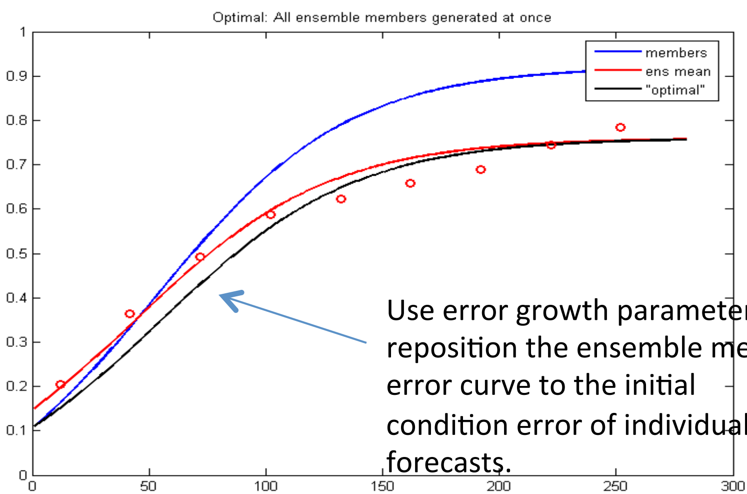
Monthly CFSv1 forecasts of Nino 3.4



Error growth parameterization to estimate mean initial errors



Individual runs have smaller initial errors ⇨ This is expected because old runs deteriorate initial conditions



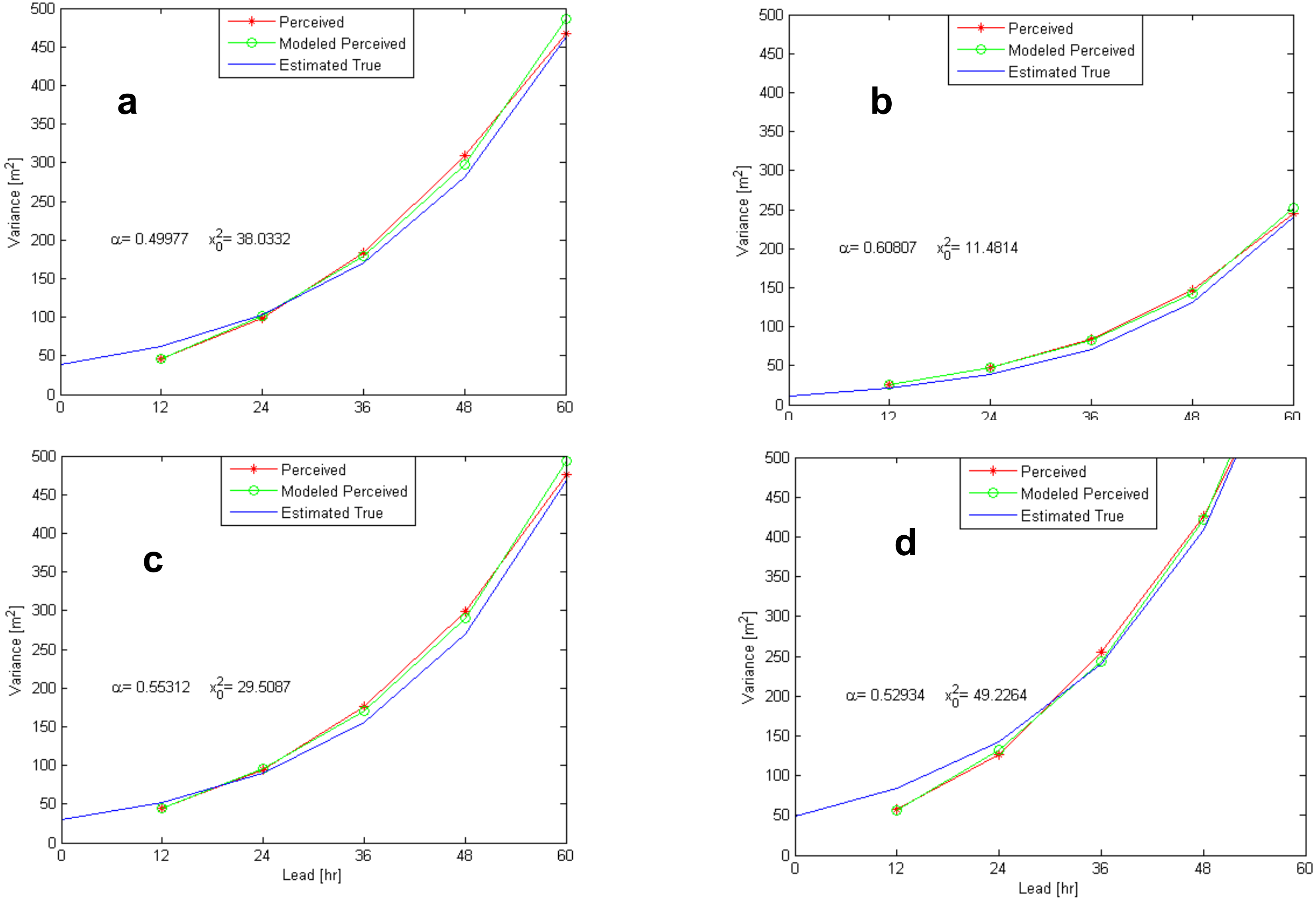
Use error growth parameters to reposition the ensemble mean error curve to the initial condition error of individual forecasts.

- ~11 days predictability gain in the CFSv1 15-members per month ensemble. Likely much less in the CFSv2.
- ~5 days using the latest 8 runs in the ensemble.
- No sophisticated ensemble generation scheme used
- For sub-seasonal predictions the gain would represent a significant improvement

approaches

model.

- The problem is that analysis uncertainty is usually not known. In variational data assimilation systems it is computationally very expensive to estimate it. In ensemble-based data assimilation methods should produce this uncertainty but with limitations
- In the mean time we developed a technique to estimate analysis uncertainty based on knowledge of the error growth and the differences between analysis and forecasts.
- The ET method currently uses historical errors fixed in time, changing month by month, as a surrogate of analysis uncertainty. The new method is aimed at producing initial perturbations consistent with analysis uncertainty. We tested the method in a perfect-model environment and in historical archives of forecasts from global operational model (GFS, ECMWF, FNMOC, CMC)

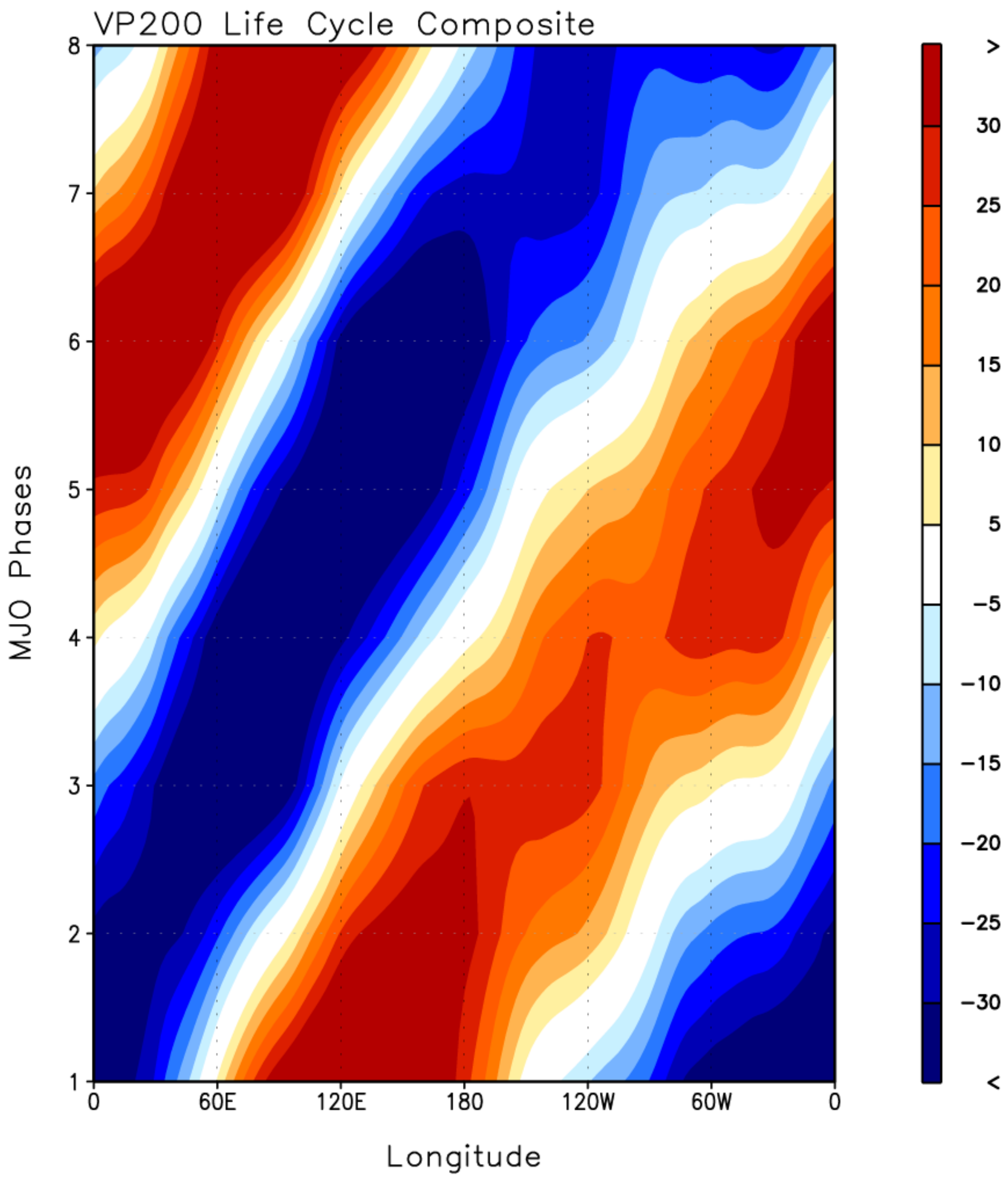


Analysis and Forecast error variances as a function of lead time for four global models: (a) GFS, (b) CMC, (c) ECMWF, and (d) FNMOC for models operational in 2008.

Plans for Final Year

- Continue evaluating ESV and ET approaches with coordinated experimentation (NASA/GMAO and EMC models)
- Implement NCEP physics into GEOS-5 model and re-assess ESV and other approaches
- Complete the development of ESMF-compatible coupled model at NCEP and test new initialization approaches

VP200 Life cycle composite



Unit : 10^5 m^2/s