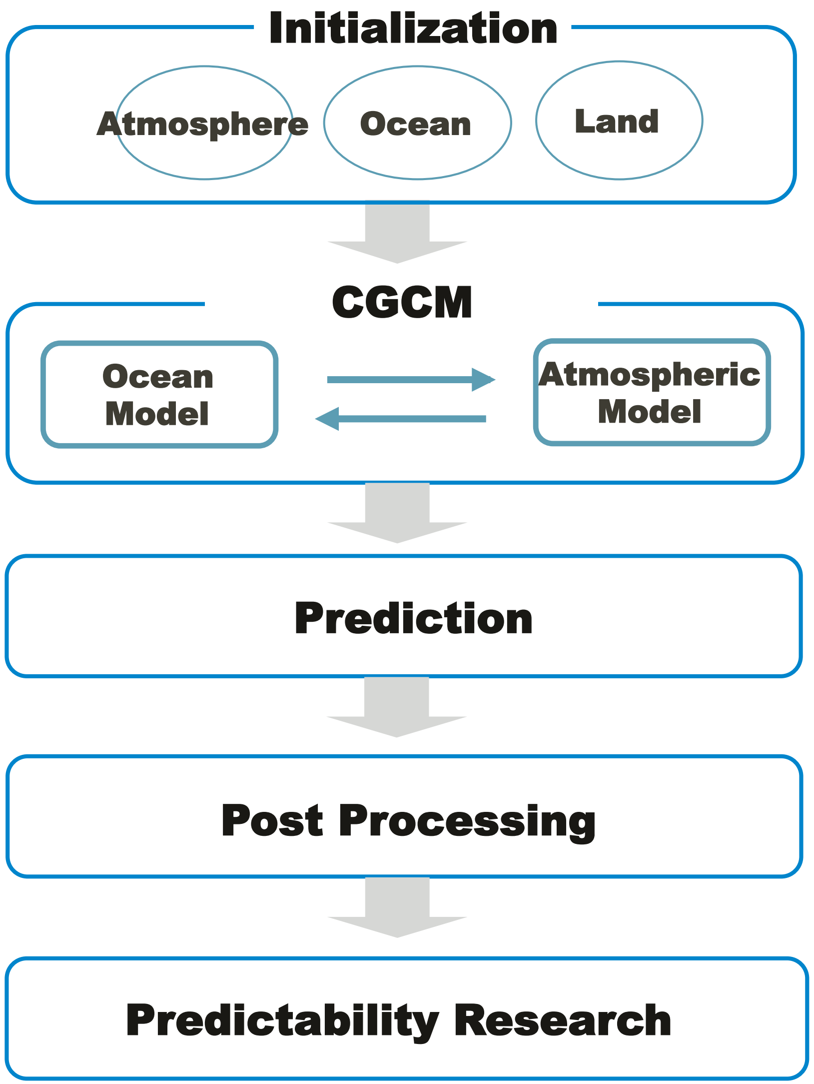
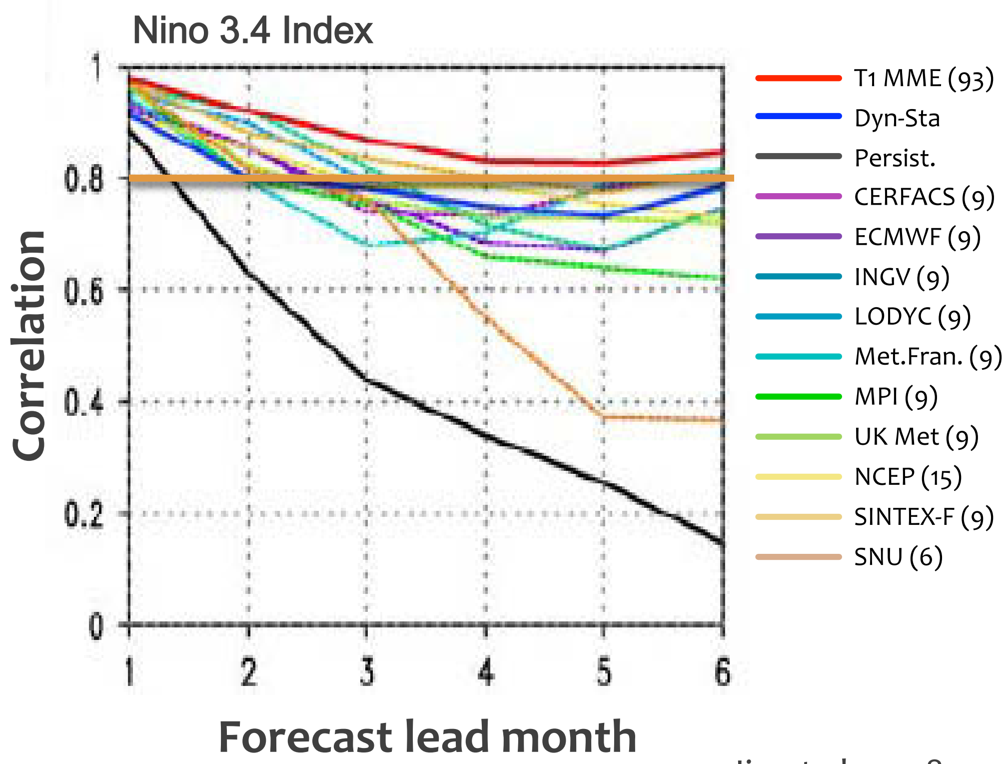
ENSO & MJO Predictions and Their Predictability

In-Sik Kang

Seoul National University

Seasonal Prediction System





<Jin et al. 2008>

※ numbers in parenthesis refer to the number of ensemble members

Contents

Prediction Model
: SNU CGCM

SNU CGCM

SNU Models	Description	References
AGCM	T42, 21 levels (2.8125X2.8125) SAS cumulus convection 2-stream k-distribution radiation Bonan (1996) land surface	Kim (1999) Kang et al. (2002) Kang et al. (2004) Kim et al. (2003) Lee et al. (2003)
OGCM	MOM2.2 + Mixed Layer Model 1/3° lat. x 1° lon. over tropics (10S-10N), Vertical 32 levels	Noh and Kim (1999) Noh et al. (2003a) Noh et al (2003b) Kim et al. (2004) Noh et al. (2004) Noh et al. (2005)
CGCM	AGCM + OGCM	

Mixed Layer Model

Vertical Eddy Viscosity $K_M = S_M ql$

Vertical Eddy Diffusivity $K_H = S_H ql$

where S_M, S_H: empirical Constant

$q^2/2$: TKE

l : the length scale of turbulence

Coupling Strategy

-2-hr interval exchange

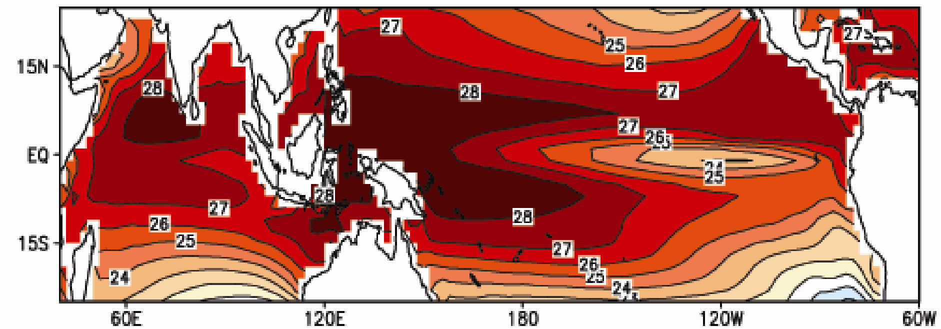
- Ocean : SST
- Atmosphere : Heat, Salt, Momentum Flux
- No Flux Correction is applied

Model Improvement   Ham et al. (2012, Climate Dyn)

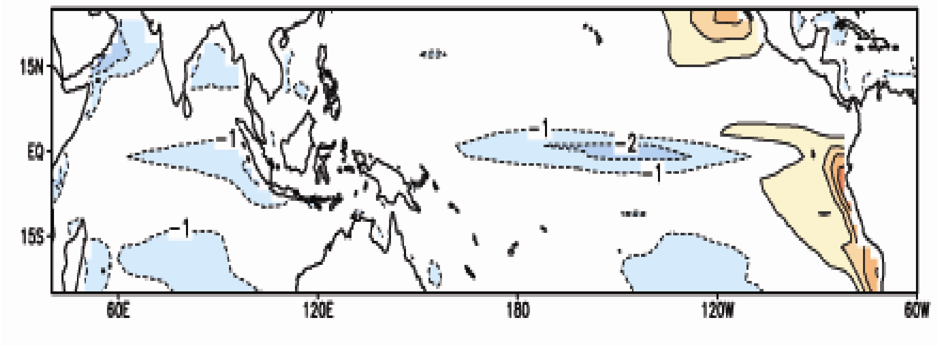
- Convective momentum transport
- Diurnal coupling
- Tokioka constraint (alpha=0.1)
- Auto conversion time scale (3200s)

CNTL CGCM

Annual mean SST

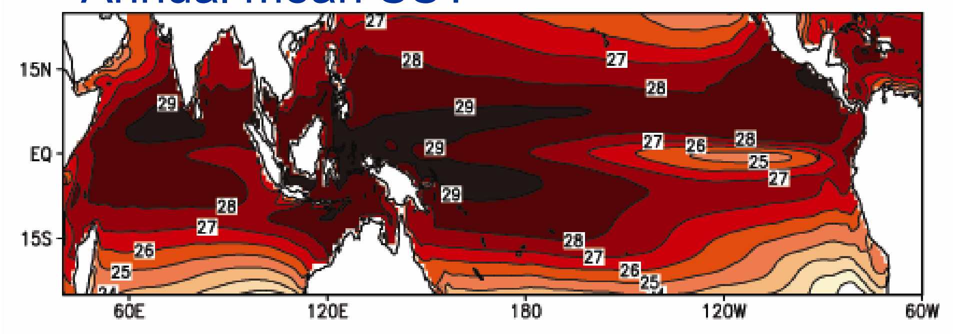


Bias

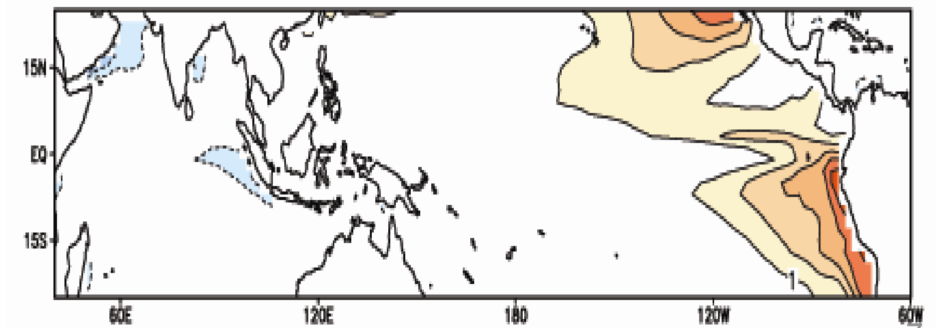


Improved CGCM

Annual mean SST



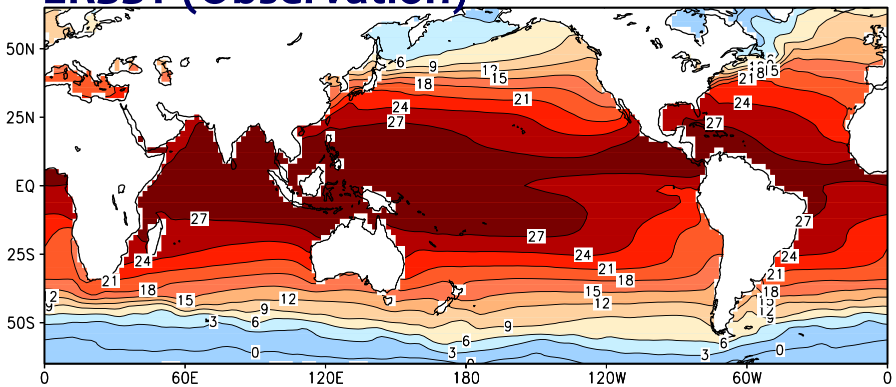
Bias



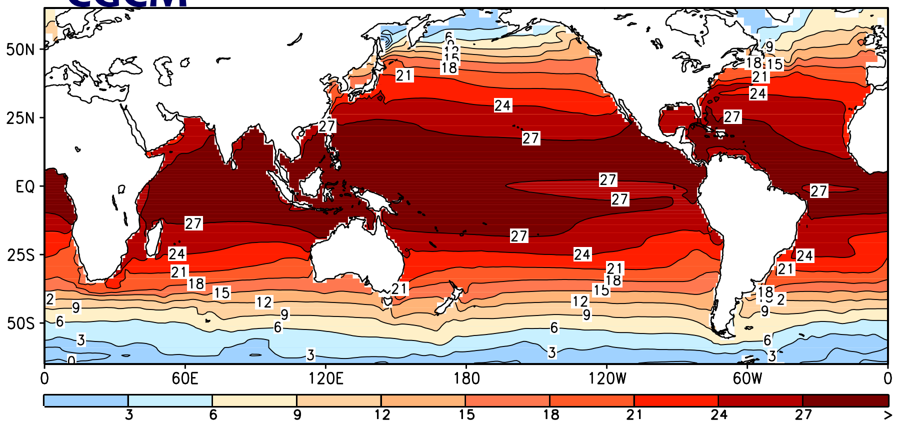
SNU CGCM

Annual mean SST

ERSST (Observation)

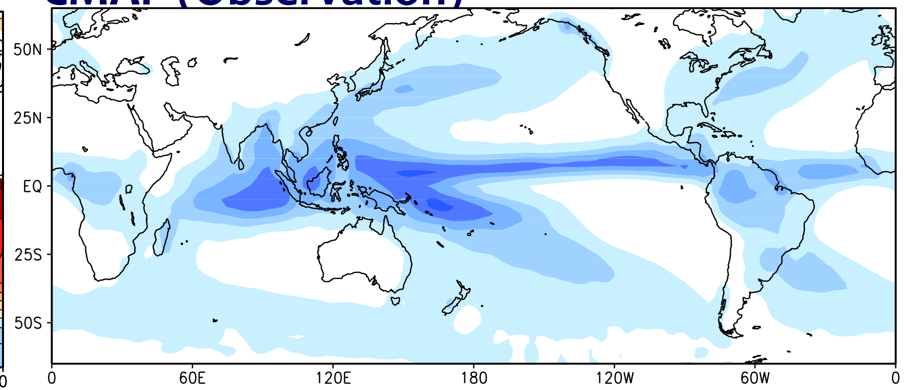


CGCM

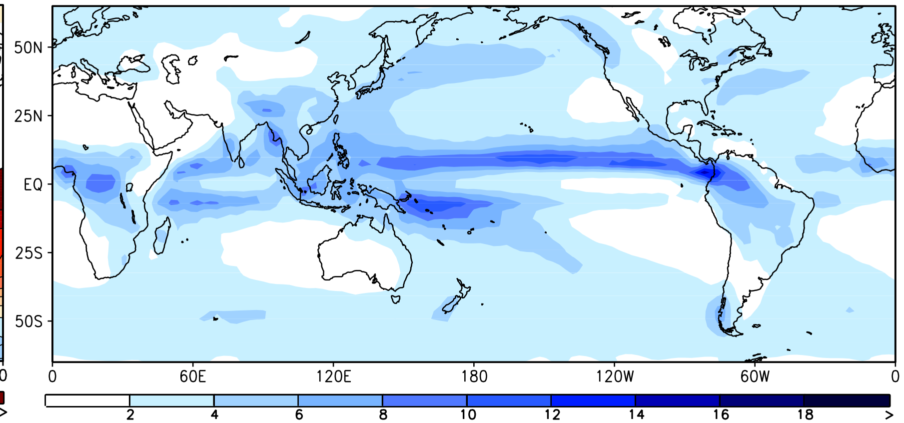


Annual mean Precipitation

CMAP (Observation)



CGCM

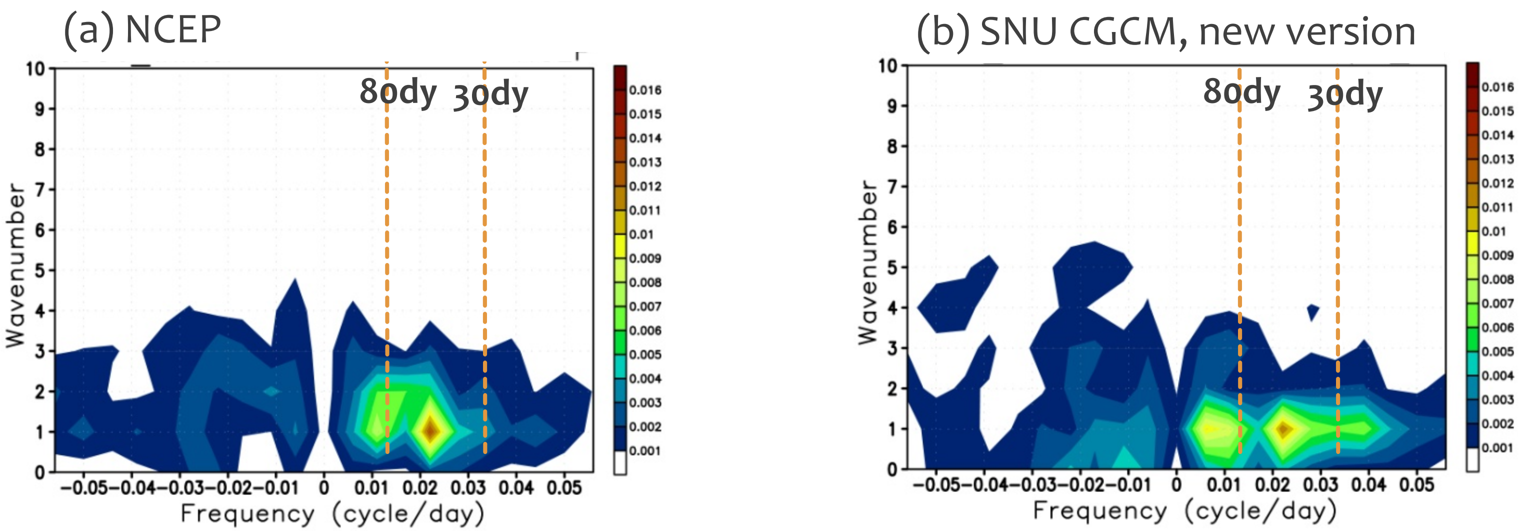


Model

- Cumulus Momentum Transport
- Convective triggering (Tokioka constraint)
- Reduced auto-conversion time scale (tau=3200s)
- Diurnal air-sea coupling

Space-time power spectrum U850, winter (Nov-Apr)

MJO



√ **Tokioka constraint coefficient (alpha) = 0.1**

√ **Convective adjustive timescale = 3200 s**

Seasonal Prediction System

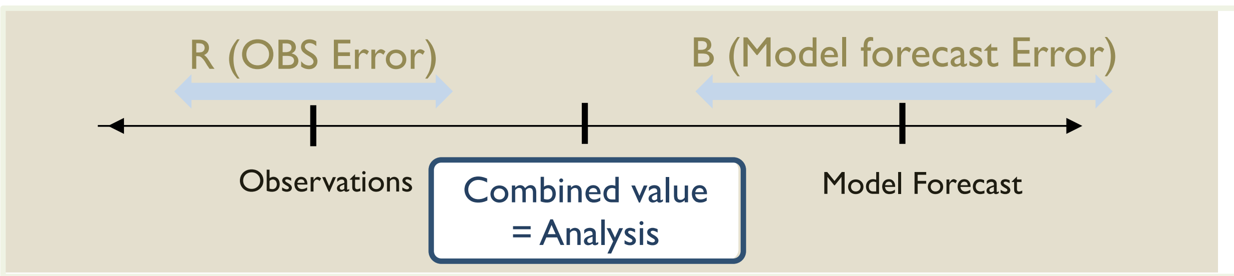
What is initialization?

Observations		Forecast model		Initial condition
Some errors	+	Erroneous	⇒	**Still Erroneous**
Irregular		Regular		Regular
Not sufficient		Sufficient		Sufficient

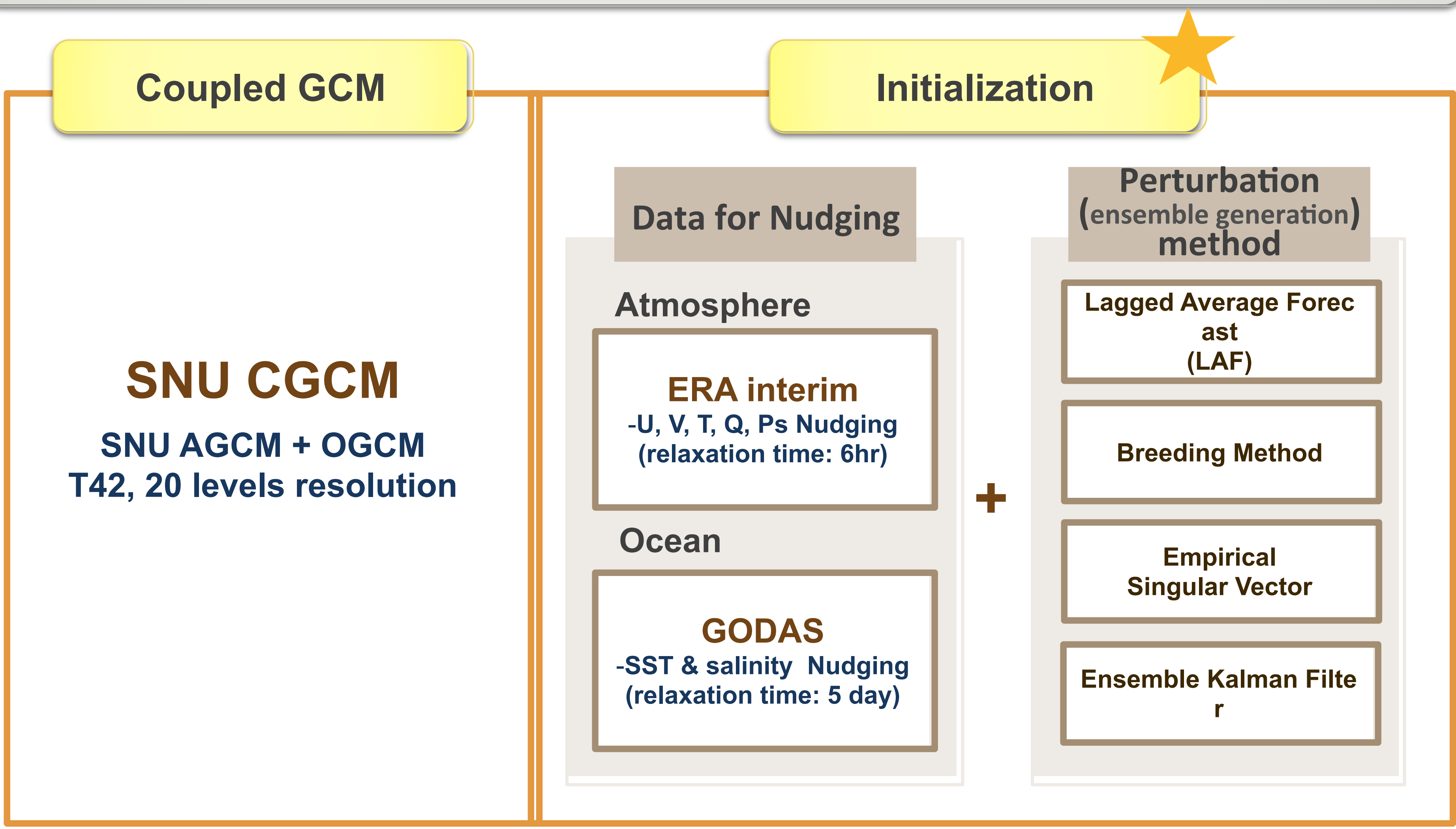
How to combine? – Initialization (Data assimilation)

$$\Psi_{Analysis} = (1-k)\cdot\Psi_{Model} + k\cdot\Psi_{OBS}$$

Weighting coefficient (k) = $\frac{B}{R+B}$ = $BH^T(HBH^T + R)^{-1}$ (matrix form)♪

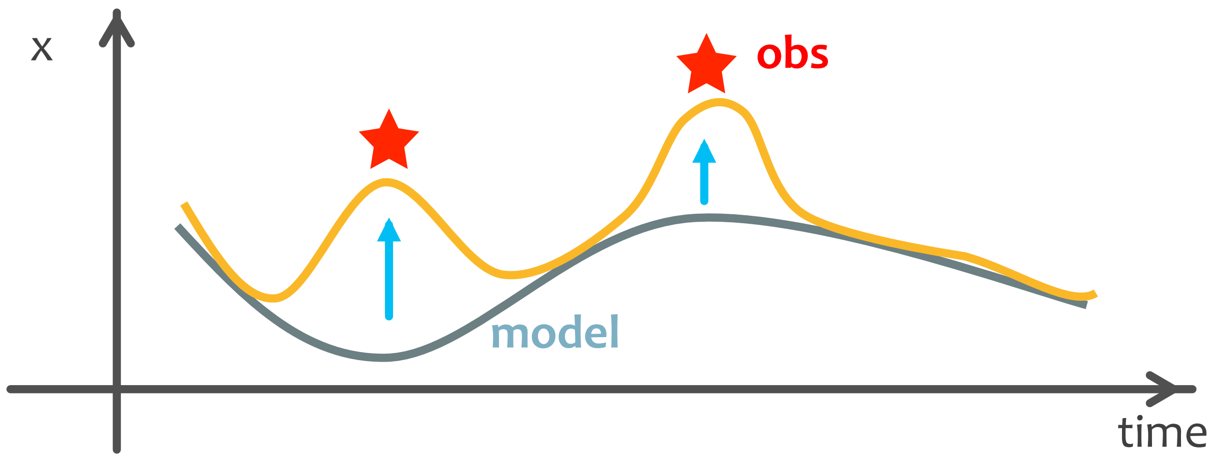


Prediction System



- Seasonal Prediction : ENSO prediction
- Intra-seasonal Prediction : MJO prediction

Nudging



<u>Nudging equation for temperature</u>

$$\frac{\partial T}{\partial t} = -v\cdot\nabla T + \frac{Q}{\rho C_P H} + \frac{T_{OBS} - T}{\tau_T}$$

τ_T : relaxation time scale to observation	
Atmosphere	6 hour
Ocean	5 day

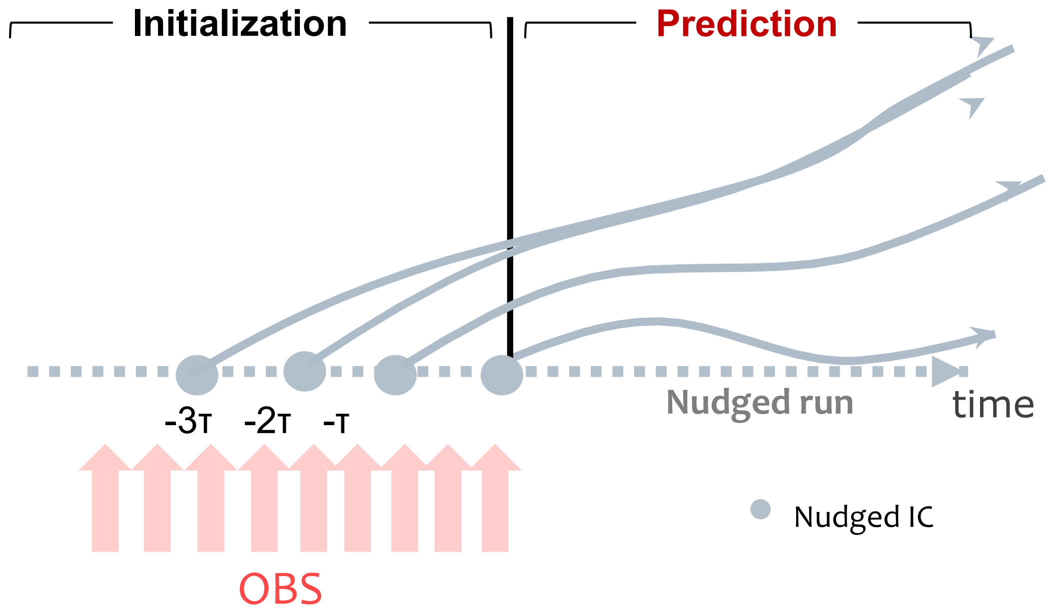
Initialization

- Nudging

Perturbation Method

- Lagged Average Forecast (LAF)
- Breeding method (BV)
- Empirical Singular Vector (ESV)
- Ensemble Kalman Filter (EnKF)

Lagged Average Forecast (LAF)



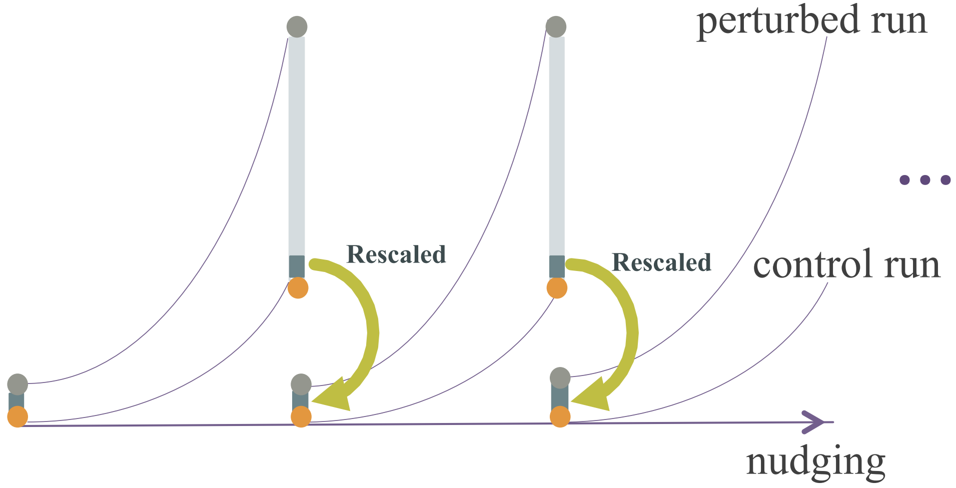
advantages

- Unlike random perturbation,
- LAF includes **dynamical influences**.
- Contains errors of the day
- Simple to perform

disadvantages

- **Old forecasts** may result in **bad ensembles**.
  (e.g. analysis at t=-3τ)

Breeding Method/Breeding Vector



Procedure

1. Integrate one cycle from random perturbation plus control initial condition
2. Calculate difference between perturbed run and control run (i.e. error)
3. Rescale the error
4. Integrate one cycle from rescaled error perturbation plus control initial condition
5. Repeat 2-4 processes until initial forecast time

Toth and Kalnay (1993)
forward integration of model
NCEP weather forecast

Bred Vectors represent fast growing mode of the model.

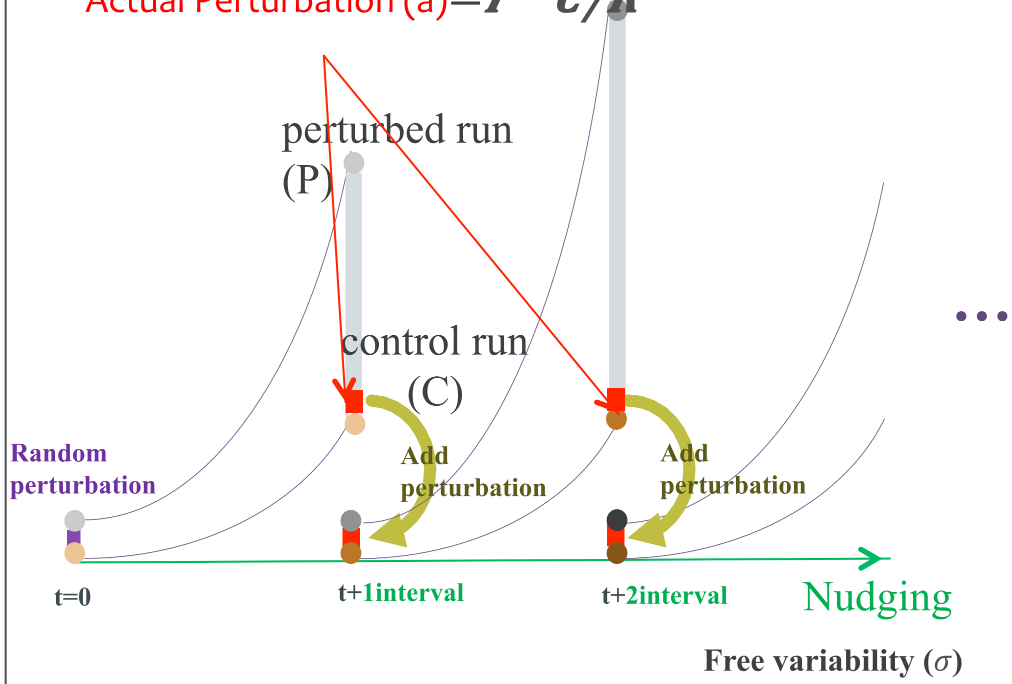
2. Breeding Method

A size of perturbation must remain same during breeding period by NORM and FREE VARIABILITY.

c.f.) If perturbation only proportional to rescaling factor, Actual Size of perturbation will differ from simulation

Resize(R)= $NORM/\sigma \cdot res$

Actual Perturbation (a)= $P-C/R$



Rescaling (res) : 10%, 15%,…

Breeding interval: 1month, 3month, 6month

Procedure

1. Integrate perturbation cycle from random perturbation plus control initial condition (nudging)
2. Calculate "Norm" using **SST**

   NORM = $\sqrt{[(P-C)^2]_{region}}$

   $[\ ]_{region}$: area average over 10S~10N, 120E~90W
3. Calculate an actual perturbation size with given rescaling factor.

   Resize (R)

   = NORM/(σ·rescaling)

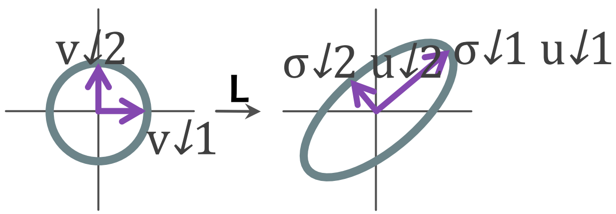
   * norm/R = σ·rescaling ;norm↑,R↑

   given and fixed
4. Add perturbation $(P-C)\downarrow i\ /R$ on nudging initial for next step of breeding. (i=u,v,..)
5. Repeat 2-4 processes until initial forecast time

Bred Vectors represent fast growing mode of the model.

Toth and Kalnay (1993)

ESV (Empirical Singular Vector)



$Y_n = X_{n+\tau} \cong L(X_n)$

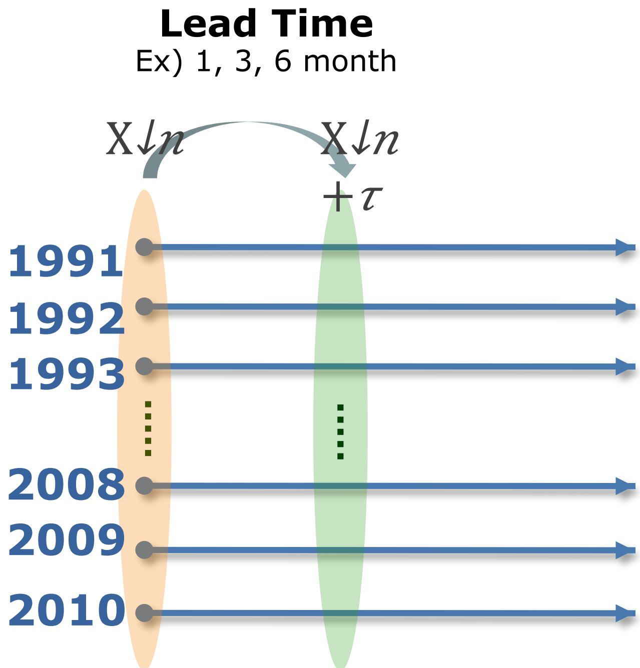
$L(X) = Y$

↳ $L = YX^t (XX^t)^{-1}$

$L = U \Sigma V^T$

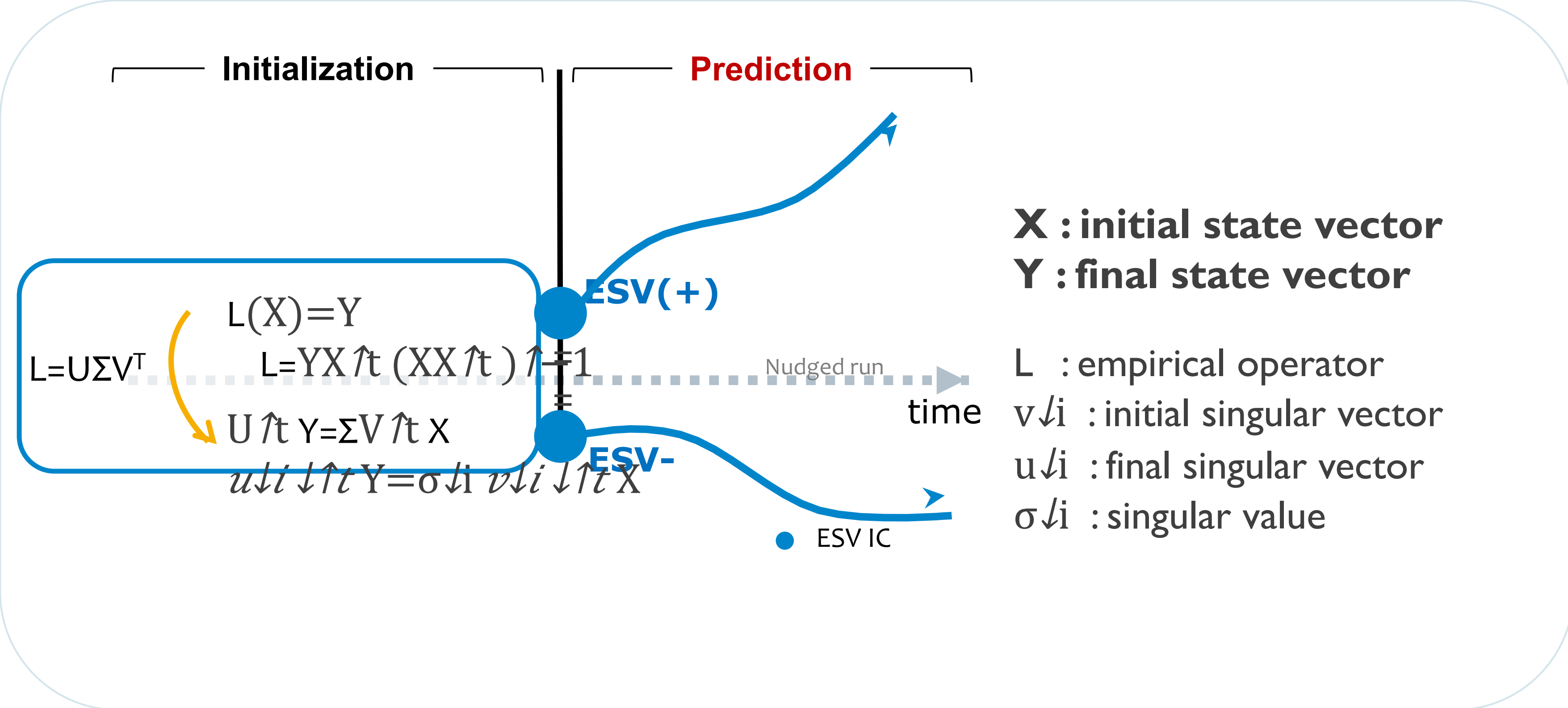
$U^t Y = \Sigma V^t X$

$u_i^t Y = \sigma_i v_i^t$



Empirical singular Vectors achieve maximum perturbation growth rate without a linear model.

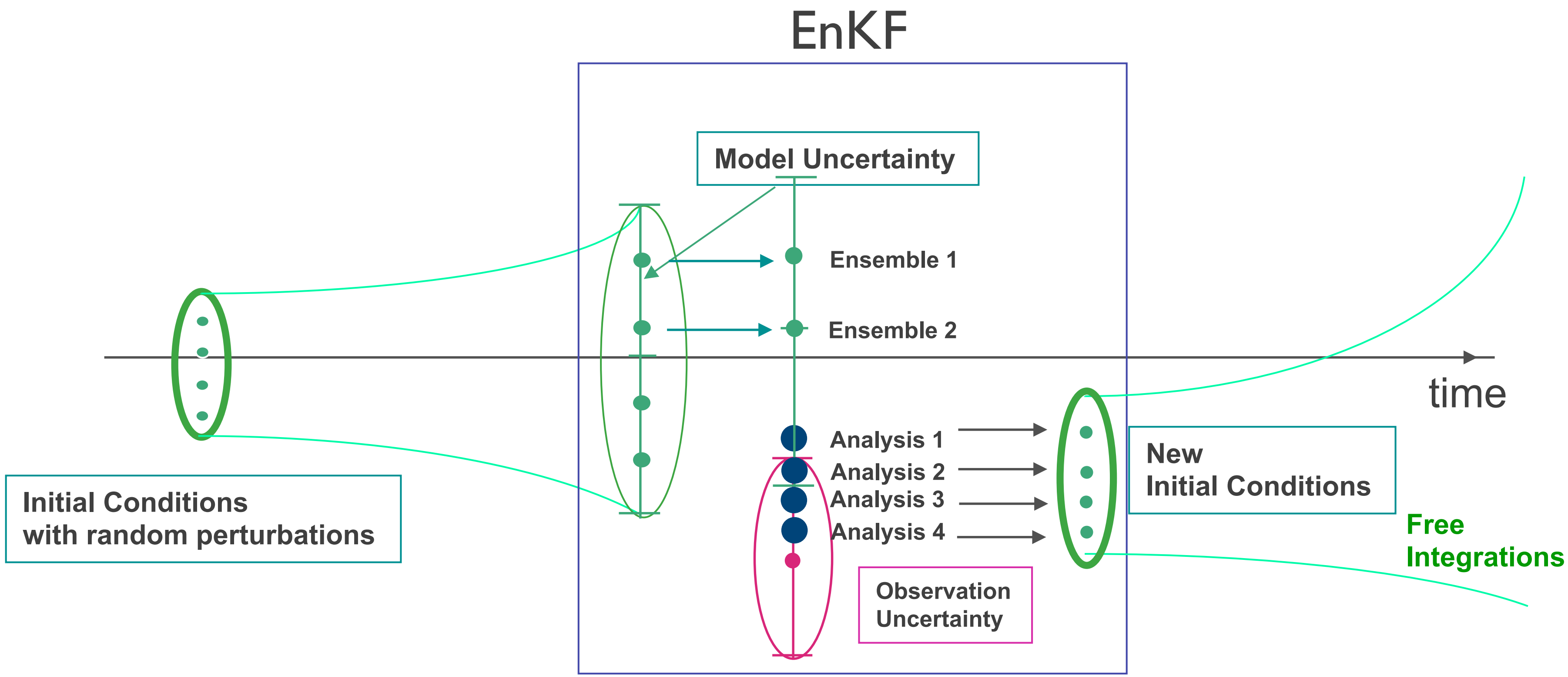
Empirical Singular Vector (ESV)



Kug et al. (2010)
mathematical technique

Empirical singular Vectors achieve maximum perturbation growth rate without linear model.

Ensemble Kalman Filter



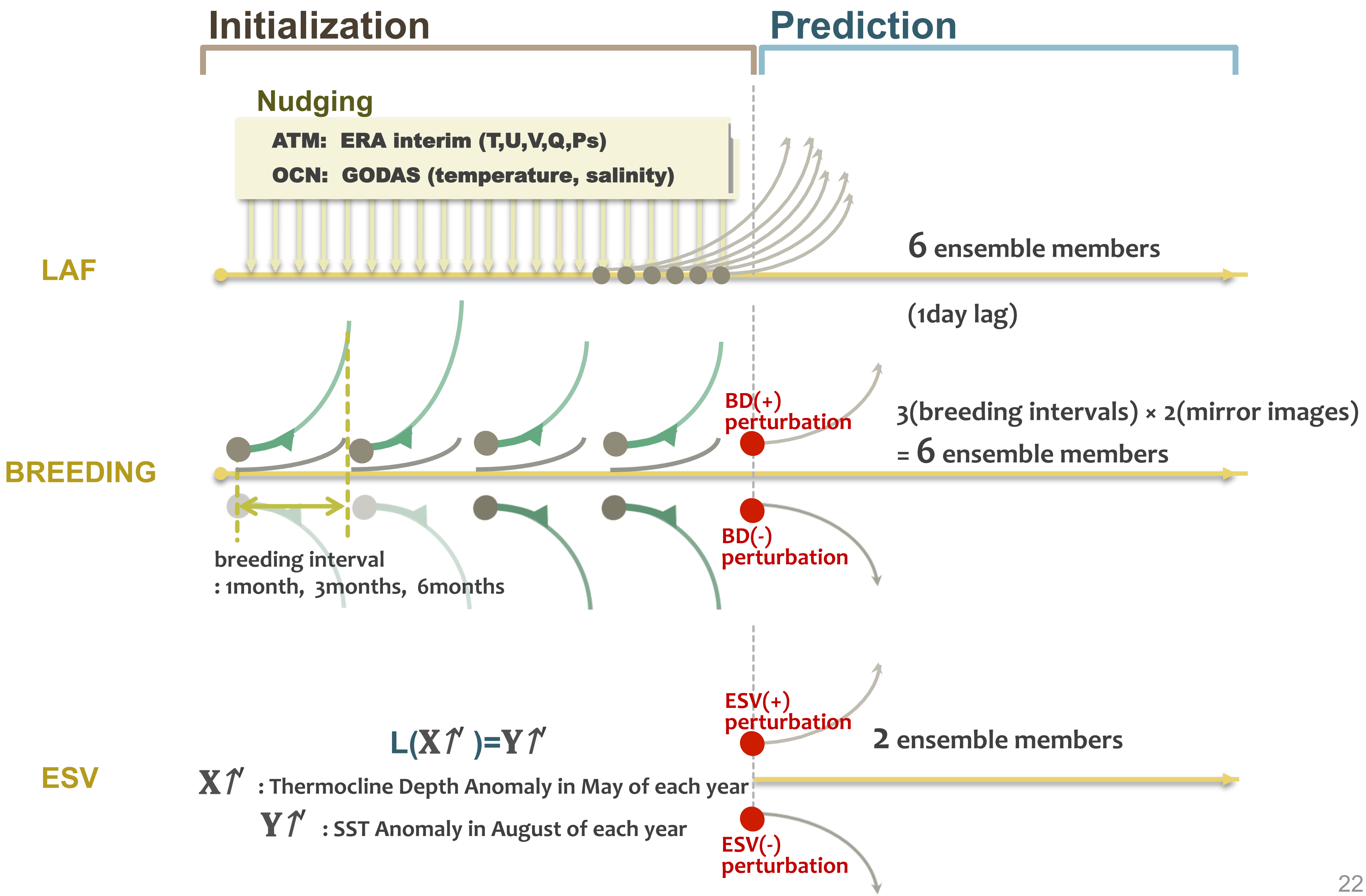
$$\Psi_{Analysis} = (1-k)\cdot\Psi_{Model} + k\cdot\Psi_{OBS}$$

Weighting coefficient (k) = $\frac{B}{R+B}$ = $BH^T(HBH^T + R)^{-1}$ (matrix form)

***B (model error) : Assumed as ensemble spread**

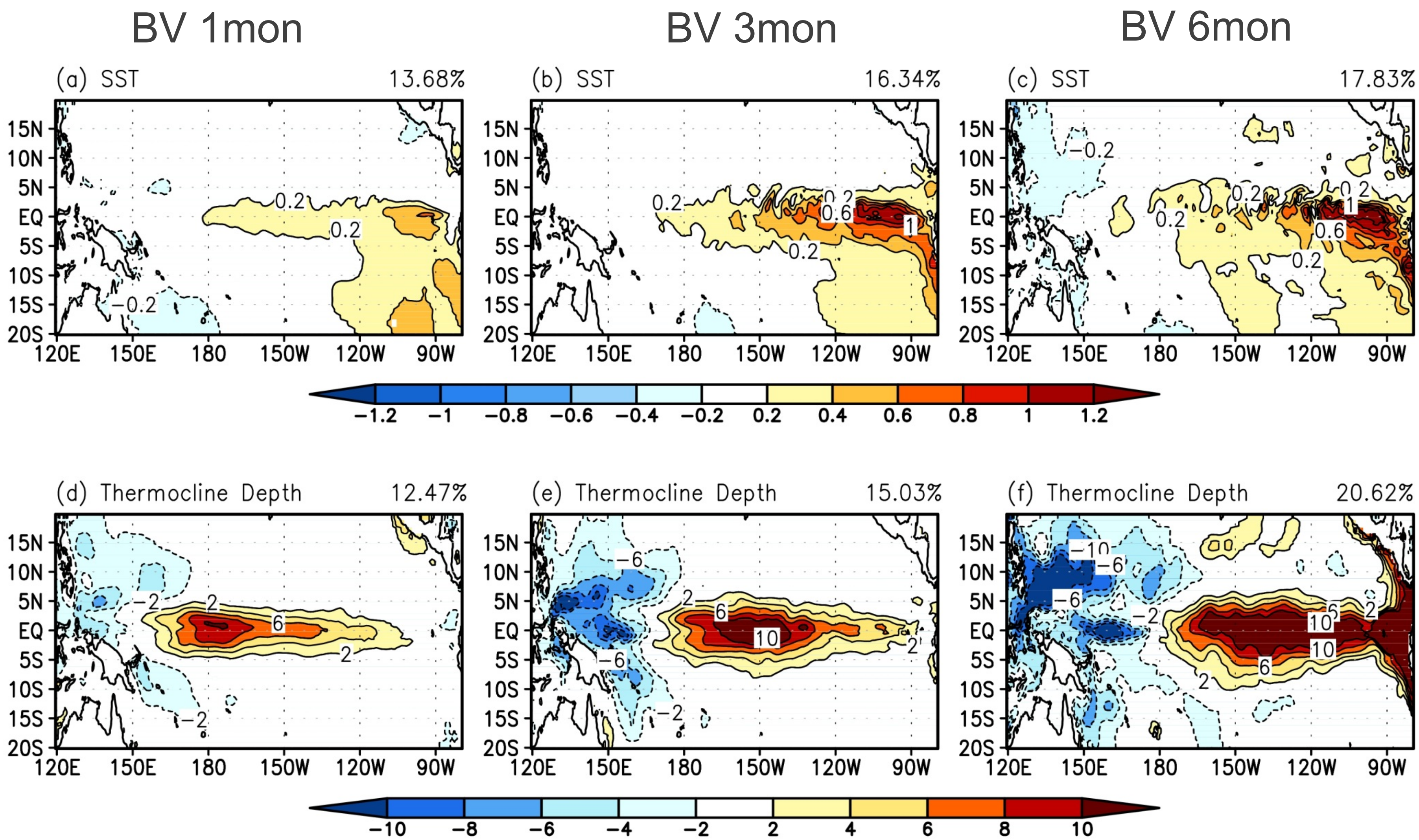
Seasonal Prediction
: ENSO Prediction

Seasonal Prediction - Initialization



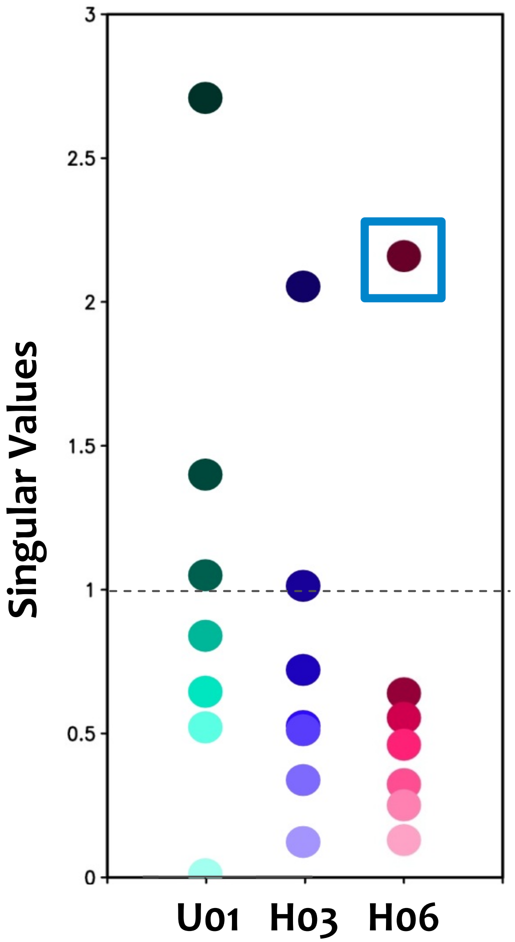
Initialization: Breeding Vector Method

1st EOF Mode of perturbations

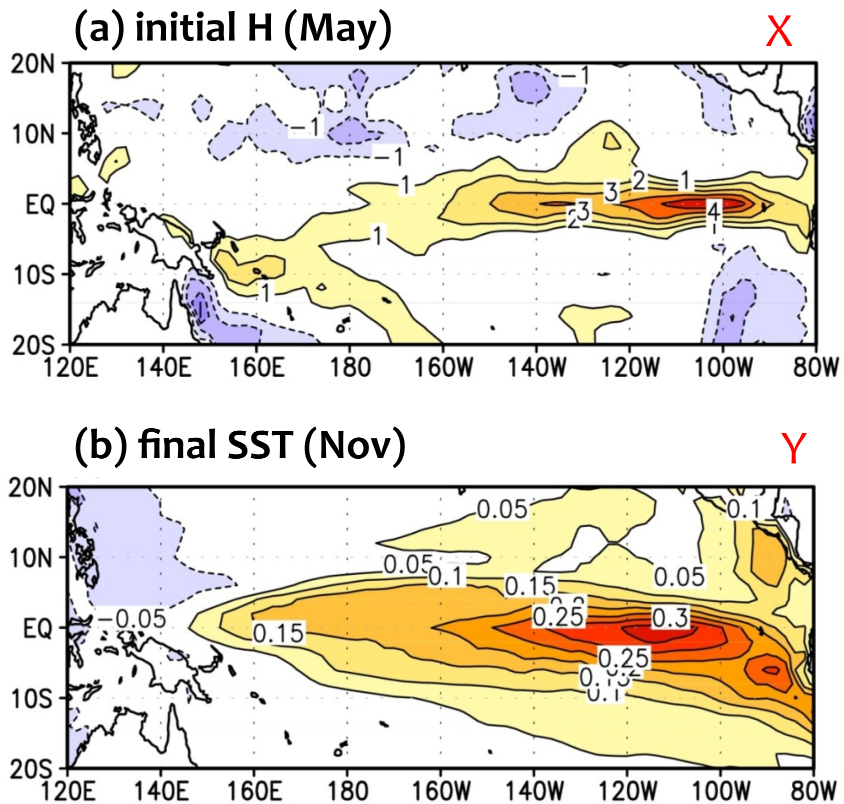


Initialization: Empirical Singular Vector (ESV) Method

■ Singular Values



■ 1st Singular Mode (H) and Final Perturbation (SST) of ESV



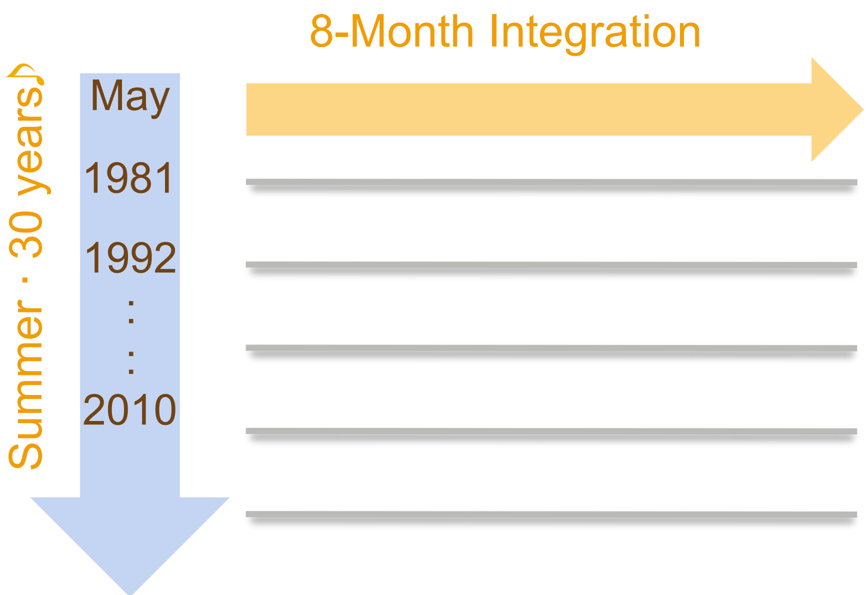
$L(X\uparrow)=Y\uparrow$

$X\uparrow$: Thermocline Depth Anomaly in May of each year

$Y\uparrow$: SST Anomaly in November of each year

Seasonal Prediction – Implementation Outline

New 30 year



14 ensemble members/year × 30 years

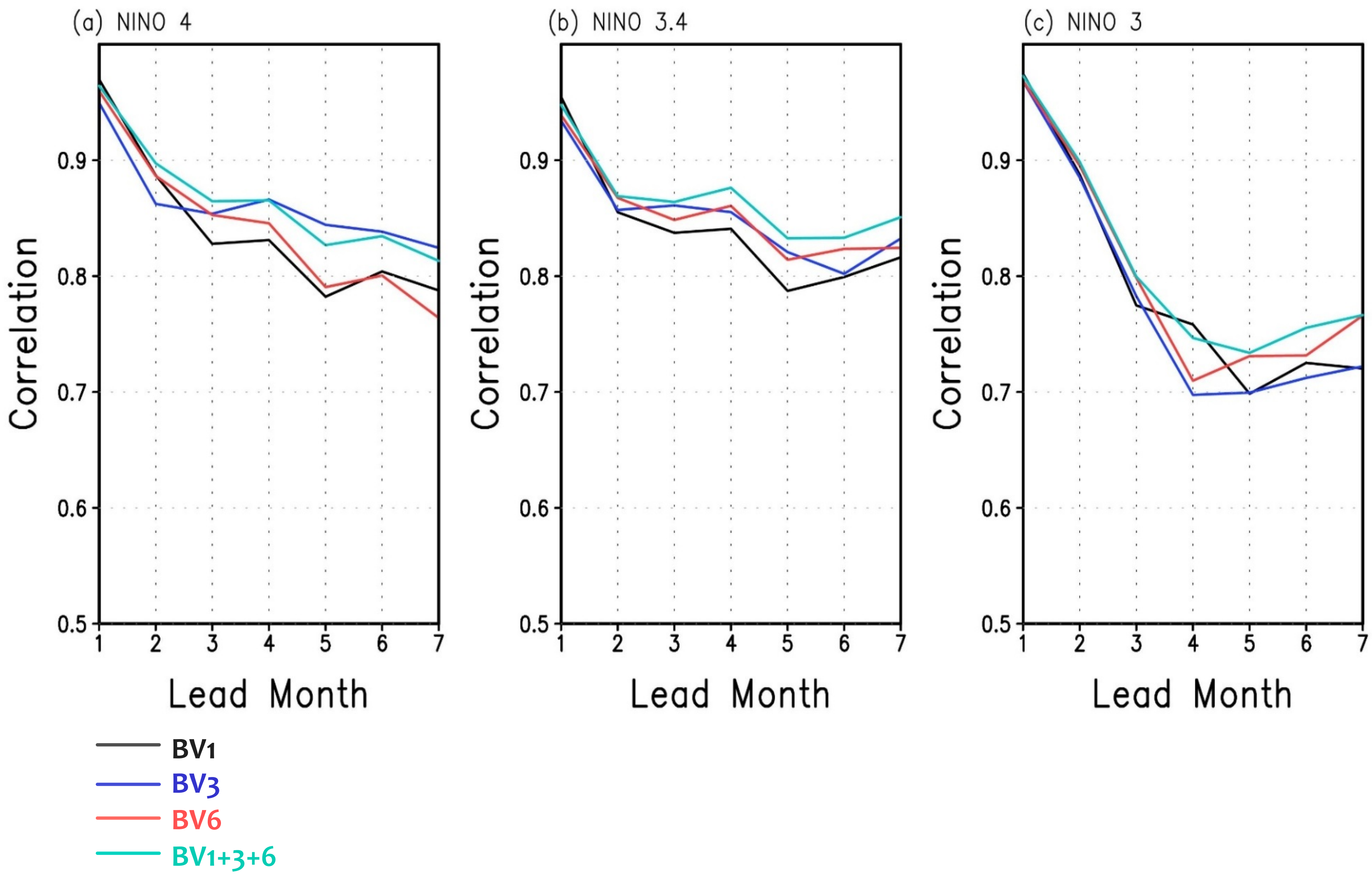
< 4 LAF + 6 BV + 2 ESV >

= 420 predictions

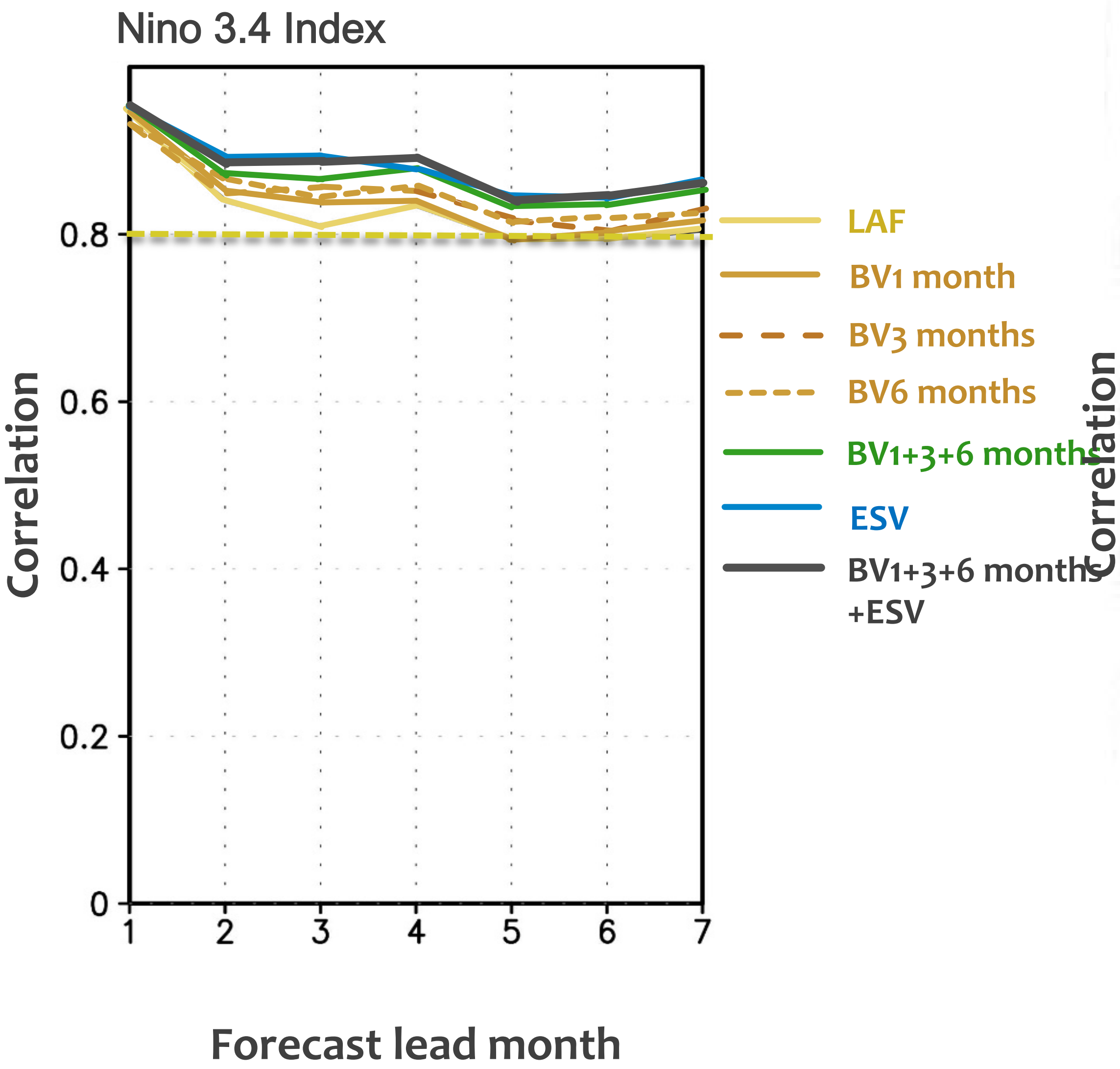
Seasonal Prediction - Results

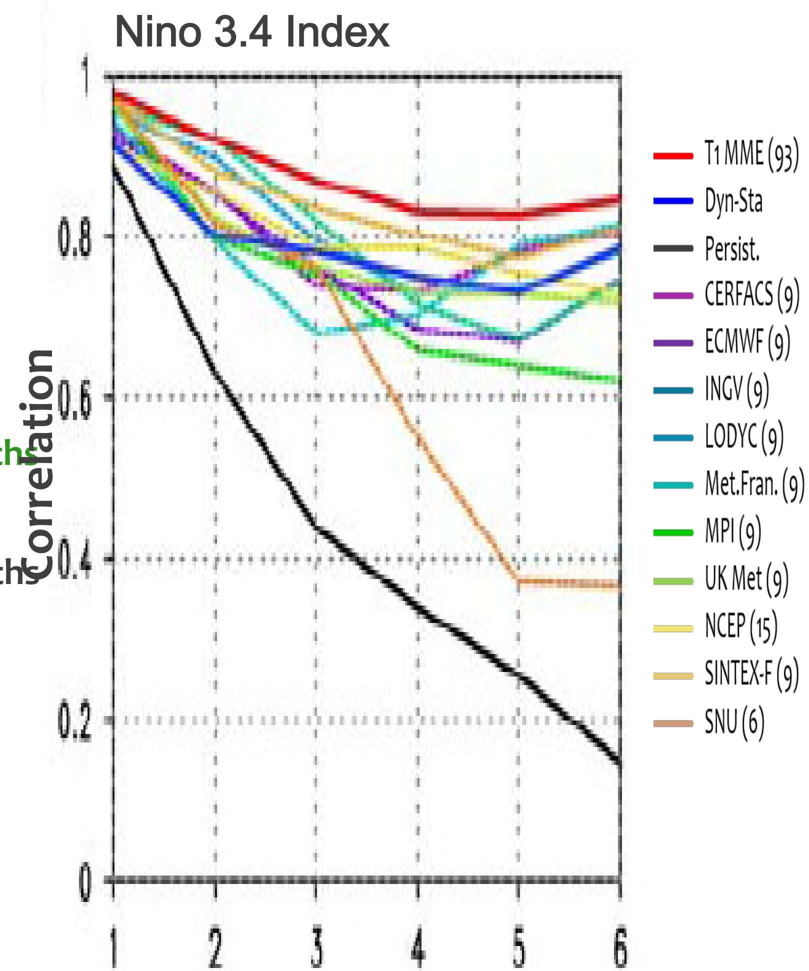
Correlation skill of Nino indices

30 years



Seasonal Prediction - Results





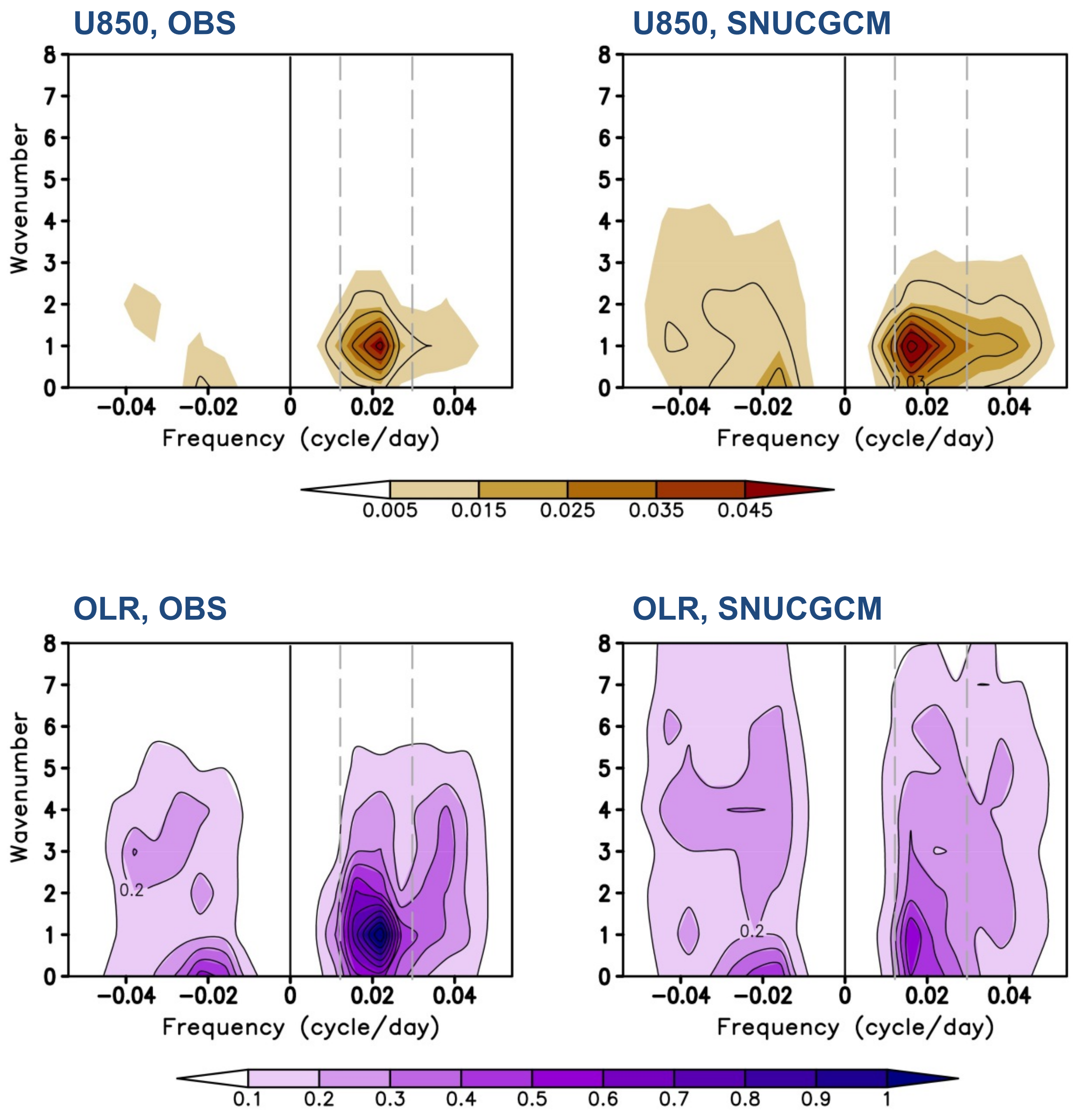
<Jin et al. 2008>

※ numbers in parenthesis refer to the number of ensemble members

Intraseasonal Prediction
: MJO Prediction

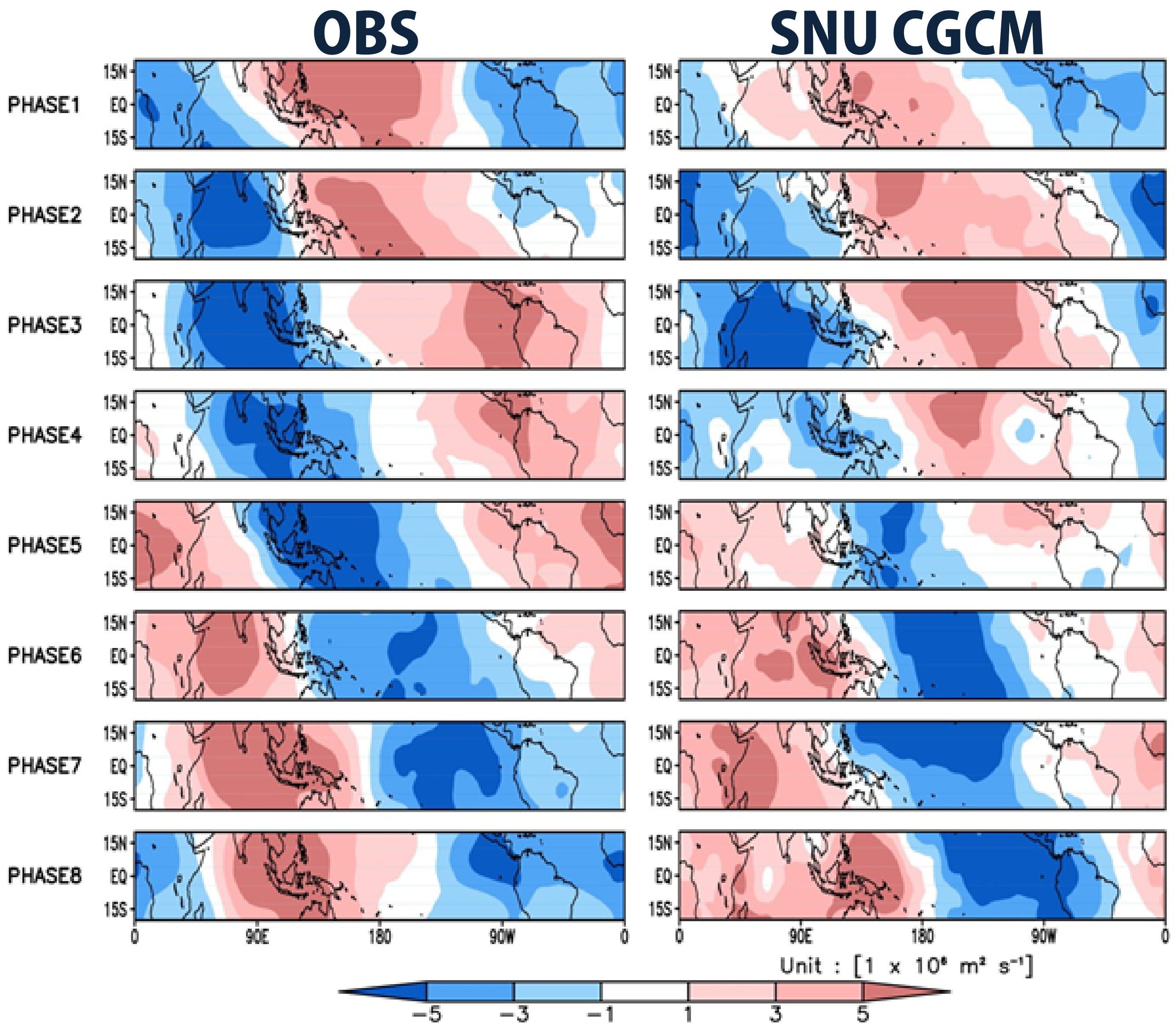
Performance of SNU CGCM ver.2

Power Spectrum (averaged 15S-15N), summer (May-Oct)

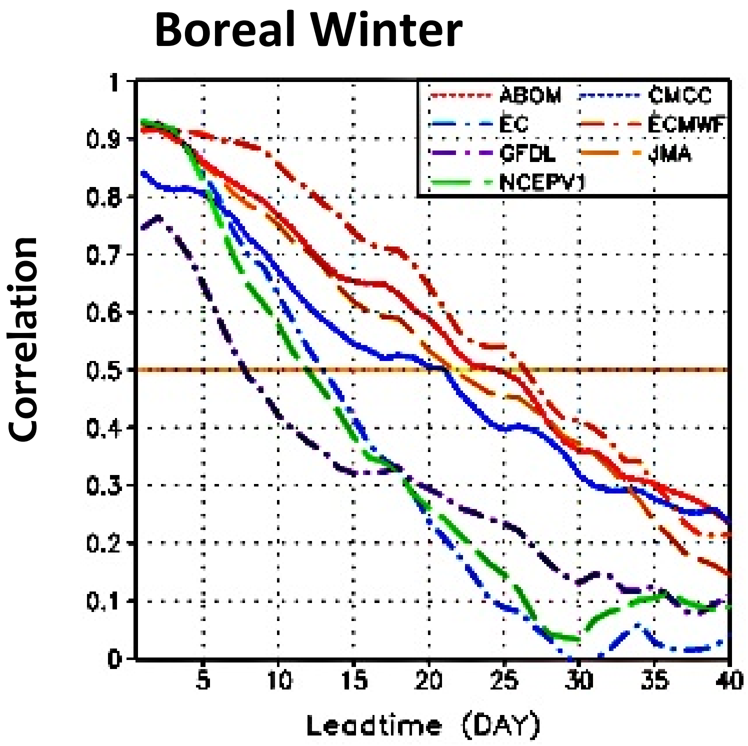


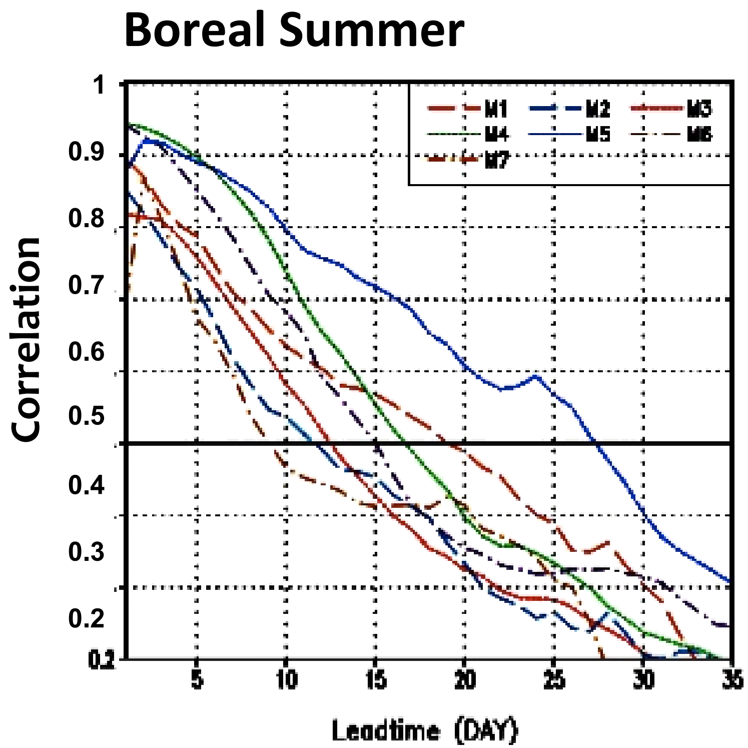
Performance of SNU CGCM

Phase composites of velocity potential at 200 hPa



RMM index

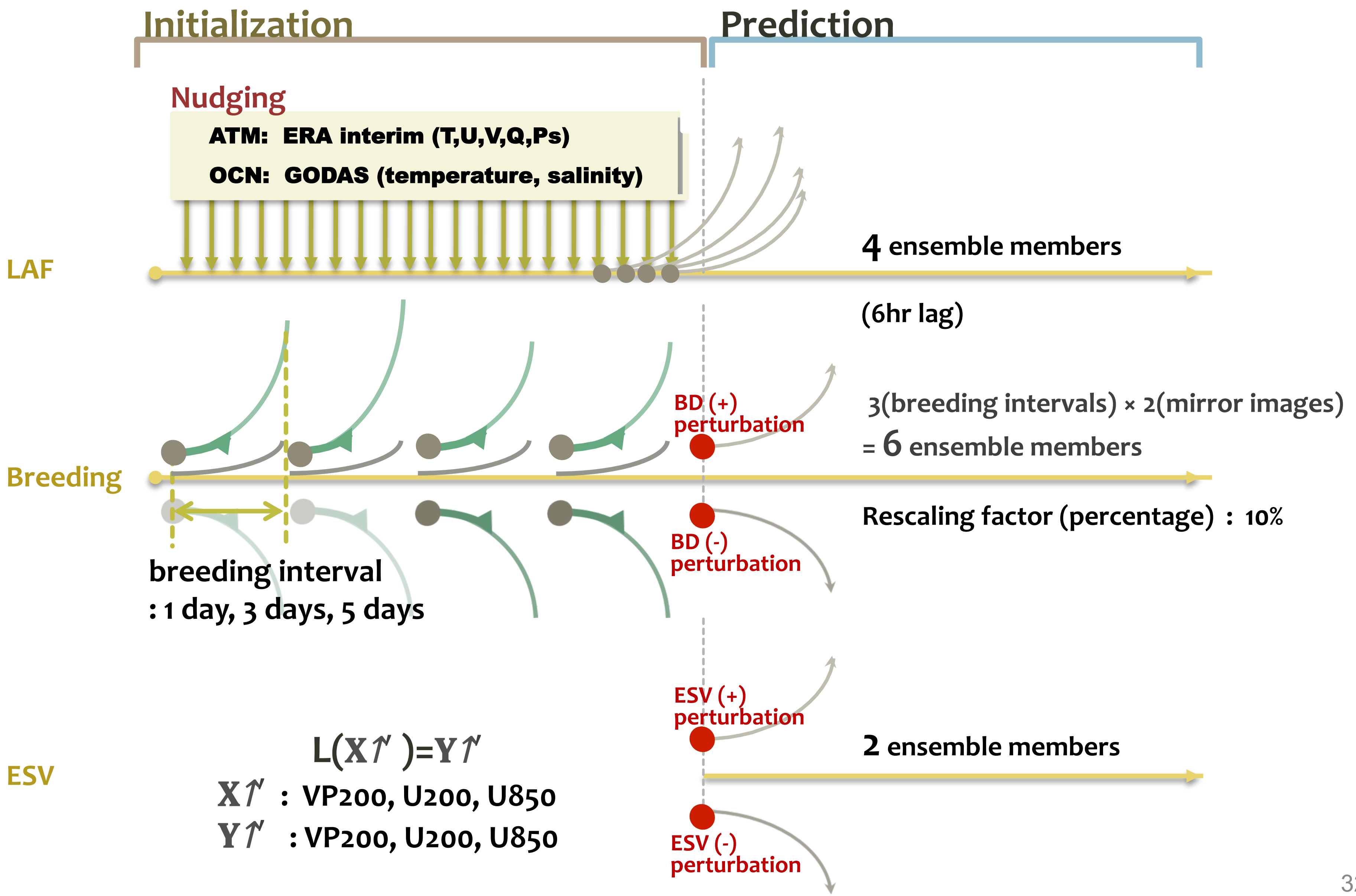




	ABOM	EC	GFDL	NCEP	CMCC	ECMWF	JMA
Ensemble number	10	10	10	5	5	15	6

Ref. CLIVAR/ISVHE
Intraseasonal Variability Hindcast Experiment

Intra-seasonal prediction

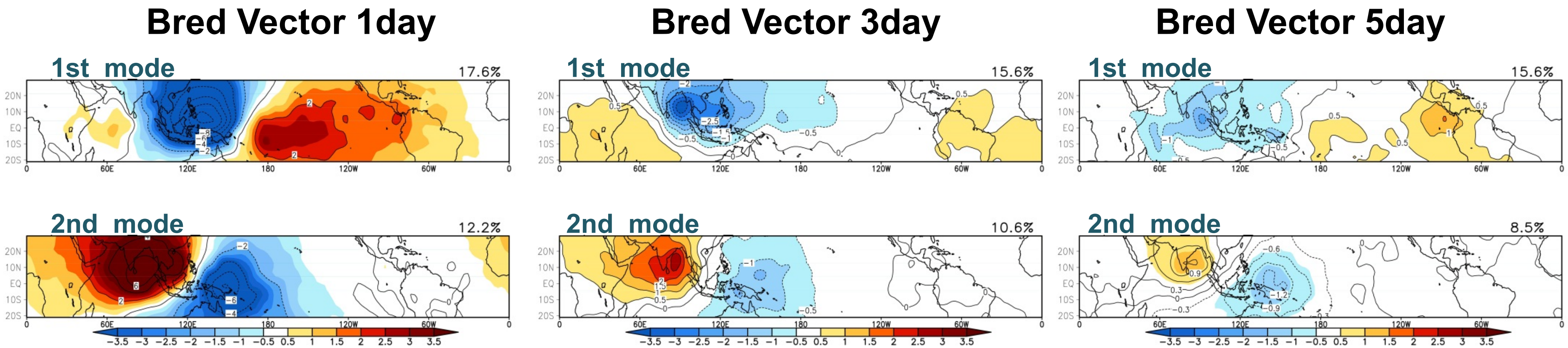


Initial Perturbation - Breeding

- Characteristics of Bred perturbations

Unit : ×10^5 (m^2/s)

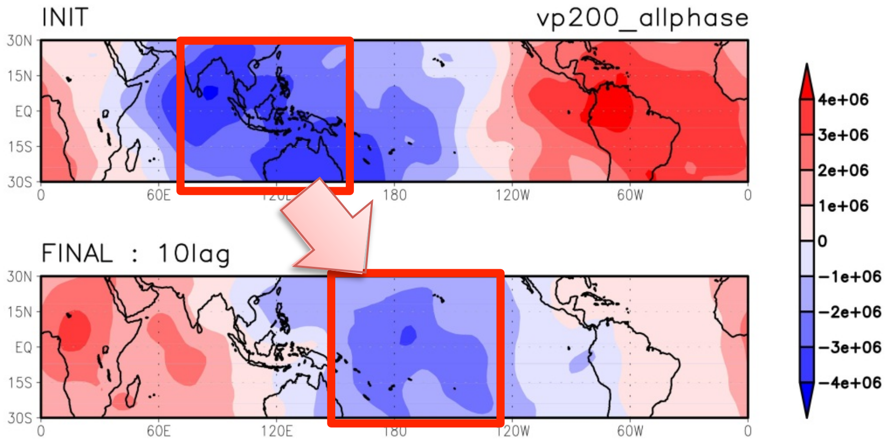
EOF of perturbations



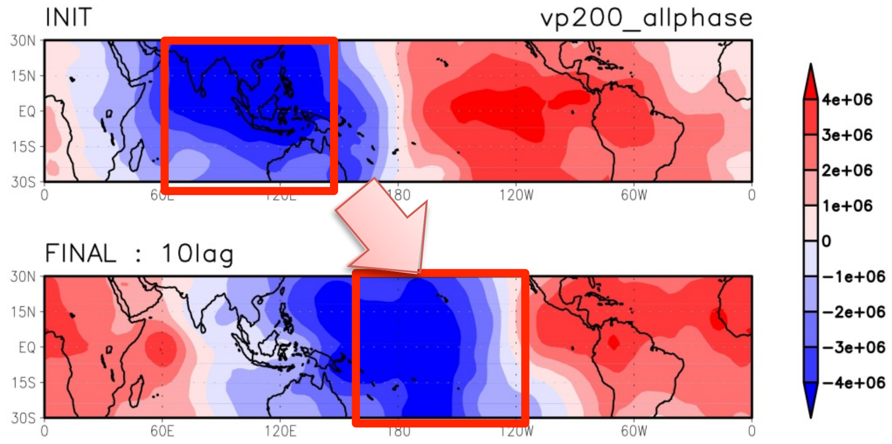
Initial Perturbation - ESV

- Singular vectors

Observation



Model

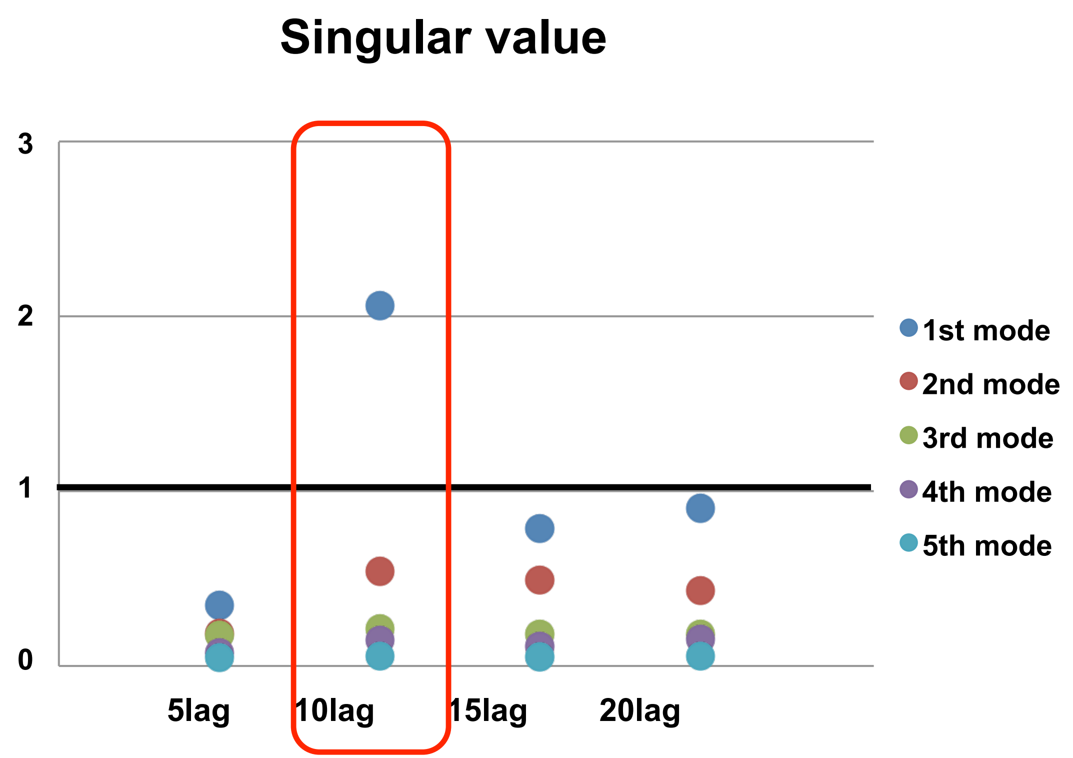


Final VP200 anomaly is on the east of initial VP200 anomaly

Eastward propagating mode

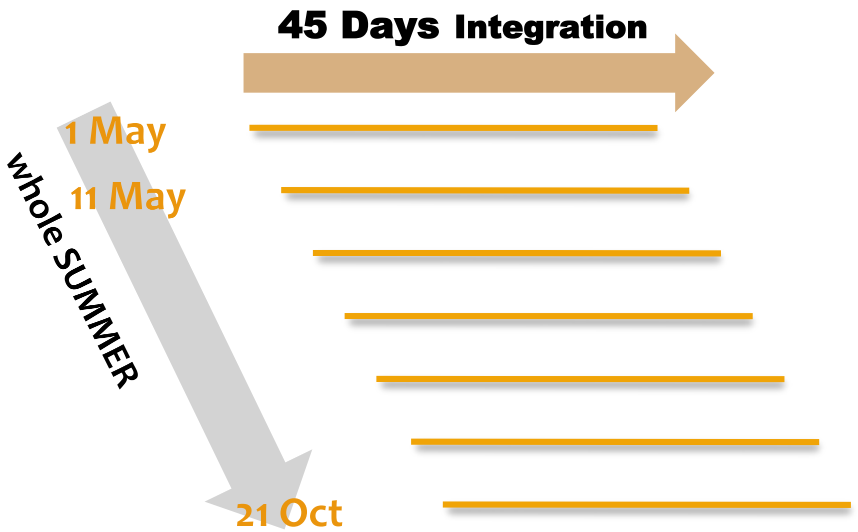
Initial Perturbation - ESV

- Singular mode of ESV



Intraseasonal Prediction - Outline

Total 360 cases per a season → Include all MJO phase



Summer :

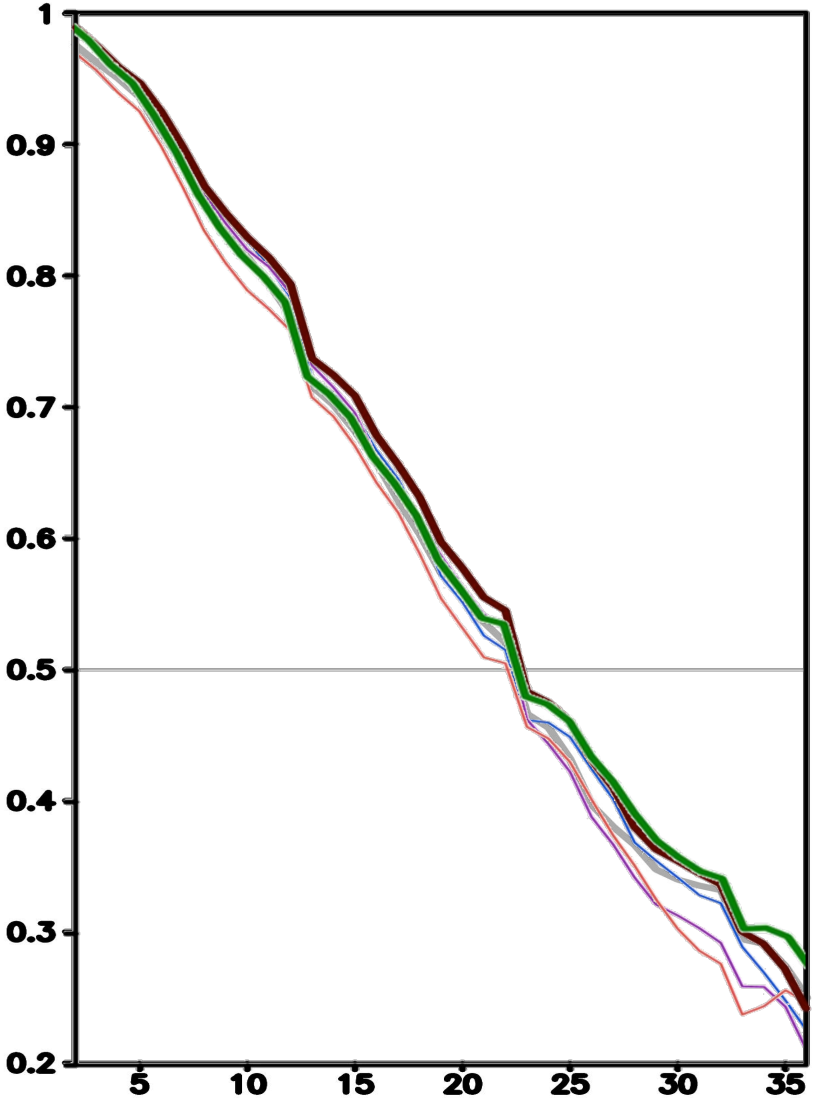
12 ensemble members/year×18cases/year×20years

< LAF(4) + BV(6) + ESV(2)> /case

= 4320 predictions

Correlation skills

■ **Correlation skill of Real-time Multivariate MJO (RMM) Index**



* The parenthesis refers ensemble members

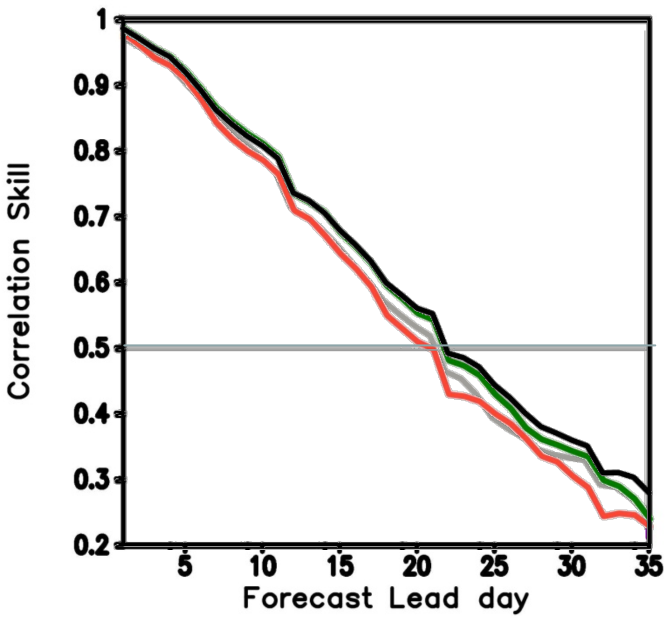
LAF [4]
BV1day [2]
BV1day+ BV3day [4]
BV3day [2]
BV5day [2]
BV1day+ BV3day+BV5day [6]

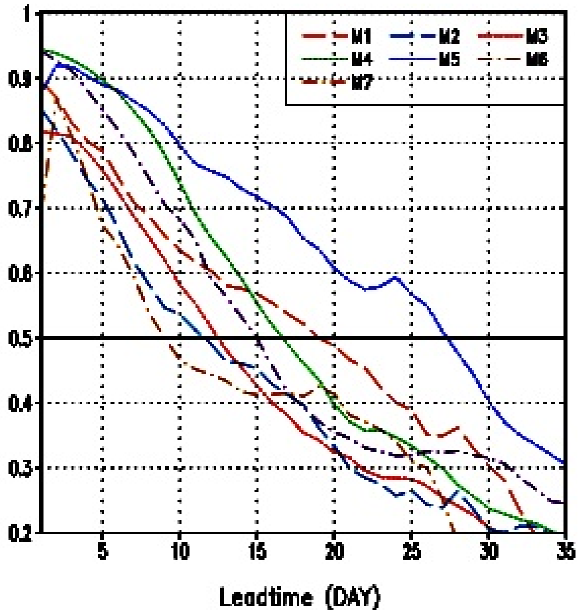
Ensemble

■ **Correlation skill of Real-time Multivariate MJO Index**

* The parenthesis refers ensemble members

Summer





LAF (4) : 4 ensemble members with 6 hours lag intervals

BV1day+BV3day+BV5day(6)

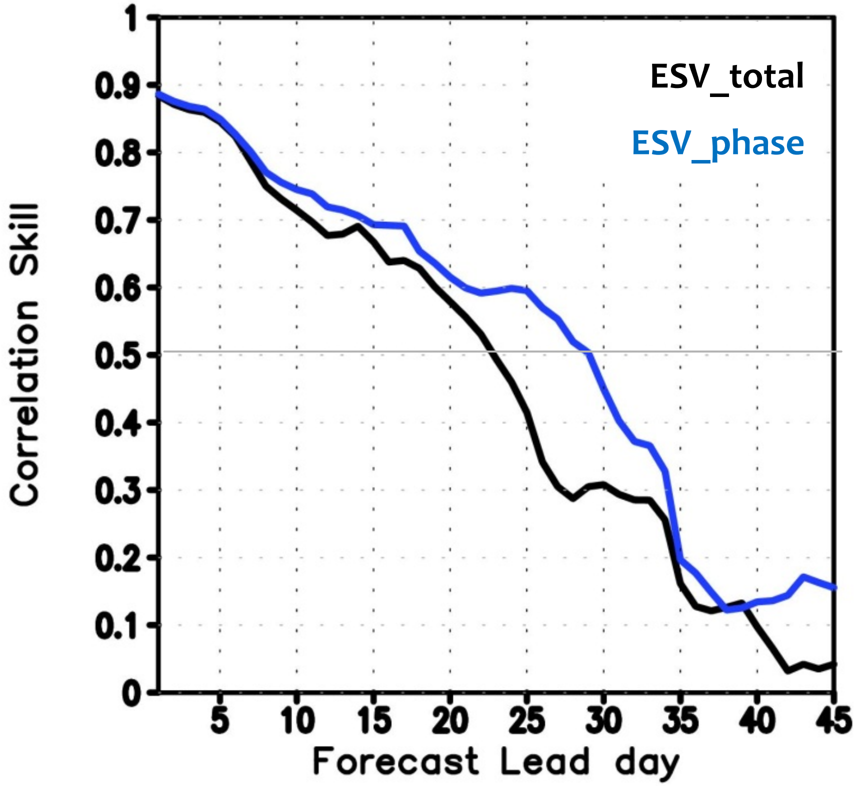
ESV (2)

ALL (12)

ESV

■ ESV phase dependency

* Note : Every 1st day of month run for 20 year



Summary

SNU Prediction System

Improved CGCM

Multi-initialization methods

↓

Ensemble ENSO prediction

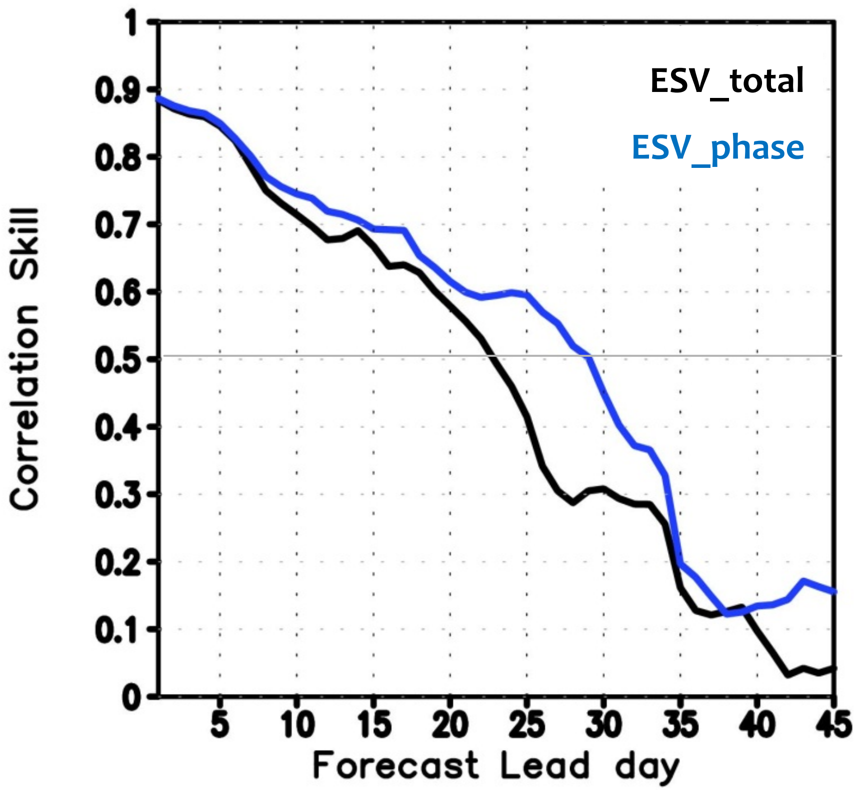
Ensemble MJO prediction

" Promising Predictions "

ESV

■ **ESV phase dependency**

*** Note : Every 1st day of month run for 20 year**



Thank You

ISVHE

The ISVHE Project

Intraseasonal Variability Hindcast Experiment

The **ISVHE** is a coordinated multi-institutional ISV hindcast experiment supported by **APCC, NOAA CTB, CLIVAR/AAMP, YOTC/MJO TF, and AMY.**

Bin Wang, June-Yi Lee, D. Waliser, H. Hendon, I.-S. Kang, K. Sperber, F. Vitart and ISVHE Team members

Supporters Website: http://iprc.soest.hawaii.edu/users/jylee/clipas

DESCRIPTION OF MODELS AND EXPERIMENT

ISVHE

One-Tier System♪

	Model	Control Run	ISO Hindcast		
			Period	Ens No	Initial Condition
ABOM	POAMA 1.5 & 2.4 (ACOM2+BAM3)	CMIP (100yrs)	1980-2006	10	The first day of every month
CMCC	CMCC (ECHAM5+OPA8.2)	CMIP (20yrs)	1989-2008	5	Every 10 days
ECMWF	ECMWF (IFS+HOPE)	CMIP(11yrs)	1989-2008	15	Every 15 days
GFDL	CM2 (AM2/LM2+MOM4)	CMIP (50yrs)	1982-2008	10	The first day of every month
JMA	JMA CGCM	CMIP (20yrs)	1989-2008	6	Every 15 days
NCEP/CPC	CFS v1 (GFS+MOM3) & v2	CMIP 100yrs	1981-2008	5	Every 10 days
PNU	CFS with RAS scheme	CMIP (13yrs)	1981-2008	3	The first day of each month
SNU	SNU CM (SNUAGCM+MOM3)	CMIP (20yrs)	1989-2008	1	Every 10 days
UH/IPRC	UH HCM	CMIP (20yrs)	1989-2008	6	The first day of every month

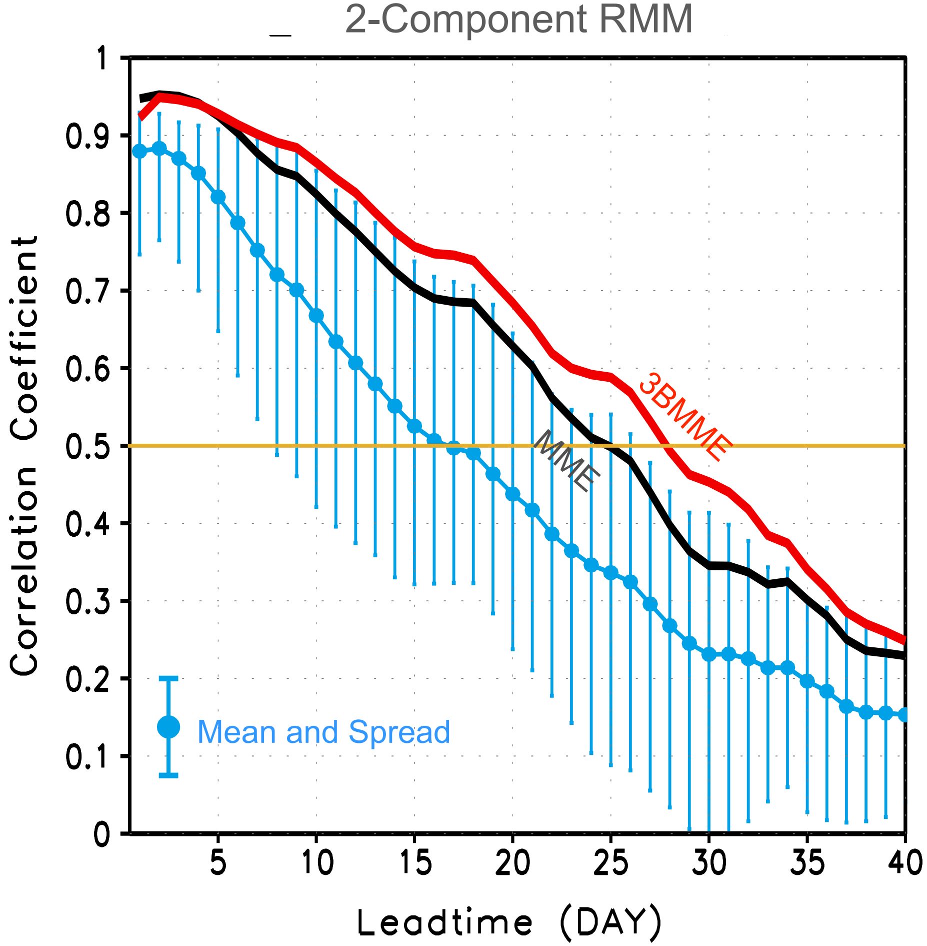
Two-Tier System♪

	Model	Control Run	ISO Hindcast		
			Period	Ens No	Initial Condition
CWB	CWB AGCM	AMIP (25yrs)	1981-2005	10	Every 10 days
MRD/EC	GEM	AMIP (21yrs)	1985-2008	10	Every 10 days

Current Status of the MME Prediction for the MJO

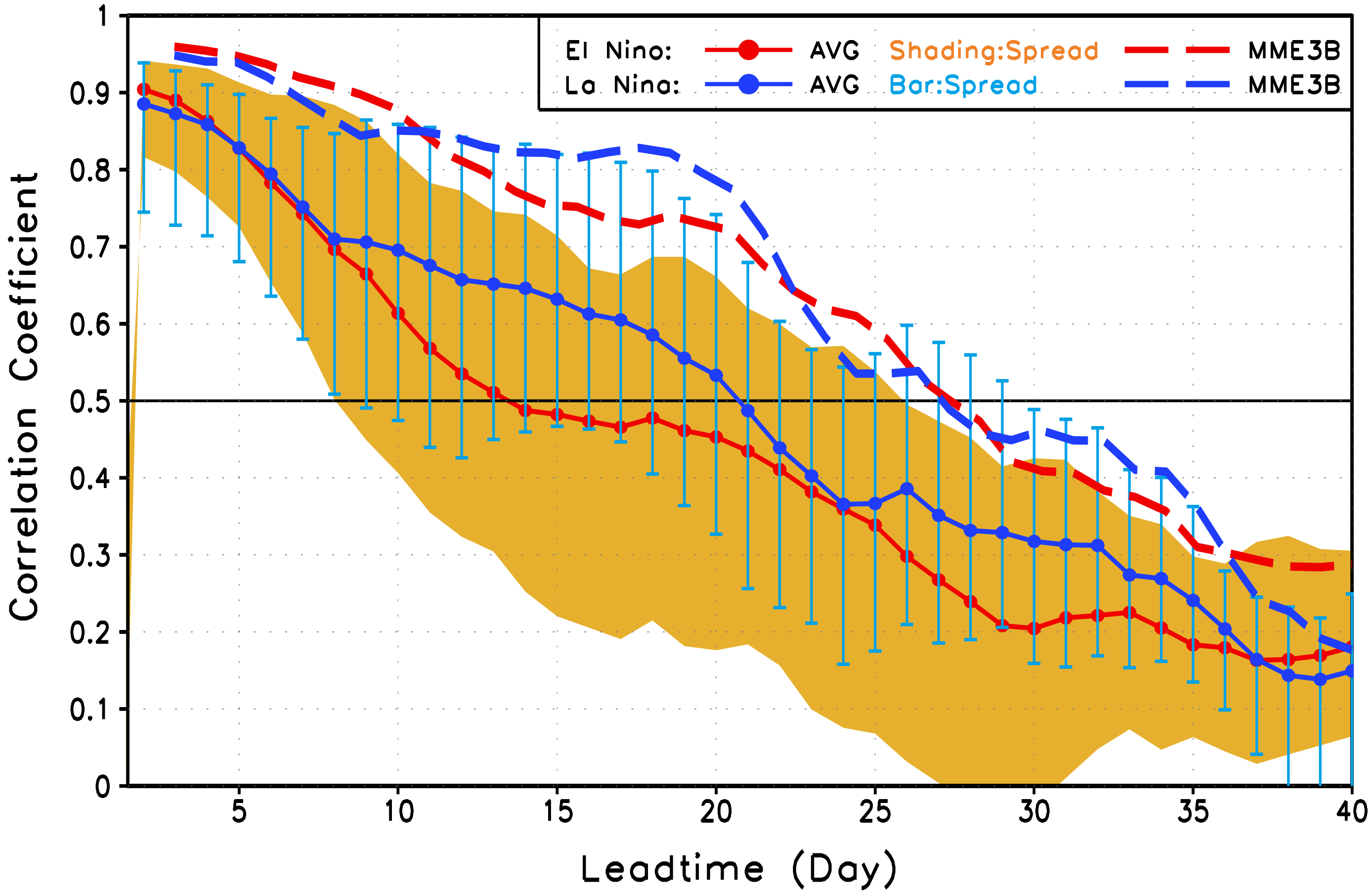
- Hindcast Period: 1989-2009
- Initial condition: 1st day of ea ch month from Nov to April
- The 3BMME has a useful sk ill for the RMM index of 0.5 up to about four weeks.

The bivariate temporal correlation coefficient

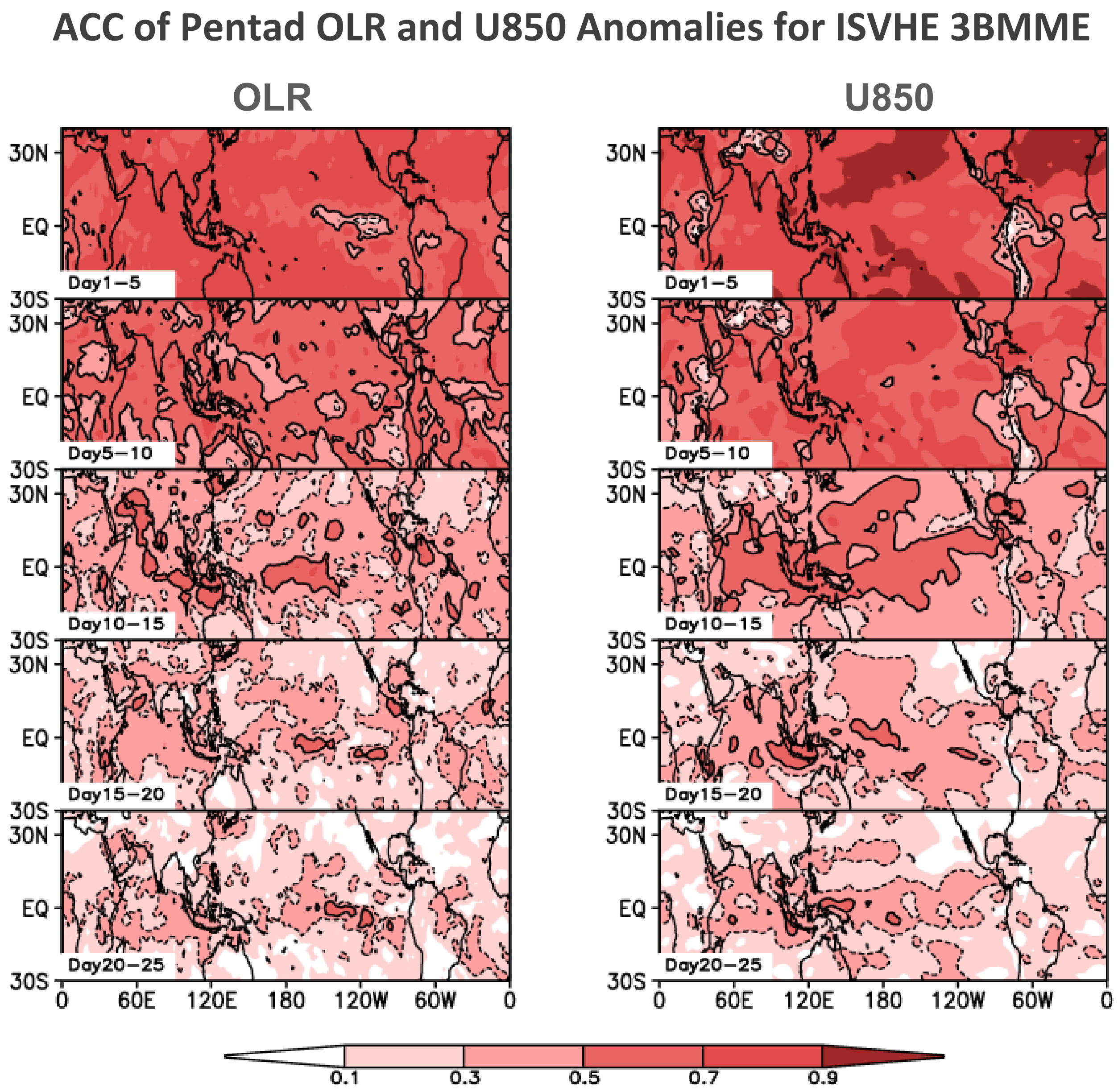


ENSO Phase Dependence

The bivariate temporal correlation coefficient skill for the RMM during El Nino and La Nina years in the ISVHE



Total ISV Forecast (NDJFMA)

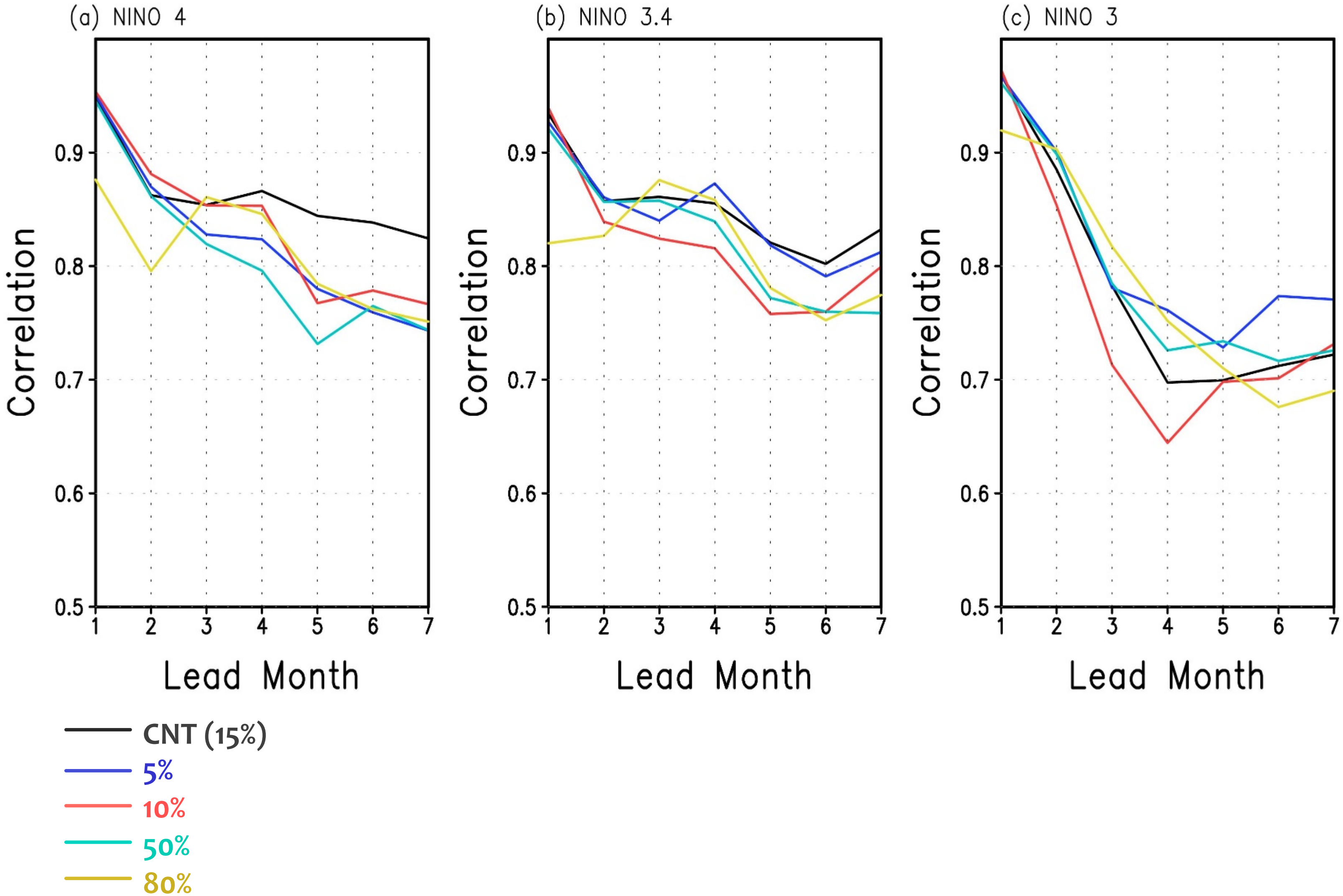


1989-2008
3BMME

Seasonal Prediction - Results

Correlation skill of Nino indices

Different rescaling amplitude **5%, 10%, 50%, and 80%**



2. Bred Vector (BV)

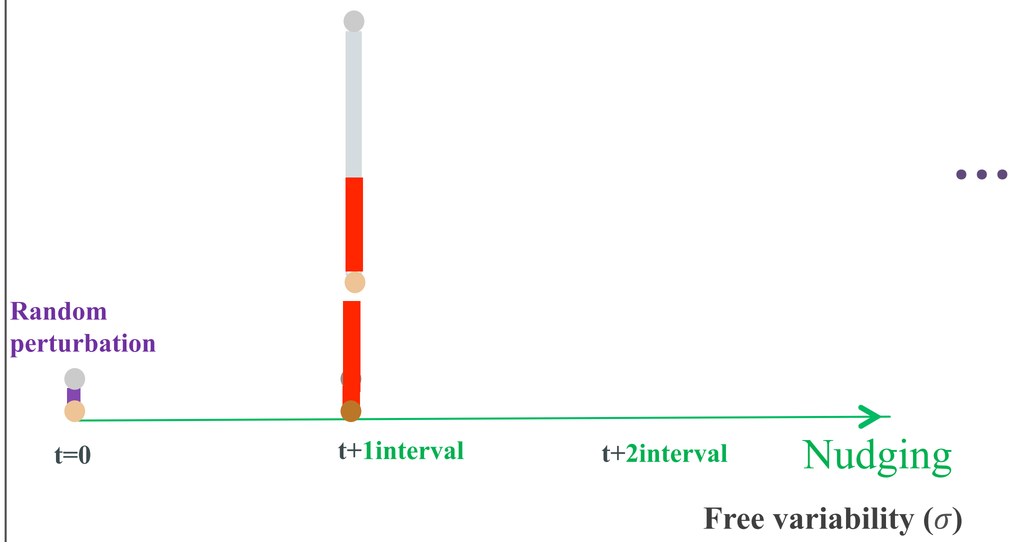
A size of perturbation must remain same during breeding period by NORM and FREE VARIABILITY.

c.f.) If perturbation only proportional to rescaling factor, Actual Size of perturbation will differ from simulation

Resize(R) $= NORM/\sigma \cdot res$

Actual Perturbation (a) $= P - C/R$

VARIOUS BREEDING



Rescaling (res) : 10%, 15%,...

Breeding interval: 1month, 3month, 6month for ENSO
1day, 3day, 6day for MJO

Procedure

1. Integrate perturbation cycle from random perturbation plus control initial condition (nudging)
2. **Calculate "Norm" using SST**
   NORM = $\sqrt{[(P-C)^2]_{region}}$
   $[\ ]_{region}$: area average over 10S~10N, 120E~90W
3. Calculate an actual perturbation size with given rescaling factor.
   Resize (R)
   = NORM/(σ·rescaling)
   * norm/R = $\underline{\sigma \cdot \text{rescaling}}$;norm↑,R↑
   given and fixed
4. Add perturbation $(P - C)\downarrow i / R$ on nudging initial for next step of breeding. (i=u,v,..)
5. Repeat 2-4 processes until initial forecast time

Bred Vectors represent fast growing mode of the model and nature.

Toth and Kalnay (1993)

Procedure

1. Make difference map (P-C)
2. Calculate NORM using SST

   NORM = $\sqrt{[(P\text{-}C)^2]_{region}}$
3. Calculate Free variability(σ) from SST of Nudging run (in this case, control runs are used)
4. Make actual perturbation using (i=u,v,t,q,..)

   Resize(R)=$NORM/\sigma \cdot res$, Actual Perturbation (a)=$(P-C)_i/R$

For exmaple>>

To make time-invariant size of perturbation

i) given σ **= 1.0**, and **rescaling = 10%**

And difference values of Pert(P) and Cntl(C) are same as below in each grid

P-C of SST :

√2	√6

ii) NORM = √((2+6)/2) = 2 (NORM = $\sqrt{[(P\text{-}C)^2]_{region}}$)

iii) apply σ **= 1.0**, and **rescaling = 10%**

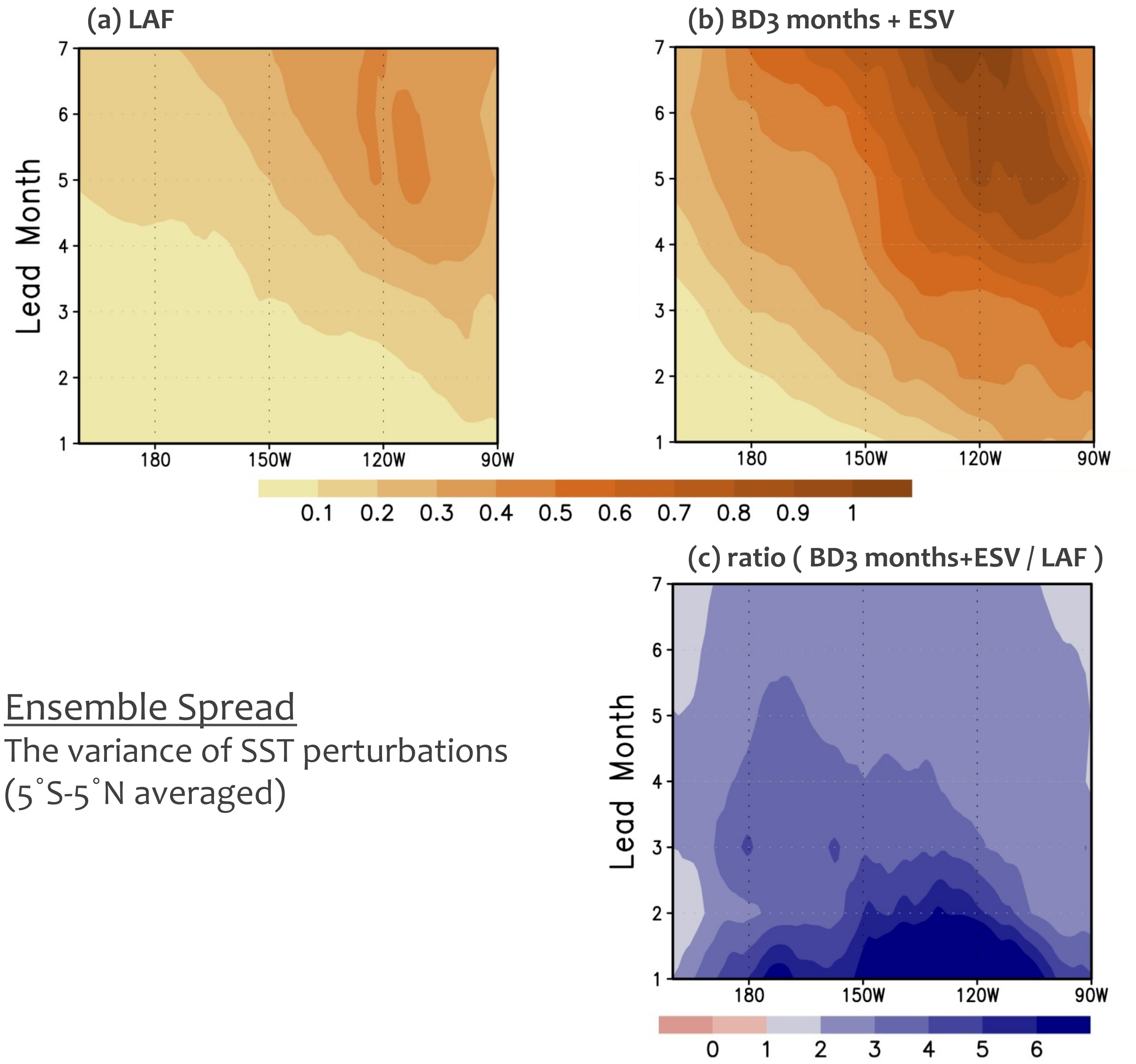
Resize(R)=$NORM/\sigma \cdot res = 2/\mathbf{1.0} \cdot 0.1$ = 20 (fixed)

iv) applying **R=20** to whole variables

Actual Perturbation (a)=$(P-C)_{variables}/20$

*if Norm is bigger than other time, R(나누는 값, SNU system에서 따로 정의된 이름은 없고, 나누는 값으로 사용하고 있습니다. 이해의 편의를 위해 임시로 정의했습니다.) will be bigger to resize, therefore actual size of perturbation will be same during the breeding period.

Ensemble Spread of Seasonal Prediction



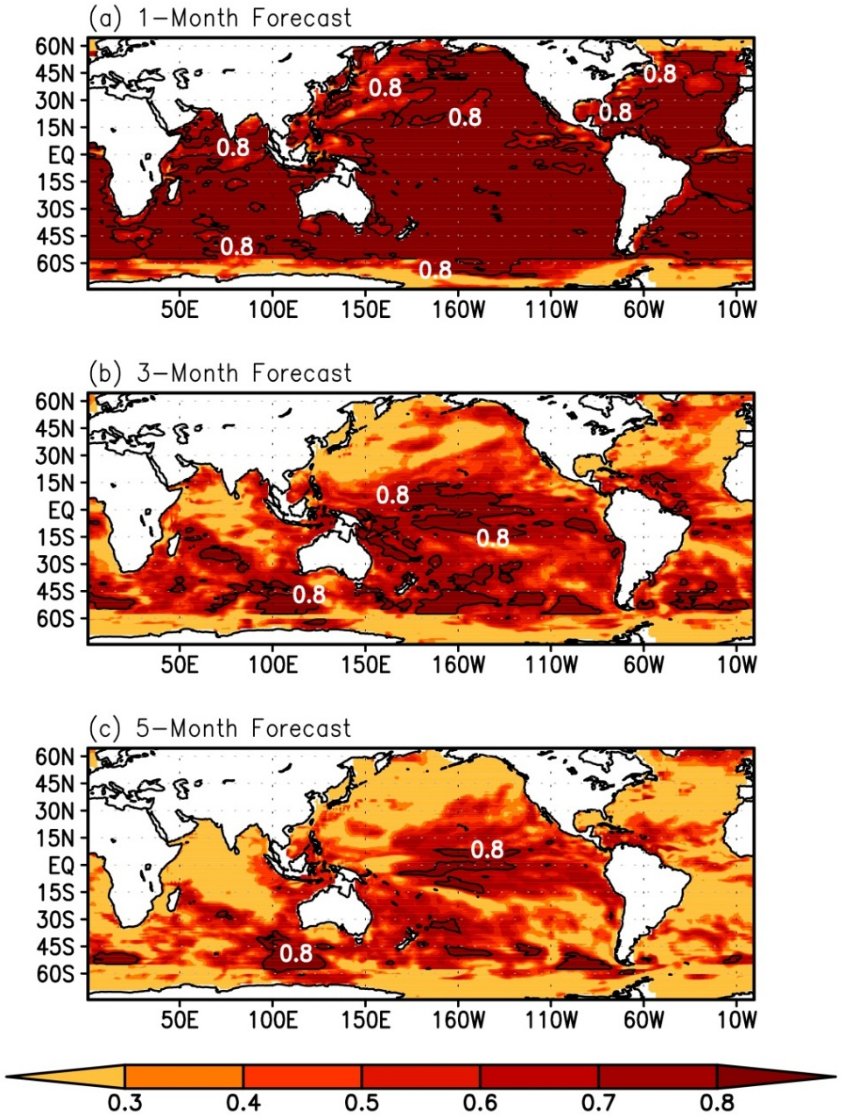
<u>Ensemble Spread</u>

The variance of SST perturbations
(5˚S-5˚N averaged)

Seasonal Prediction - Results

Spatial distribution of correlation skill

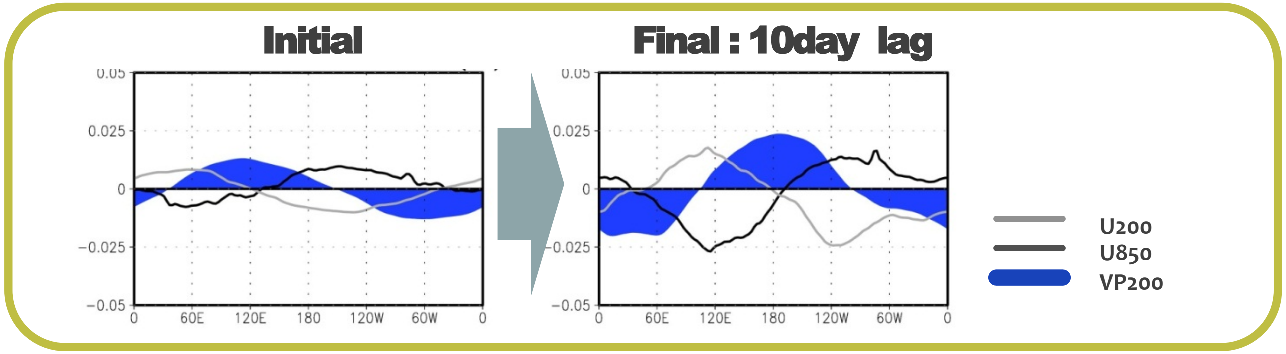
LAF+BV1+BV3+BV6



ESV

■ ESV phase dependency

ESV



ESV
(considering phas e)