STOCHASTIC FORCING OF CP AND EP ENSO EVENTS: OBSERVATIONS VS CESM-LE

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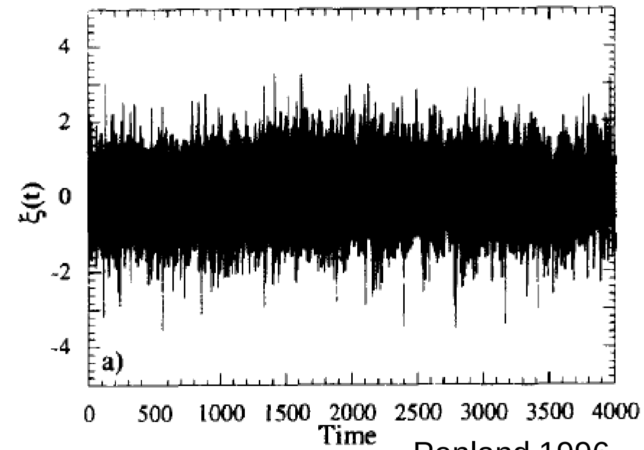
What is Stochastic Forcing ?

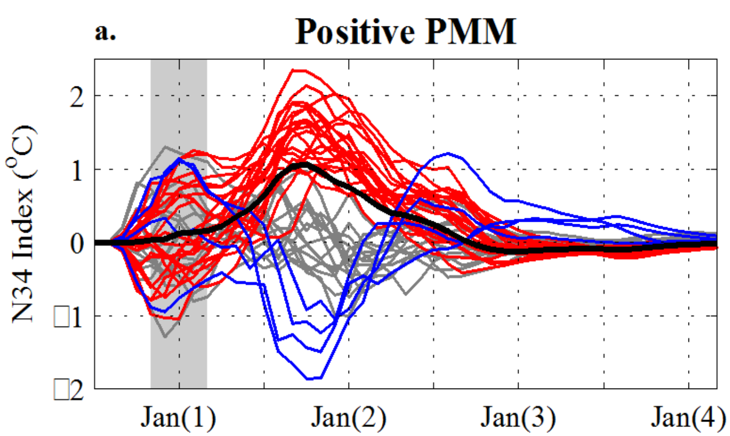
- Forcing that is white *in time* (not space)
- Physical systems contain processes on many time scales
    - Approximate the ‘fast’ processes (chaotic & non-linear) as white noise



Penland 1996

Why is it important?

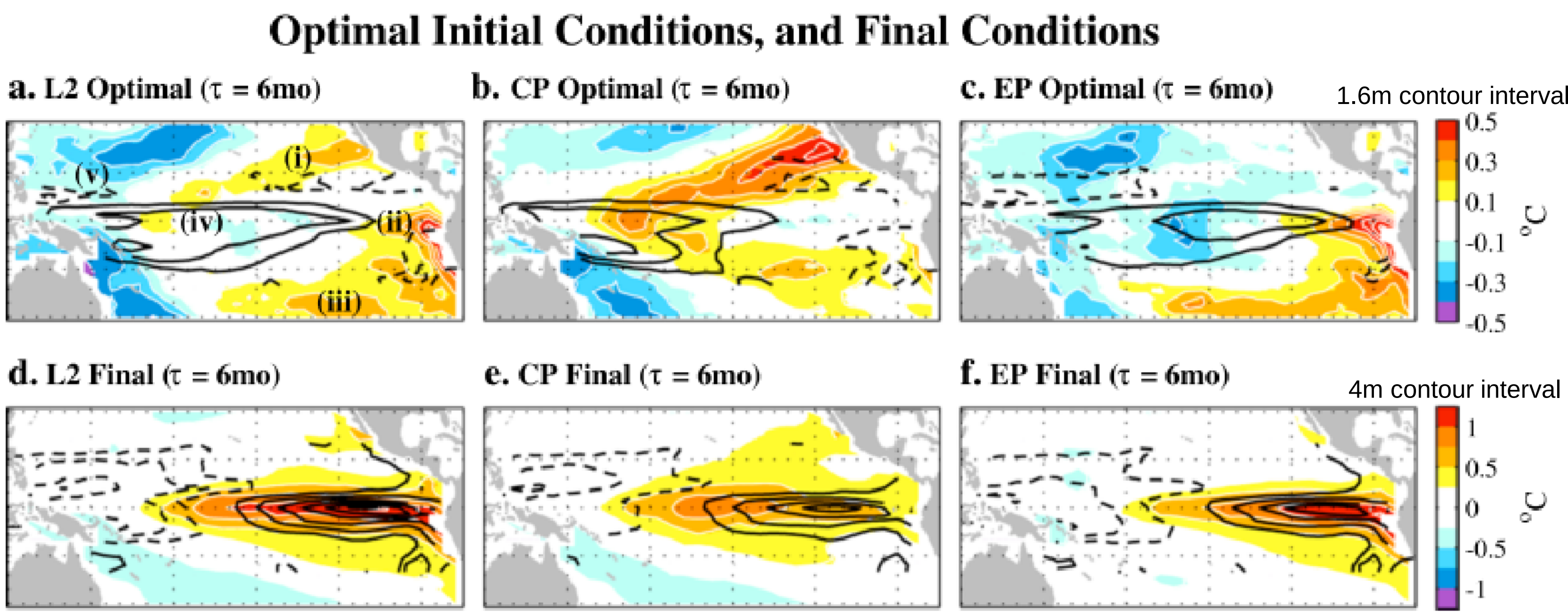
- Many physical model experiments show ENSO is sensitive to natural variability
    - Initial conditions
    - **Noise forcing**



Thomas and Vimont 2016

Role of Noise Forcing in Generating ENSO Diversity

- Observational evidence for *optimal initial conditions* that maximize EP and CP growth



Vimont, Alexander and Newman 2014

- **What noise forcing can *lead to the generation* of these optimals?**

Methods

1. Estimate Dynamics - Linear Inverse Model (LIM)
2. Identify Optimal Initial Conditions
3. Calculate Noise Forcing

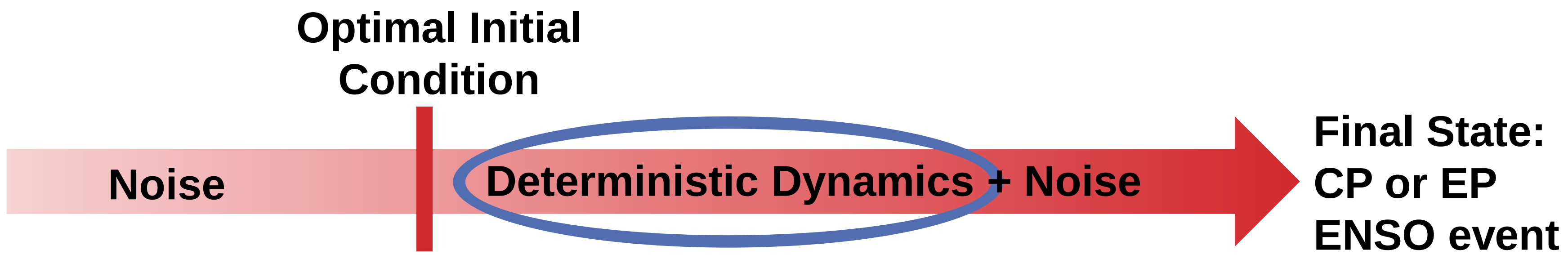
Observations

- 1982-2015
- SST: monthly + daily IOSST
- Thermocline depth (20^{o} Isotherm depth): monthly + daily GODAS
- Daily NCEP Reanalysis

CESM Large Ensemble

- 1982-2015
- 35 Ensemble Members
- SST: monthly + daily
- SSH: monthly + daily
- Daily Atmospheric Variables

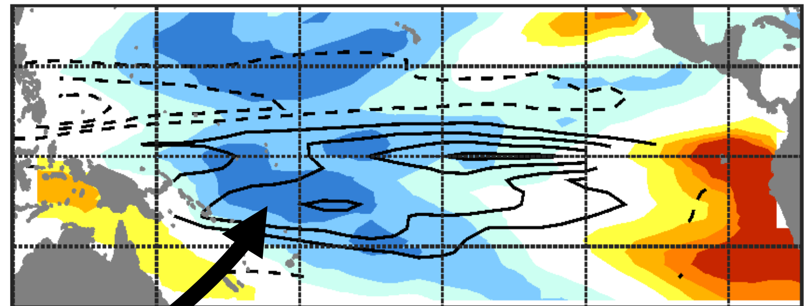
Using Linear Inverse Modeling (LIM) to Estimate Noise Forcing



1) Calculate Dynamics,
2) Identify the Optimal Initial Conditions,
3) Estimate Noise Forcing

Using Linear Inverse Modeling (LIM) to Estimate Noise Forcing

EP Optimal



SST (shaded)
Thermocline Depth (contours)

Optimal Initial Condition

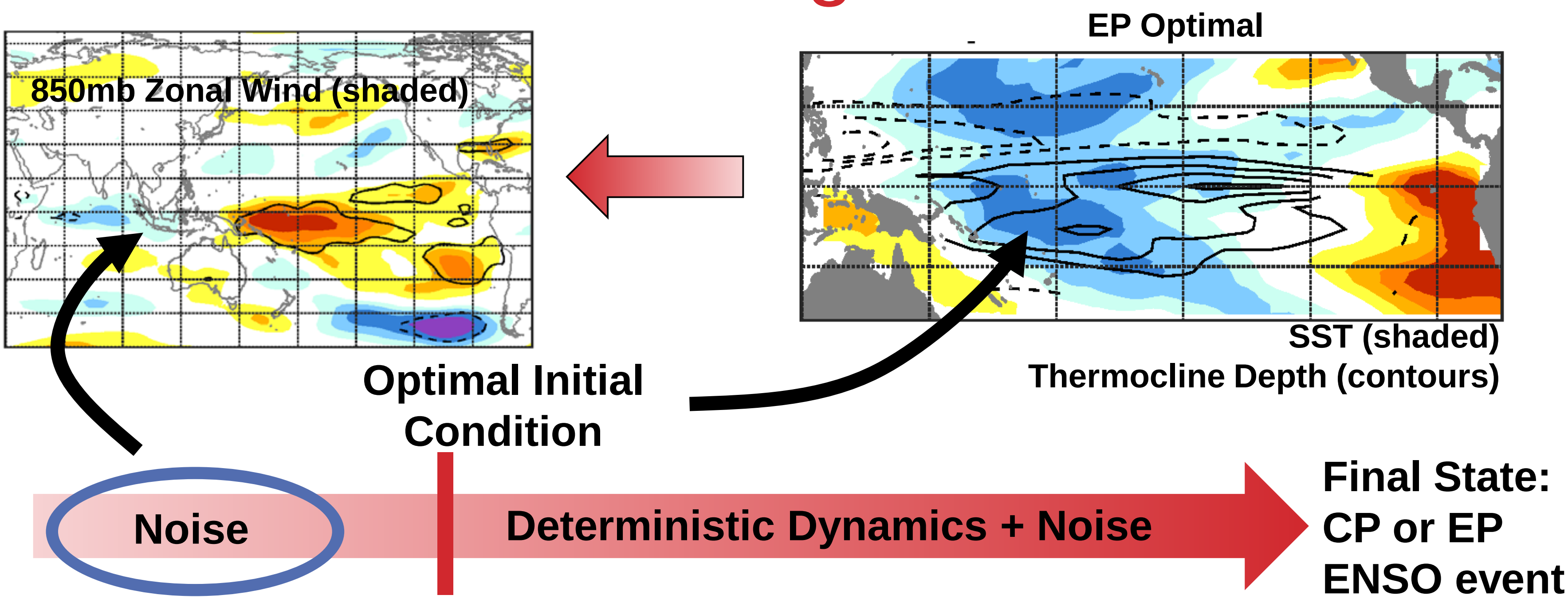
Noise | **Deterministic Dynamics + Noise** → **Final State: CP or EP ENSO event**

1) Calculate Dynamics,

2) Identify the Optimal Initial Conditions,

3) Estimate Noise Forcing

Using Linear Inverse Modeling (LIM) to Estimate Noise Forcing



1) Calculate Dynamics,
2) Identify the Optimal Initial Conditions,
3) Estimate Noise Forcing

Dynamics: Linear Inverse Model

General linearized model describes the Tropical Pacific:

$$d\mathbf{X}/dt = \mathbf{L}\mathbf{X} + \boldsymbol{\xi}$$

White Noise Forcing
(does not include atmospheric noise)

Deterministic Dynamics

X = State Vector [SST; Thermocline Depth or SSH]
L = Linear Operator describing the slow, linear dynamics of the system
ξ = Noise Forcing

Solution:

$$\mathbf{X}(\tau) = \exp(\mathbf{L}\tau)\mathbf{X}(0)$$

Calculate Linear Dynamics **L** from *statistics* of observations:

$$\mathbf{C}(\tau) = \exp(\mathbf{L}\tau)\mathbf{C}(0)$$

$$\mathbf{L} = \ln(\mathbf{C}_\tau/\mathbf{C}_0)/\tau$$

Optimal Initial Conditions

$$\mathbf{X}(\tau) = \exp(\mathbf{L}\tau)\,\mathbf{X}(0) = \mathbf{G}_\tau\,\mathbf{X}(0)$$

Solve generalized eigenvalue problem for *optimal* initial conditions (**p**) that *maximize growth* (**μ**) in the direction specified by *Norm* (**N**)

$$\mathbf{G}_\tau^{T} N \mathbf{G}_\tau\,\mathbf{p} = \boldsymbol{\mu}(\tau)\mathbf{p}$$

"CP" or "EP Norm" defines *direction* of growth

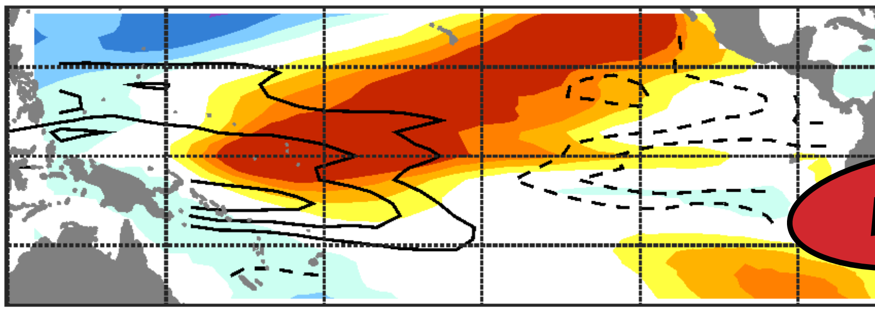
Optimal Initial Condition

Maximized Growth

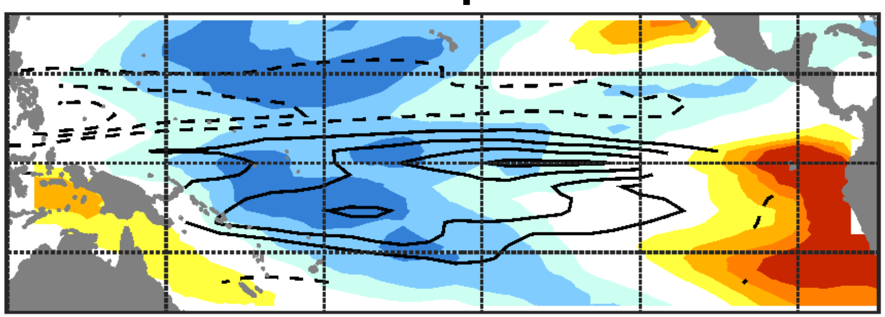
Optimal Initial Conditions

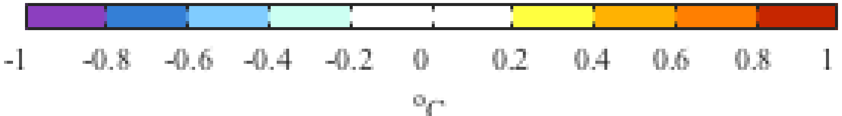
Observations

6mo CP Optimal



6mo EP Optimal



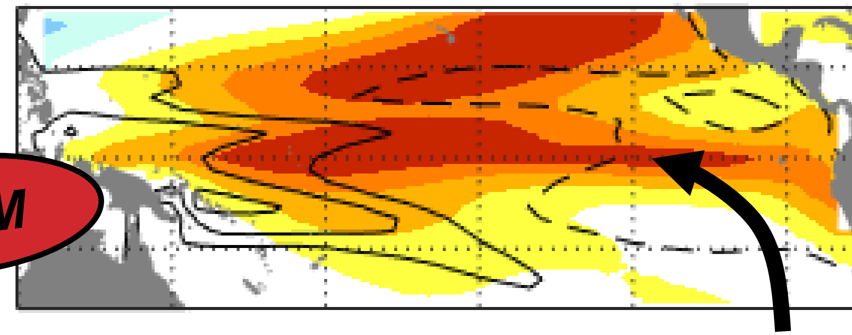


Thermocline contour interval: 4m

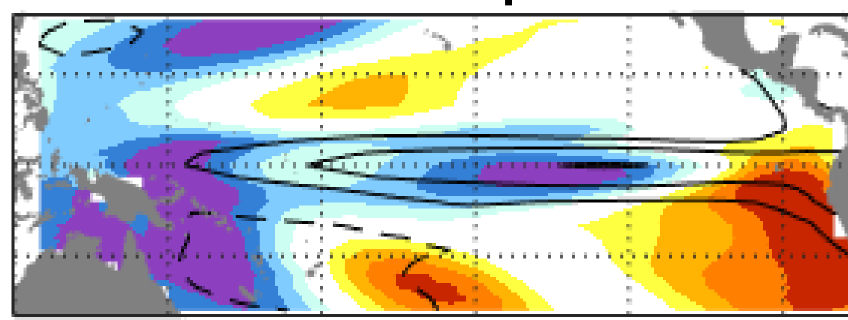
PMM

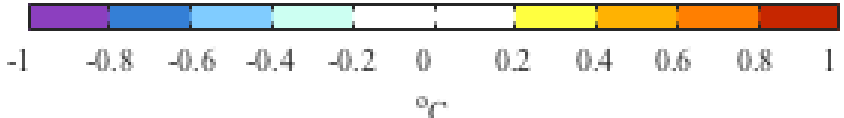
CESM-LE

6mo CP Optimal



6mo EP Optimal



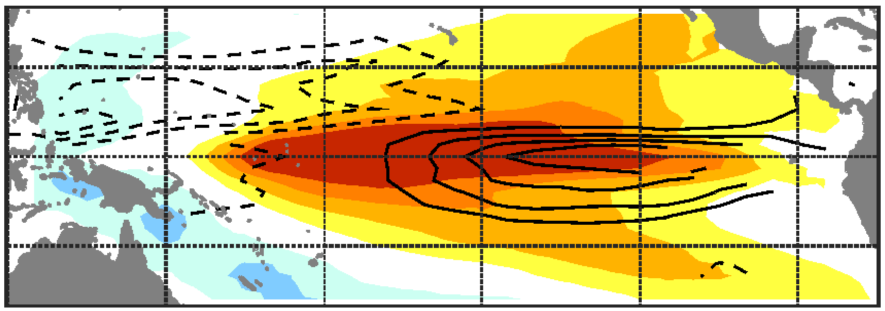


SSH contour interval: 2cm

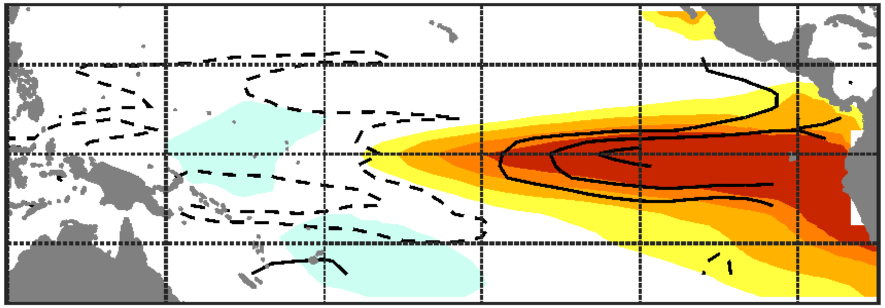
Final Conditions

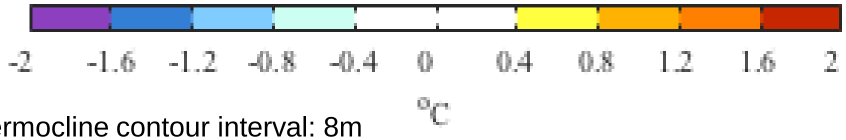
Observations

CP Final



EP Final

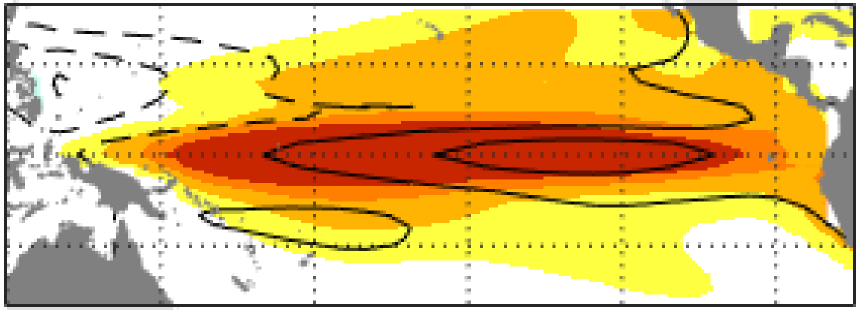




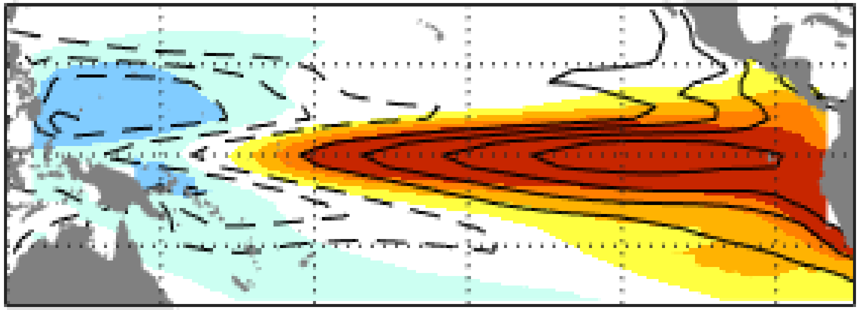
Thermocline contour interval: 8m

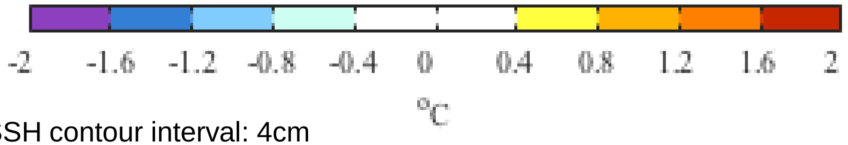
CESM-LE

CP Final



EP Final





SSH contour interval: 4cm

Noise Forcing

$$dX/dt = \mathbf{L}\mathbf{X} + \boldsymbol{\xi}$$

$$\xi(t) = \frac{[x(t+\Delta t) - x(t-\Delta t)]}{2} - Lx(t)$$

x = High Frequency (pentad) State Vector

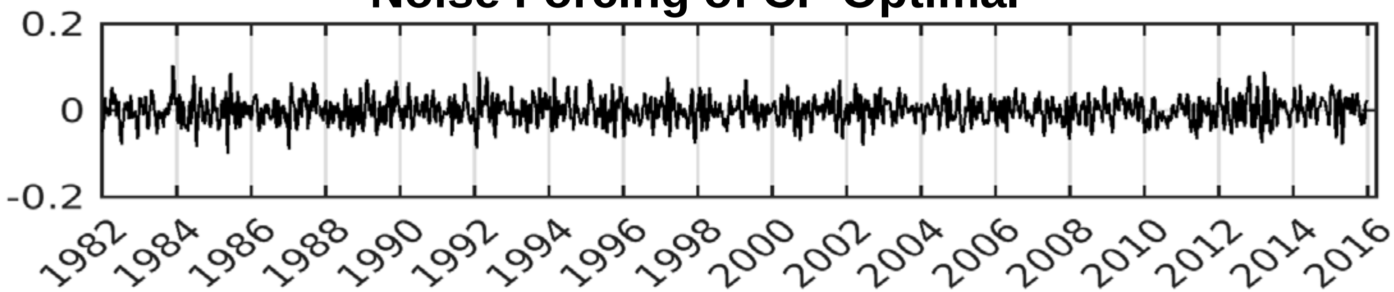
L = Linear Dynamics of the system

ξ(t) = Noise Forcing *(time and space dependent)*

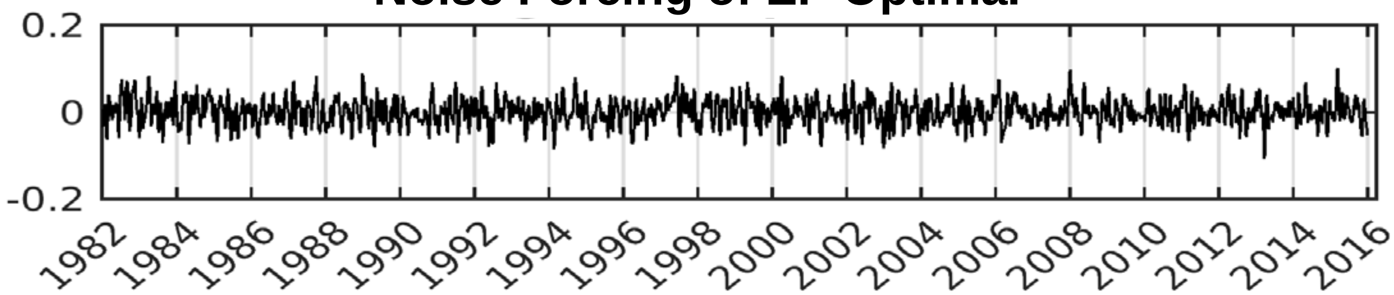
Observations

Regress **ξ**(t) onto the spatial patterns of optimal initial conditions

Noise Forcing of CP Optimal

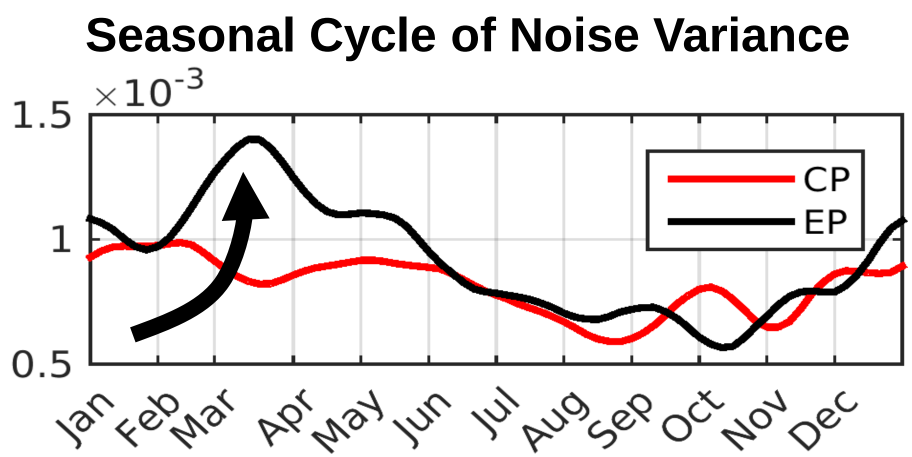


Noise Forcing of EP Optimal

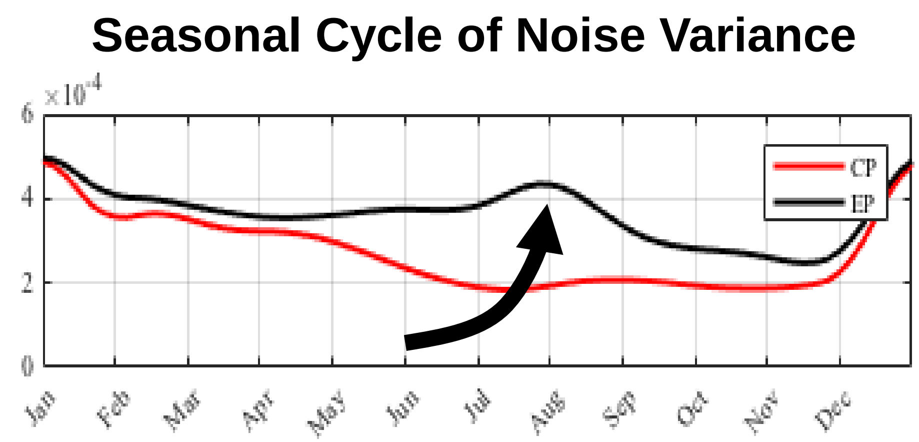


Noise Forcing

Observations



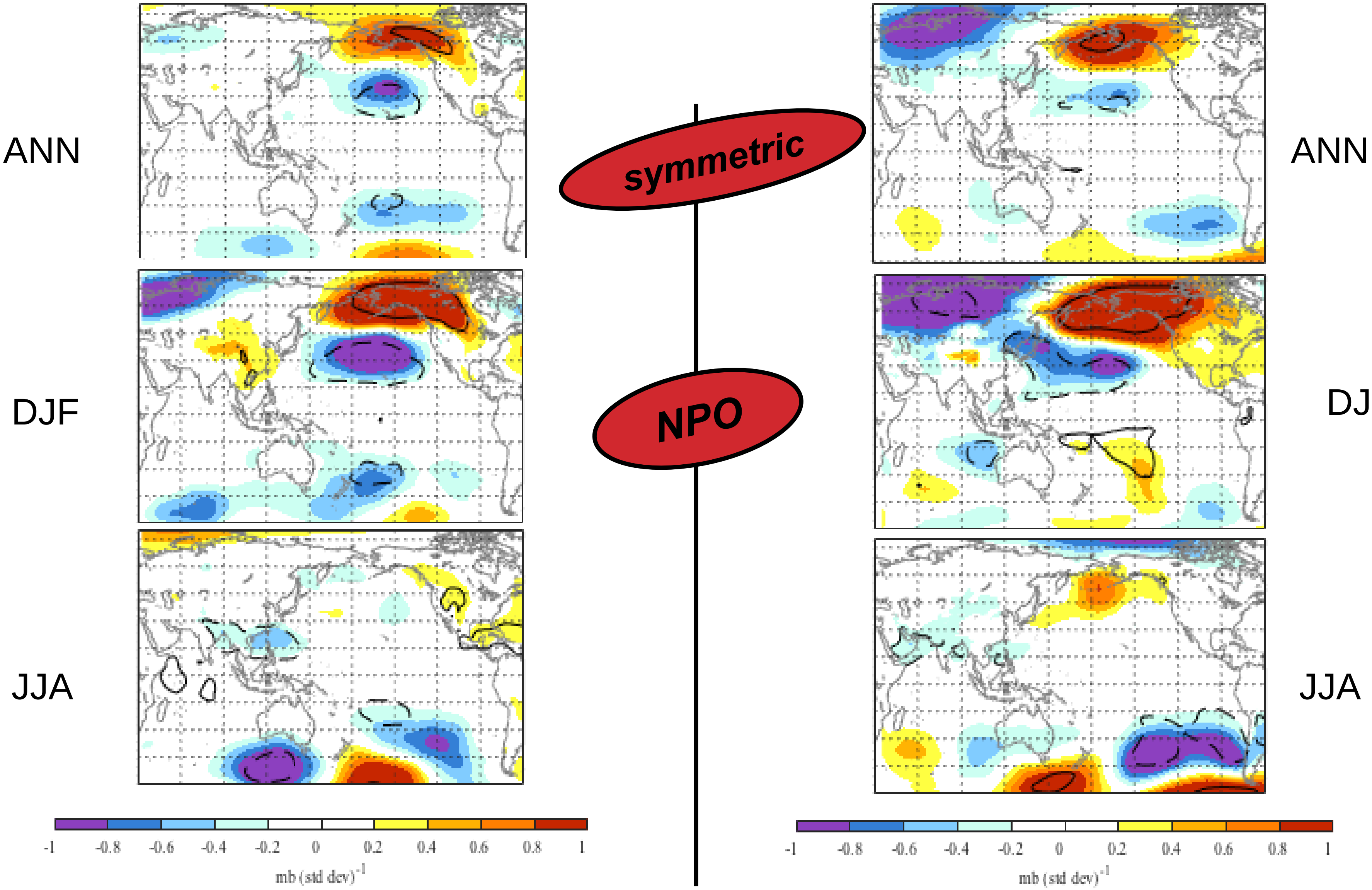
CESM-LE



CP Noise: Sea Level Pressure

Observations

CESM-LE



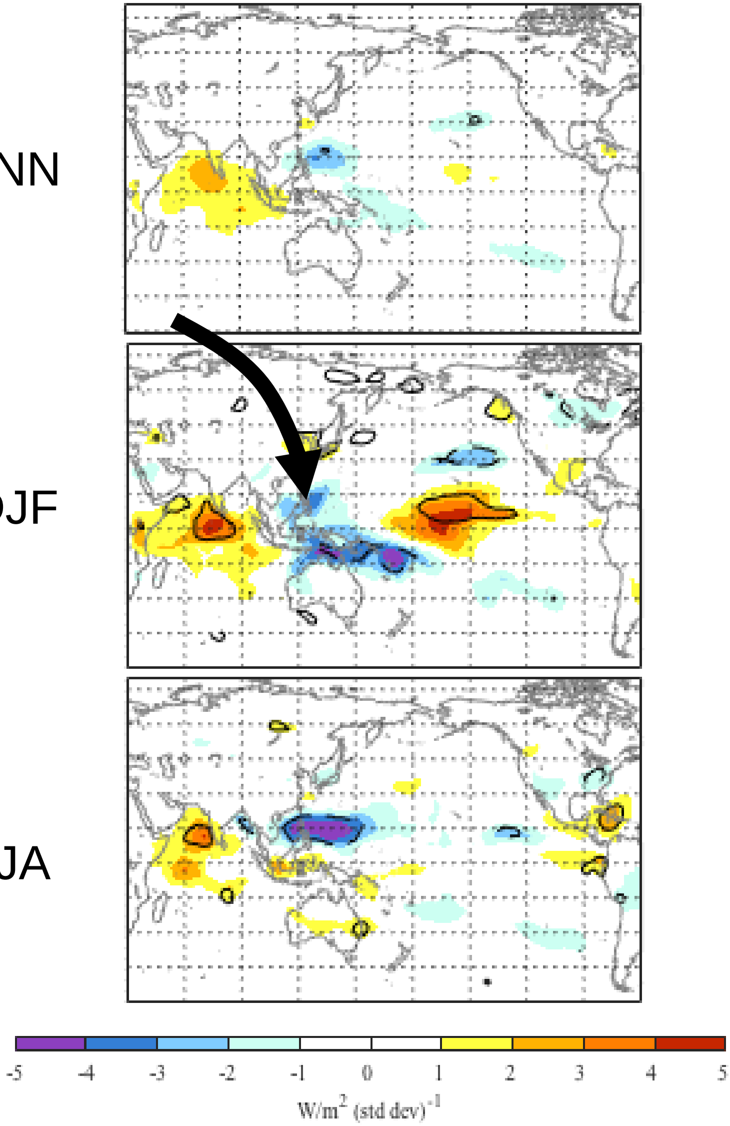
CP Noise: OLR

Observations

ANN

DJF

JJA



CESM-LE

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DJF

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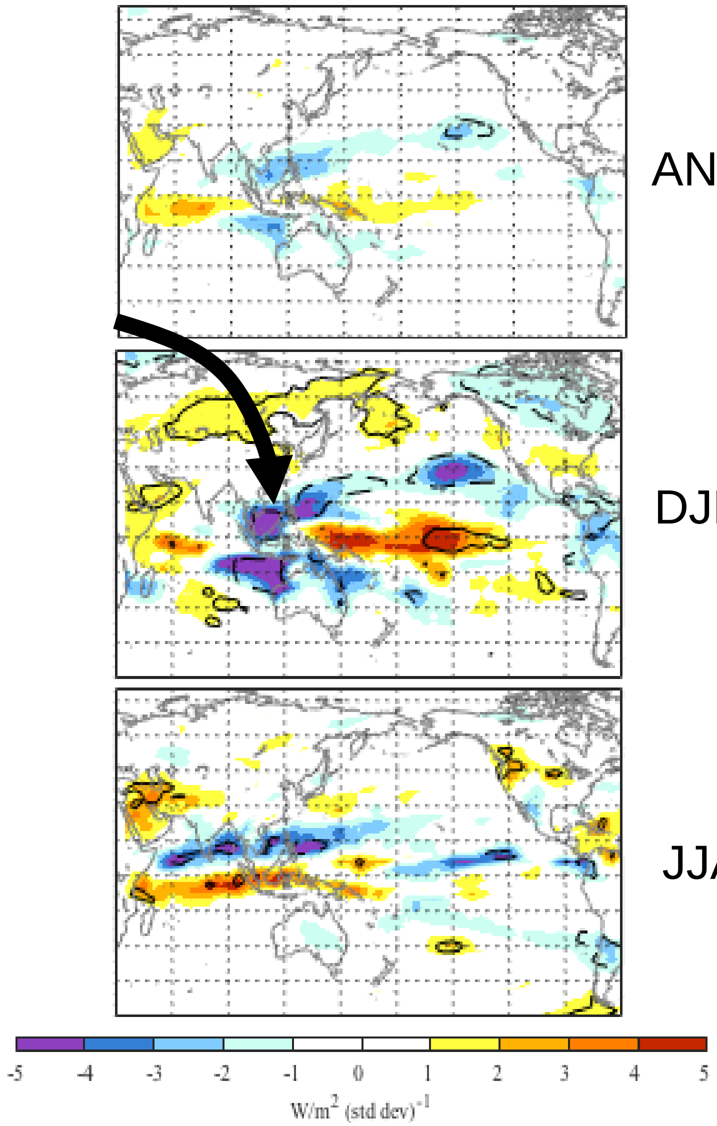

EP Noise: Sea Level Pressure

Observations

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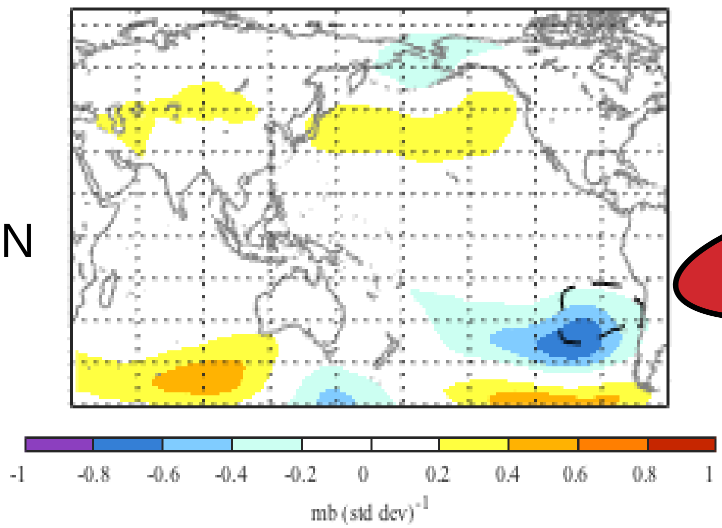

weaker

CESM-LE

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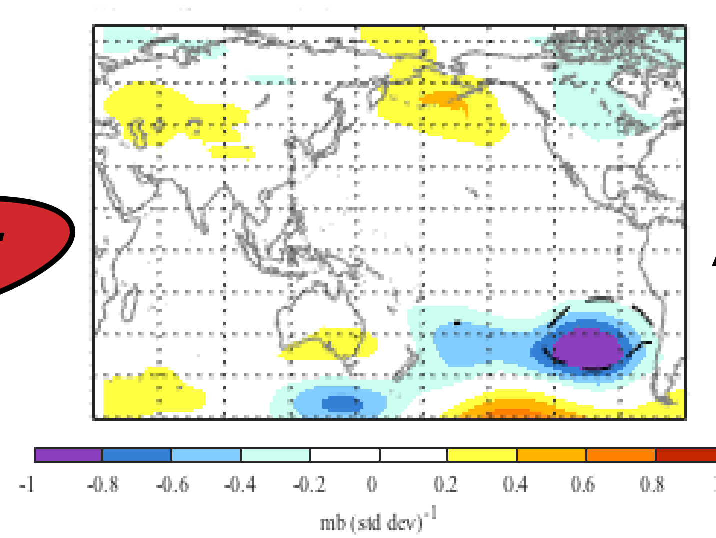
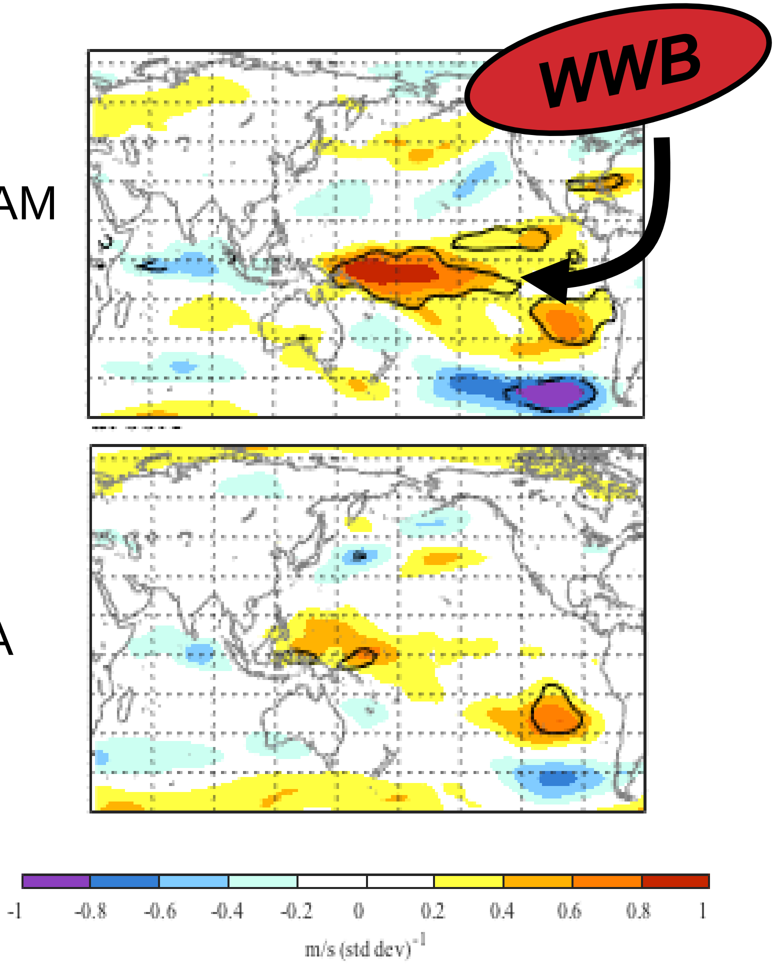


Noise: EP 850mb Zonal Wind

Observations

MAM

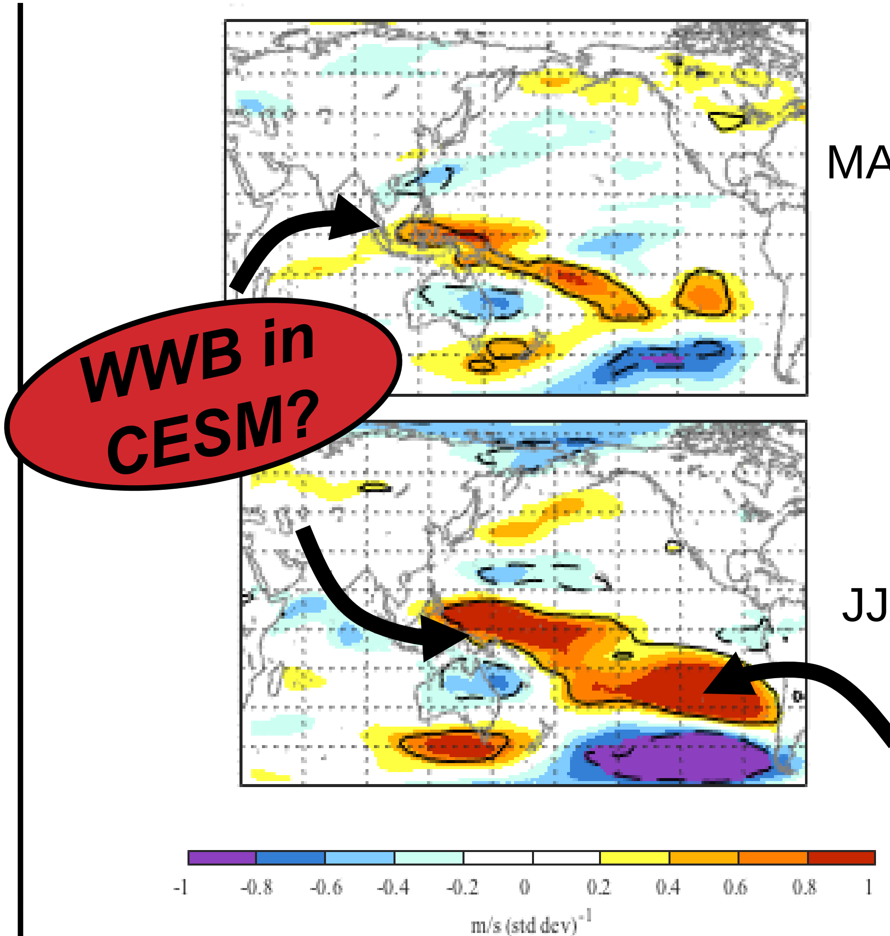
JJA



CESM-LE

MAM

JJA



Noise: EP OLR

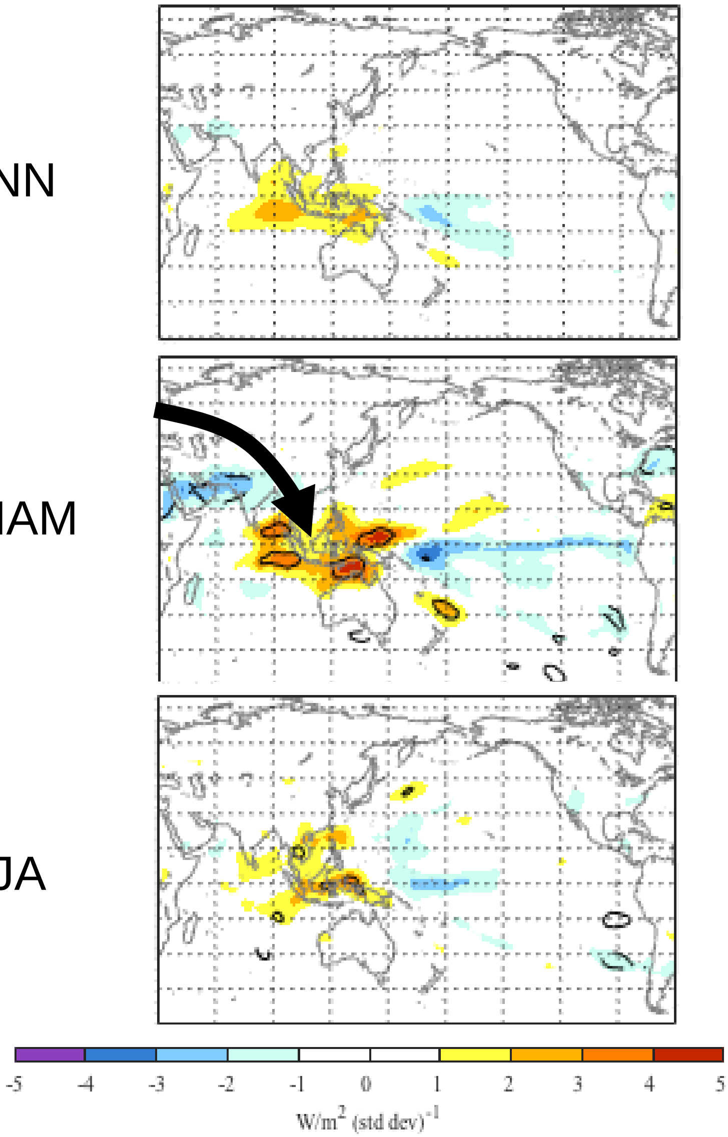
Observations

CESM-LE

ANN

MAM

JJA



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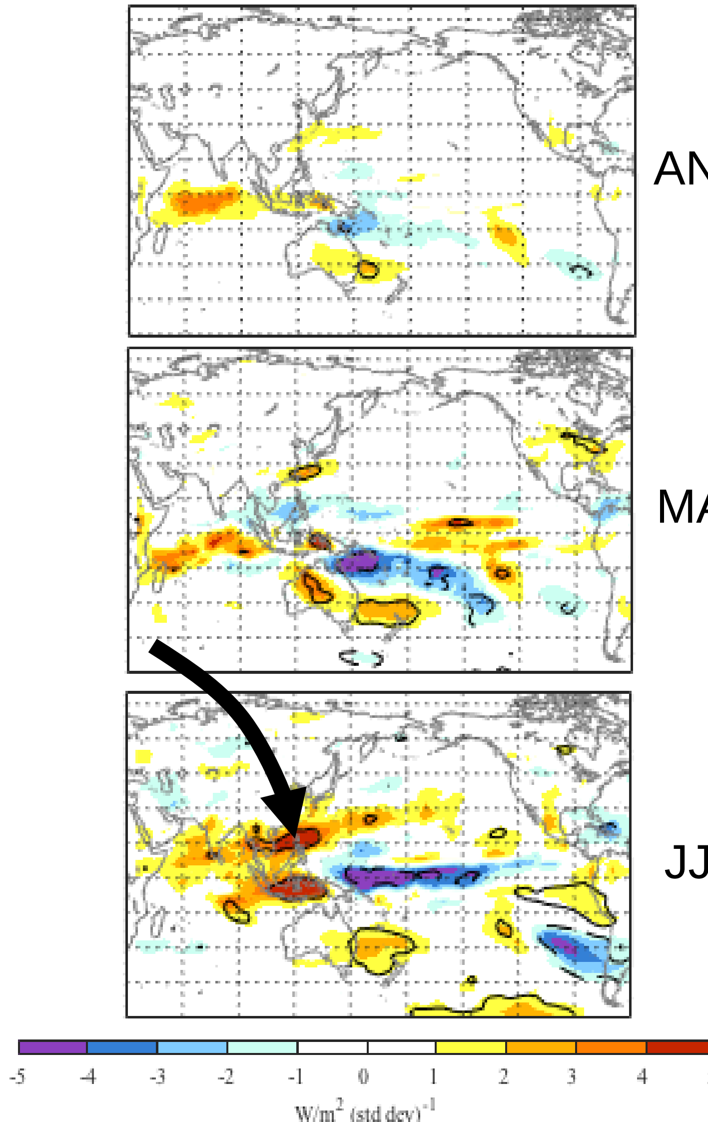
MAM

JJA



Final Remarks:

1. Central Pacific:
   - Optimal initial condition: **P**acific **M**eridional **M**ode
   - Noise forcing: **N**orth **P**acific **O**scillation (DJF)

2. Eastern Pacific:
   - Optimal initial condition: SST anomalies in Eastern Pacific, depressed thermocline
     - Kelvin Wave / Thermocline
   - Noise forcing: Zonal Wind anomalies (MAM)
     - WWB

3. Differences in CESM-LE analysis:
   - CP Optimal + final
   - EP Optimal + final
   - EP Noise Variance: peaks in JJA
   - EP Wind Structures: JJA

Thank you!