



*Annual Review of Marine Science*

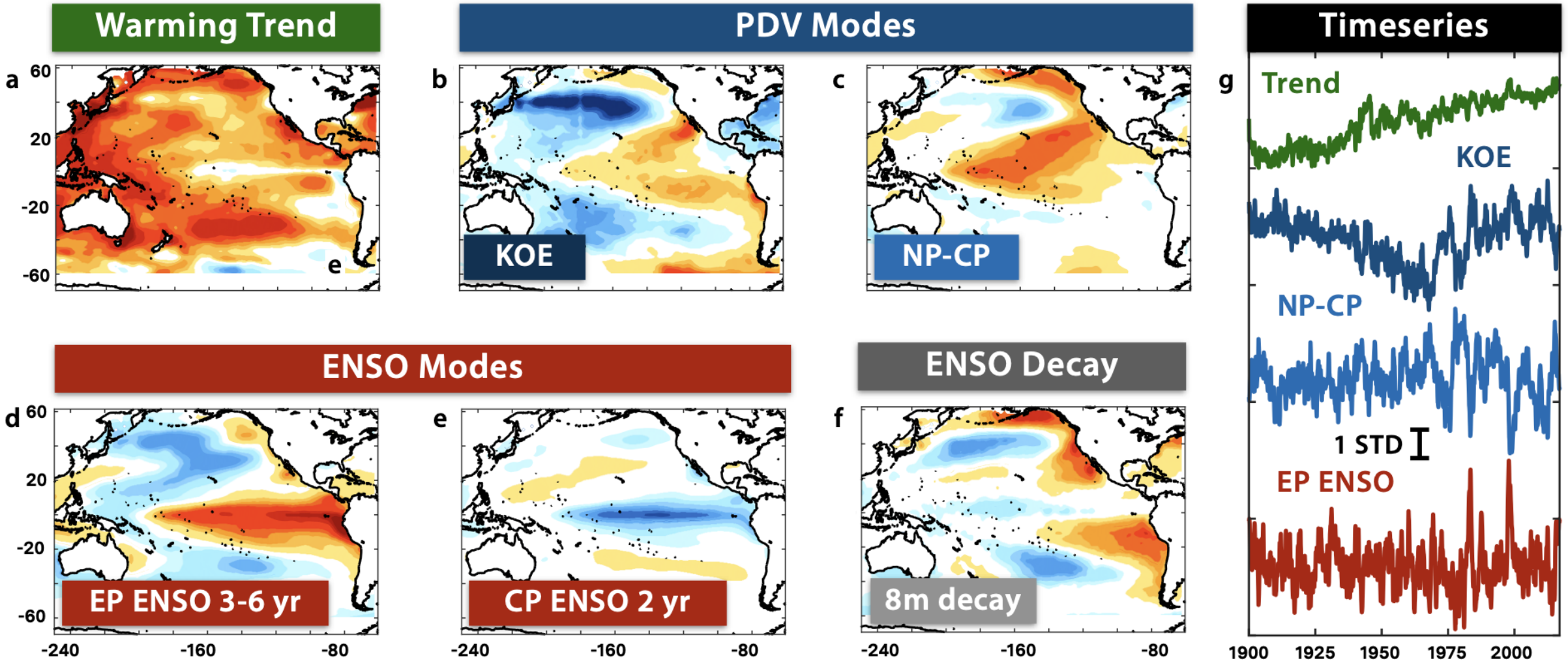
# Modes and Mechanisms of Pacific Decadal-Scale Variability



[www.pdv-tools.org](http://www.pdv-tools.org)

E. Di Lorenzo,<sup>1</sup> T. Xu,<sup>2</sup> Y. Zhao,<sup>3</sup> M. Newman,<sup>2,4</sup>  
A. Capotondi,<sup>2,4</sup> S. Stevenson,<sup>5</sup> D.J. Amaya,<sup>2</sup>  
B.T. Anderson,<sup>6</sup> R. Ding,<sup>7</sup> J.C. Furtado,<sup>8</sup> Y. Joh,<sup>9</sup>  
G. Liguori,<sup>10,11</sup> J. Lou,<sup>2,4</sup> A.J. Miller,<sup>12</sup> G. Navarra,<sup>13</sup>  
N. Schneider,<sup>14</sup> D.J. Vimont,<sup>15</sup> S. Wu,<sup>16</sup> and H. Zhang<sup>17</sup>

We use a **Linear Inverse Model (LIM)**  
to Diagnose the **PDV modes** in observations and models

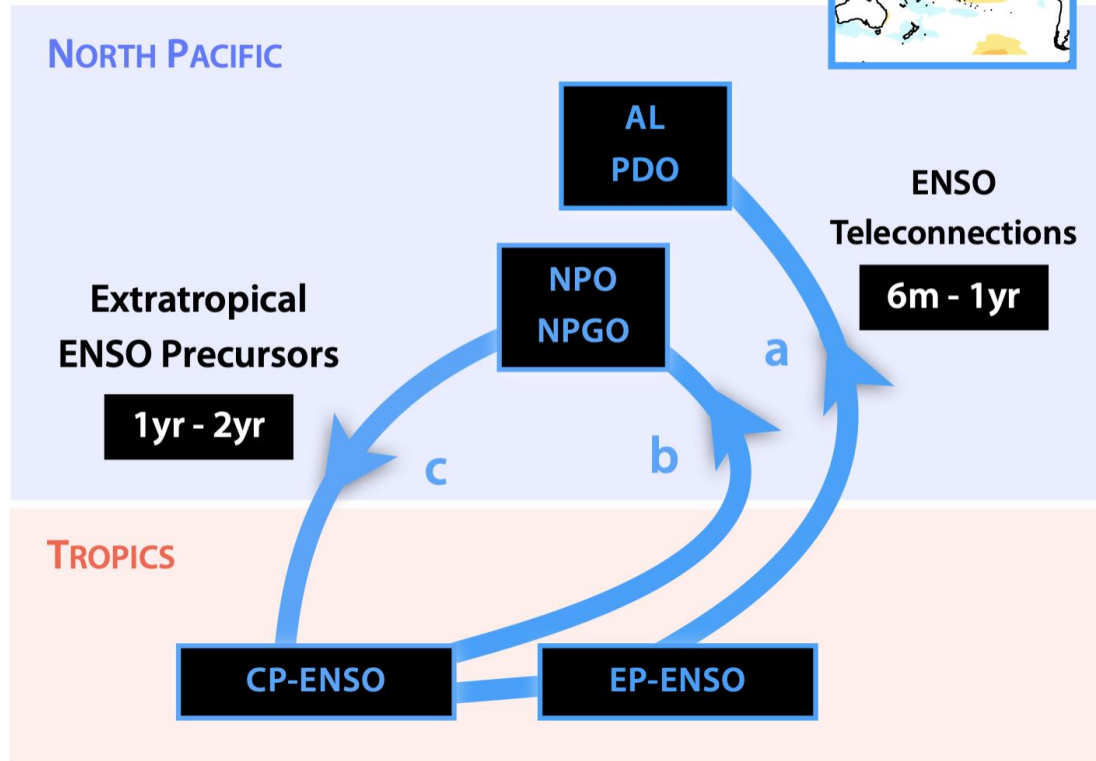


Di Lorenzo, E., et al. (2023), Modes and Mechanisms of Pacific Decadal-Scale Variability, *Annual Review of Marine Science*, 15(1), 249-275, doi:10.1146/annurev-marine-040422-084555.

# Two PDV mechanisms emerge as dominant

## PANEL 1

### Mechanisms of the NP-CP Mode



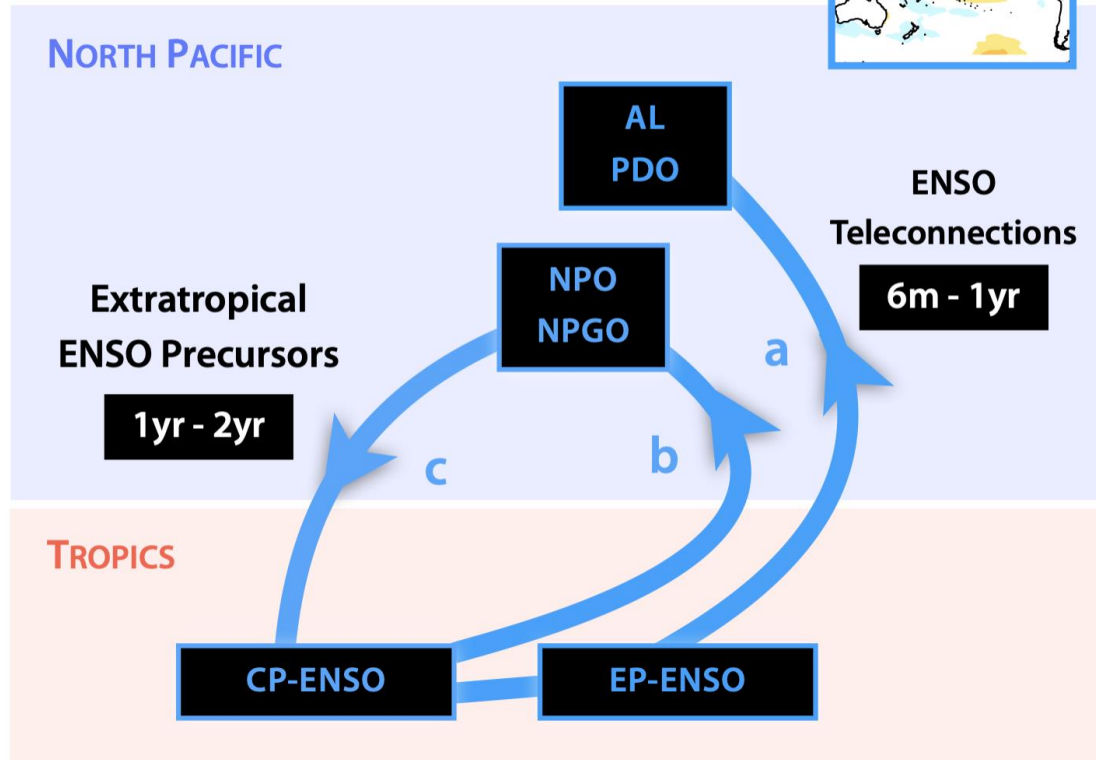
## NP-CP Mode

North Pacific-Central Pacific Mode

# Two PDV mechanisms emerge as dominant

## PANEL 1

### Mechanisms of the NP-CP Mode

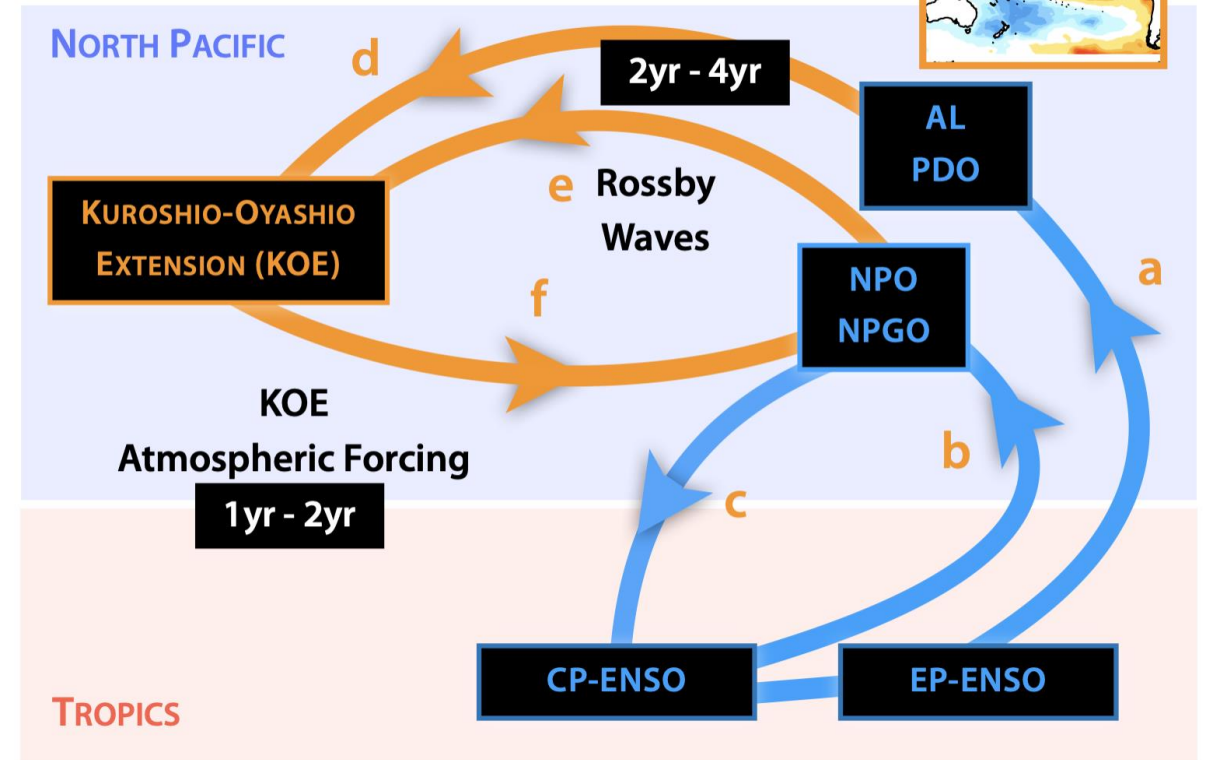


## NP-CP Mode

North Pacific-Central Pacific Mode

## PANEL 2

### Mechanisms of the KOE Mode



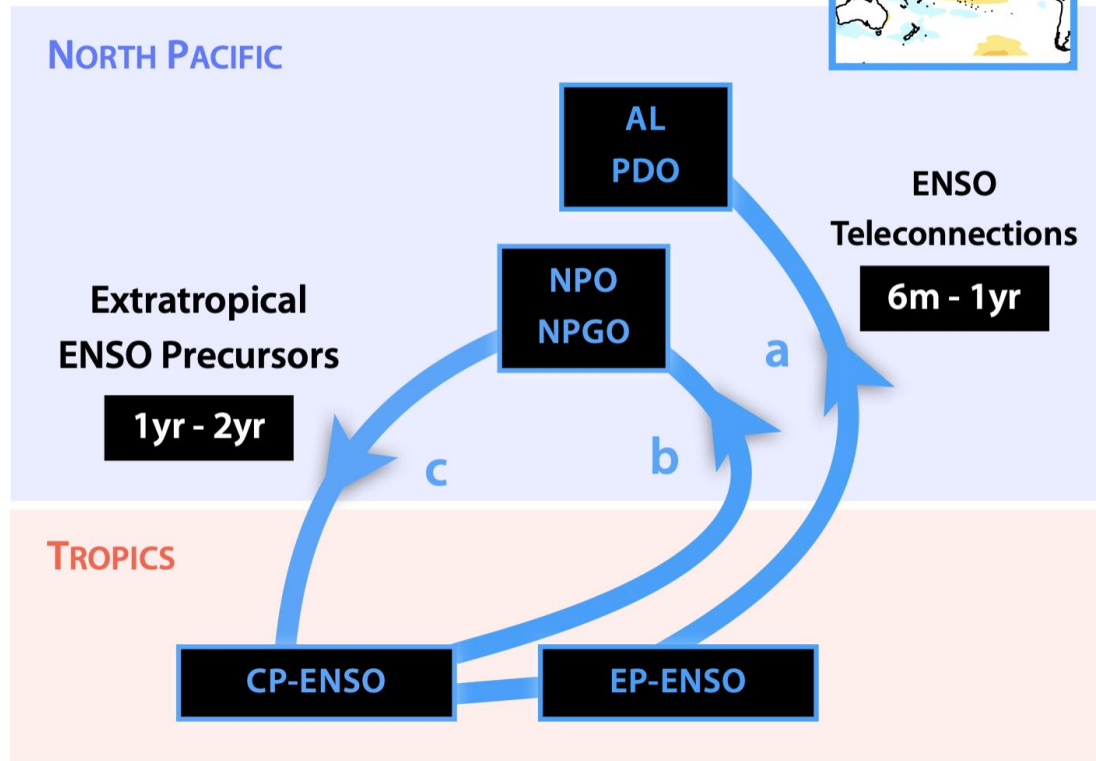
## KOE Mode

see Song, Stevenson et al. 2024, in prep

# The NP-CP mode energizes a large 70% to Central Tropical Decadal Variability

## PANEL 1

### Mechanisms of the NP-CP Mode



*Zhao, Y. Y., E. Di Lorenzo, D. X. Sun, and S. Stevenson (2021), Tropical Pacific Decadal Variability and ENSO Precursor in CMIP5 Models, J. Clim., 34(3), 1023-1045, doi:10.1175/jcli-d-20-0158.1.*

## Multi-state LIM Diagnostic

*State 1: Tropics*

*State 2: Extra-tropical*

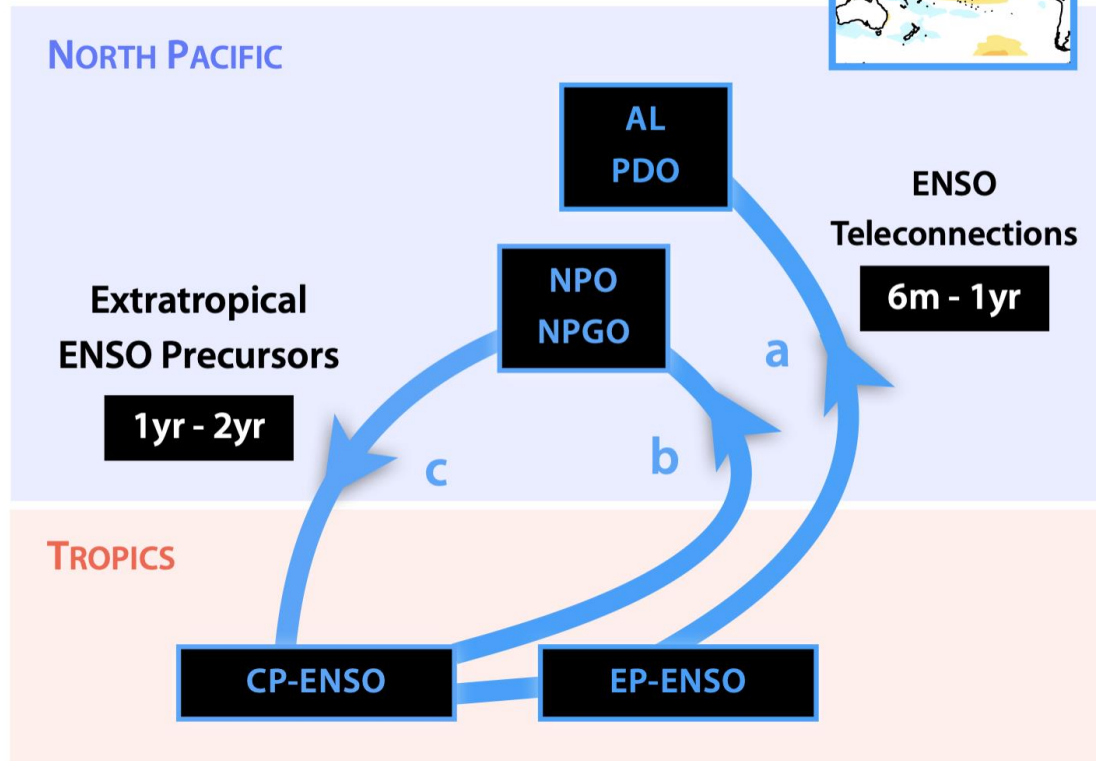
## NP-CP Mode

North Pacific-Central Pacific Mode

# However, North Pacific has little control on Tropical Interannual Variability

## PANEL 1

### Mechanisms of the NP-CP Mode



*Zhao, Y., D. Sun, E. Di Lorenzo, G. Liu and S. Wu:  
Separate the Role of Southern and Northern Extra-  
tropical Pacific in Tropical Pacific Climate Variability.  
Geophysical Research Letters, accepted.*

## Multi-state LIM Diagnostic

**State 1: Tropics**

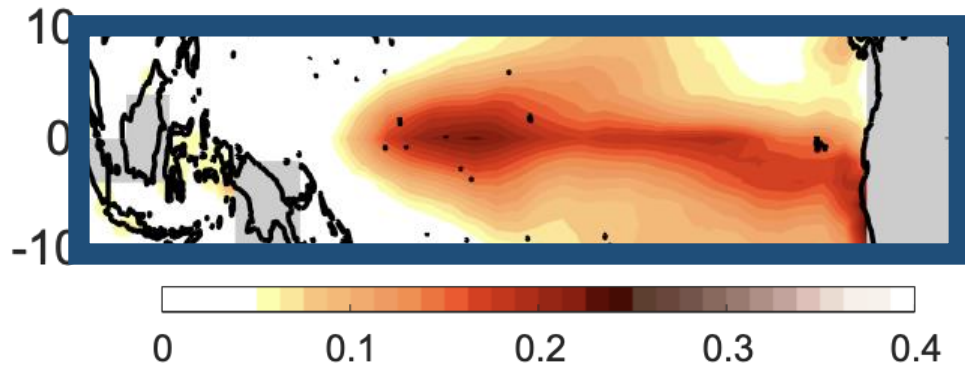
**State 2: North Pacific**

**State 3: South Pacific**

## NP-CP Mode

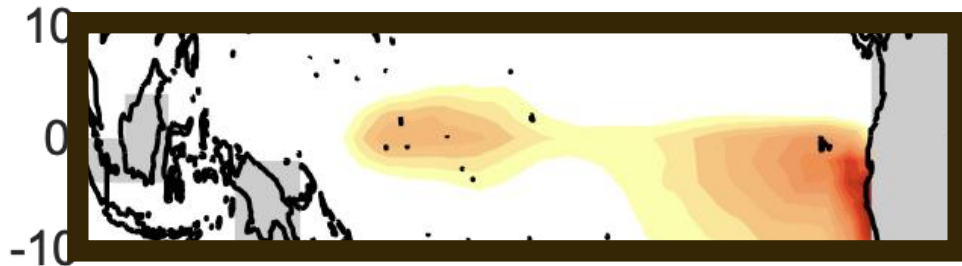
North Pacific-Central Pacific Mode

# Separating the North and South Pacific Contribution to TPDV

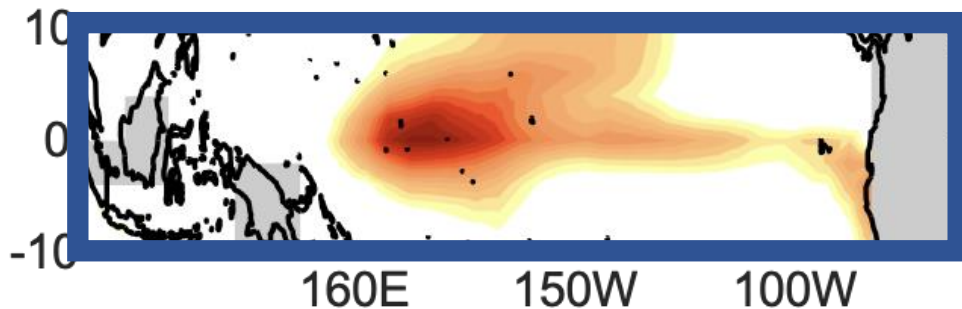


## Tropical Decadal Variability (TPDV)

*Zhao, Y., D. Sun, E. Di Lorenzo, G. Liu and S. Wu:  
Separate the Role of Southern and Northern Extra-  
tropical Pacific in Tropical Pacific Climate Variability.  
Geophysical Research Letters, accepted.*



**South Pacific contribution**



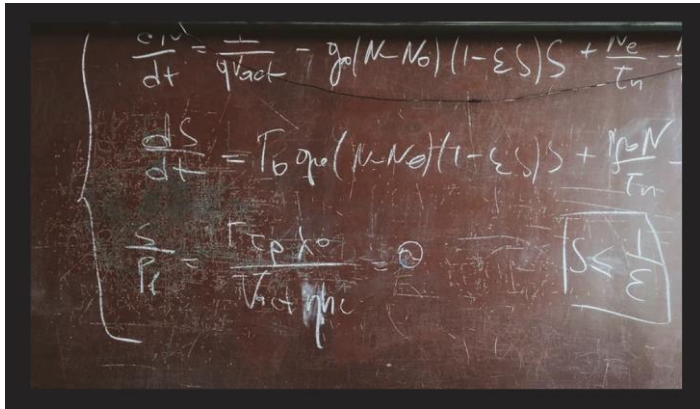
**North Pacific contribution**

# Multi-state LIM Diagnostic for Pacific Climate Variability

**State 1: Tropics**

**State 2: North Pacific**

**State 3: South Pacific**

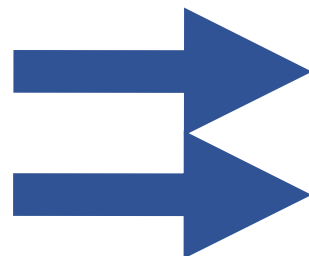


**Zhao, Y. Y., E. Di Lorenzo, D. X. Sun, and S. Stevenson (2021), *Tropical Pacific Decadal Variability and ENSO Precursor in CMIP5 Models*, J. Clim., 34(3), 1023-1045, doi:10.1175/jcli-d-20-0158.1.**

**Zhao, Y., D. Sun, E. Di Lorenzo, G. Liu and S. Wu: *Separate the Role of Southern and Northern Extratropical Pacific in Tropical Pacific Climate Variability*. Geophysical Research Letters, accepted.**

**Di Lorenzo, E., et al. (2023), *Modes and Mechanisms of Pacific Decadal-Scale Variability*, Annual Review of Marine Science, 15(1), 249-275, doi:10.1146/annurev-marine-040422-084555.**

**CMIP model with weak NP-CP representation**



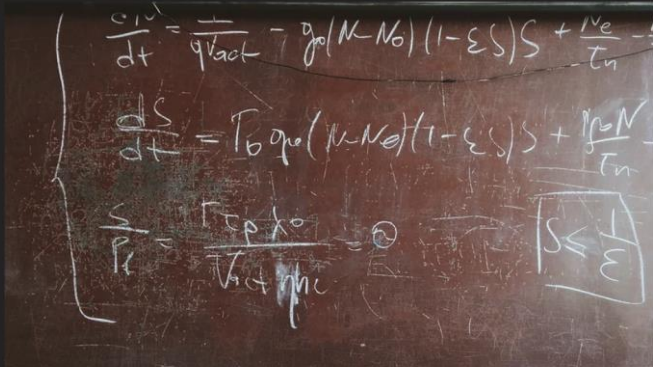
**no realistic TPDV**

**less realistic ENSO**



# Modes and Mechanisms of Pacific Decadal-Scale Variability

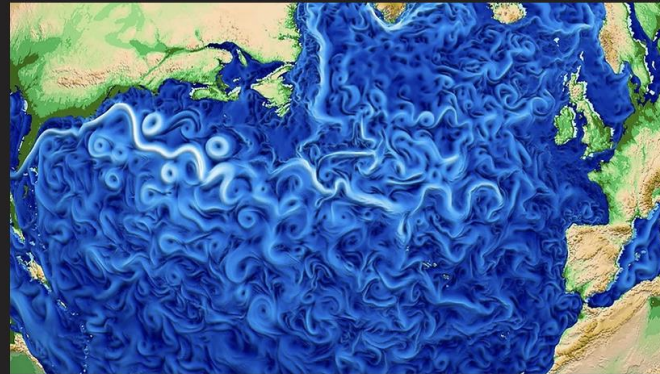
## DATA & MODELS



Handwritten mathematical equations on a chalkboard, likely representing climate model equations. The equations include terms like  $\frac{dS}{dt}$ ,  $\frac{dN}{dt}$ , and  $\frac{S}{N}$ , along with various constants and variables such as  $q_{fact}$ ,  $g_0(N-N_0)$ ,  $(1-\epsilon_S)S$ ,  $\frac{1-\epsilon_e}{\tau_n}$ ,  $\tau_{top}$ ,  $\frac{g_0 N_0}{\tau_n}$ , and  $\frac{g_0 N_0}{\tau_n + \tau_{top}}$ .

**A Linear Inverse Modeling  
Toolbox for Pacific Climate**

[GIT SITE DOWNLOAD](#)



**New E3SMv1 20-Member  
Large-Ensemble**

[ACCESS DATA](#)

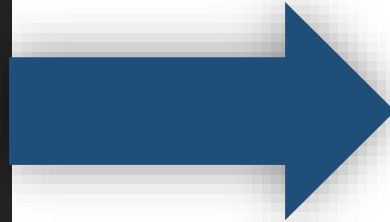


[www.pdv-tools.org](http://www.pdv-tools.org)

# LIM Dynamic Filtering

We examine the impact of the PDV modes on statistical modes like the PDO

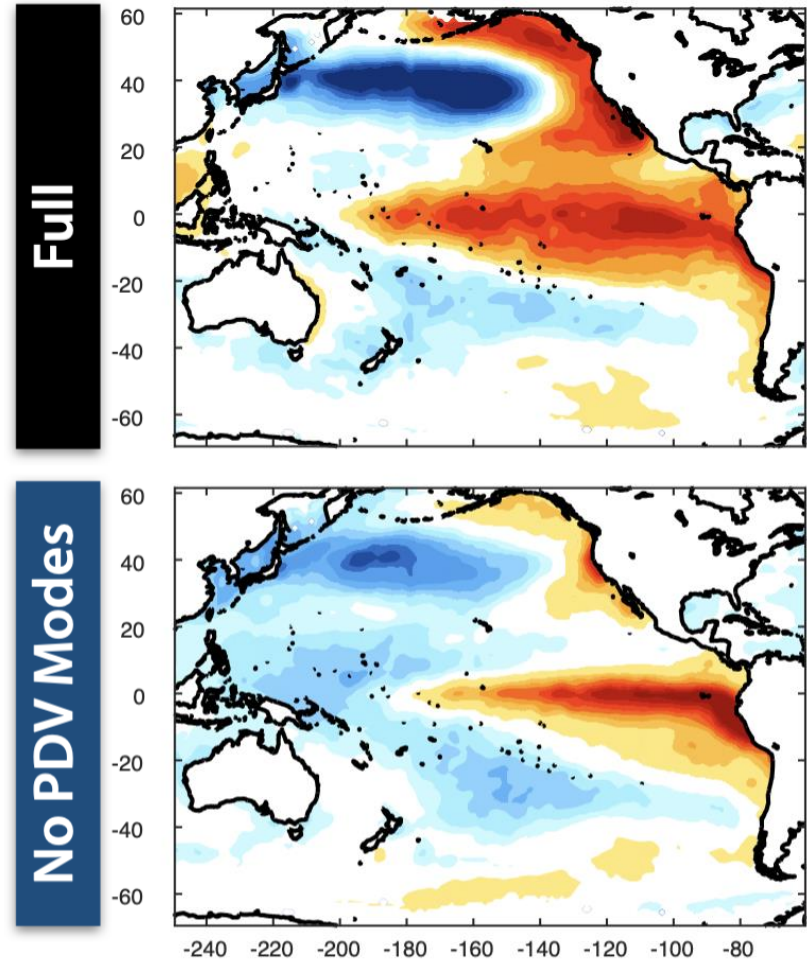
$$\begin{cases} \frac{dS}{dt} = \frac{1}{\tau_{\text{fact}}} - \frac{g_0(N-N_0)}{\rho_0(N-N_0)}(1-\epsilon_S)S + \frac{1}{\tau_n} \\ \frac{dS}{dt} = \frac{1}{\tau_{\text{fact}}} - \frac{g_0(N-N_0)}{\rho_0(N-N_0)}(1-\epsilon_S)S + \frac{1}{\tau_n} \\ \frac{S}{K} = \frac{\tau_{\text{fact}}}{\tau_{\text{fact}} + \tau_n} \end{cases}$$



Pacific Decadal Oscillation (PDO) =

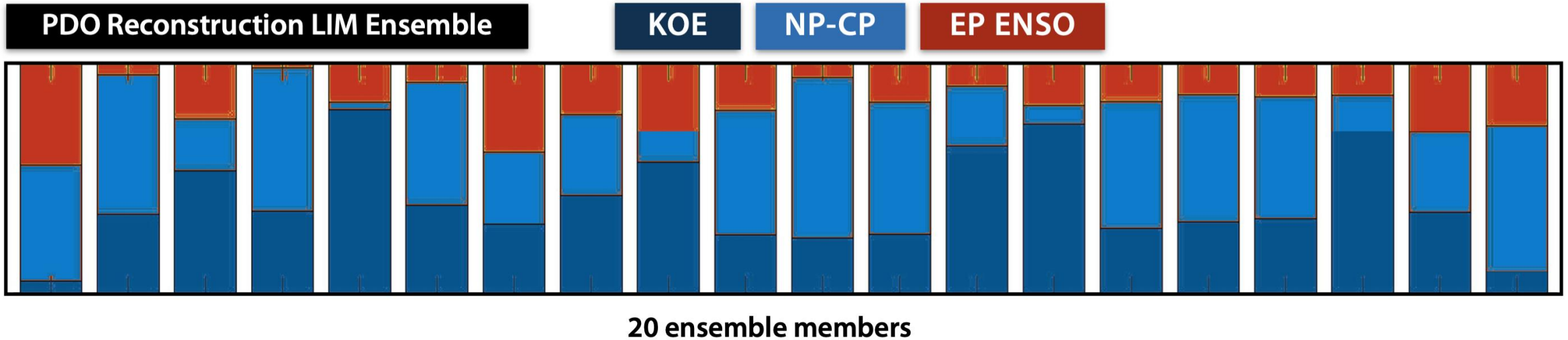
KOE Mode + NP-CP Mode + ENSO Mode

PDO



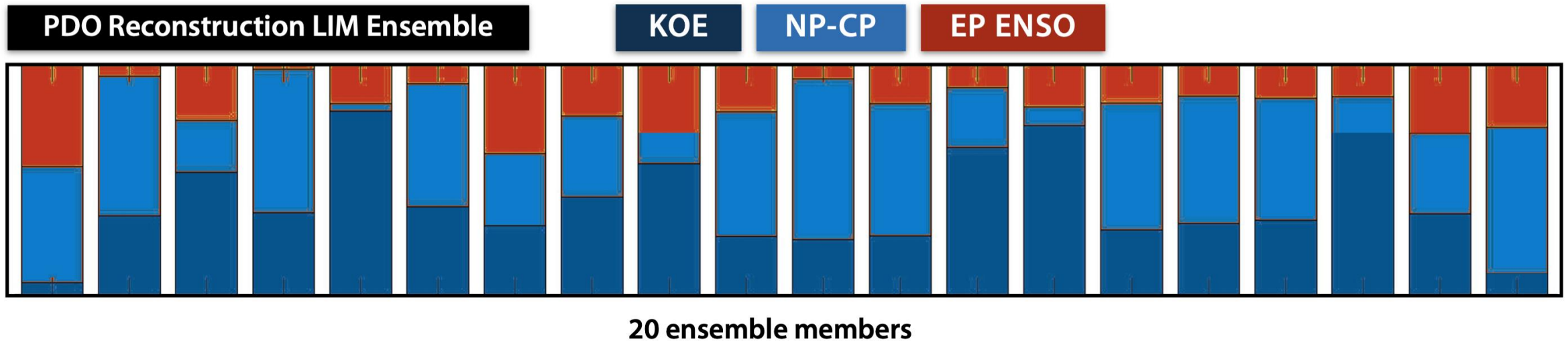
# LIM Dynamic Filtering

The relative contribution of the “dynamical modes” to PDV can change



## LIM Dynamic Filtering

The relative contribution of the “dynamical modes” to PDV can change



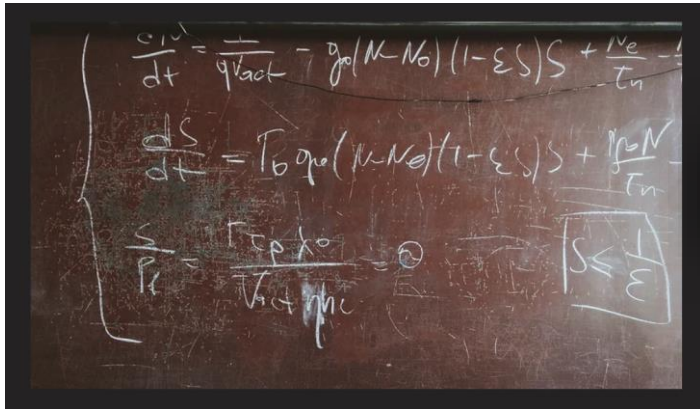
We find that this is true also in CMIP6 models

ENSO and NP-CP Modes become stronger in warming climate

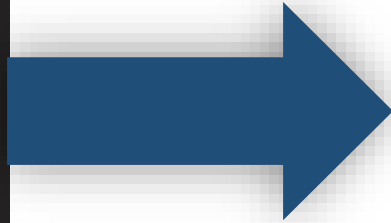
*see Wu et al. 2024, Nature CC, in review*

## LIM Dynamic Filtering

We examine the impact of the PDV modes on statistical modes like the PDO



The image shows a chalkboard with three equations written in white chalk. The first equation is  $\frac{dS}{dt} = \frac{1}{\tau_{act}} - \frac{q_0(N-N_0)(1-\epsilon_S)S}{\tau_n} + \frac{I_{eq}}{\tau_n}$ . The second equation is  $\frac{dS}{dt} = \frac{1}{\tau_{act}} - \frac{q_0(N-N_0)(1-\epsilon_S)S}{\tau_n} + \frac{I_{eq}}{\tau_n}$ . The third equation is  $\frac{S}{K} = \frac{I_{eq} \tau_n}{q_0(N-N_0)(1-\epsilon_S)S} - \tau_{act}$ . There is also a small box containing the letter 'E'.

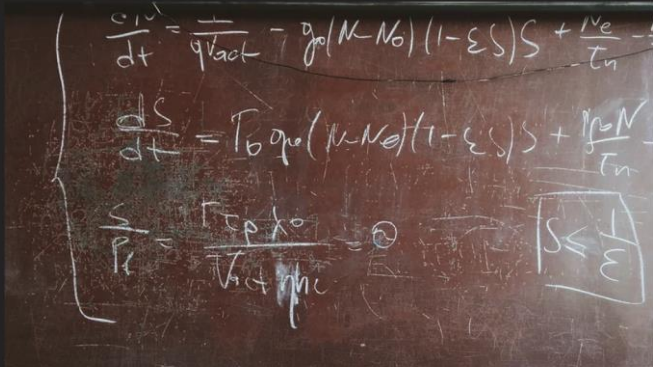


*The NP-CP mode is also responsible for the multi-year duration of North Pacific Marine Heatwaves*

**see Capotondi et al. 2024, in prep**

# Modes and Mechanisms of Pacific Decadal-Scale Variability

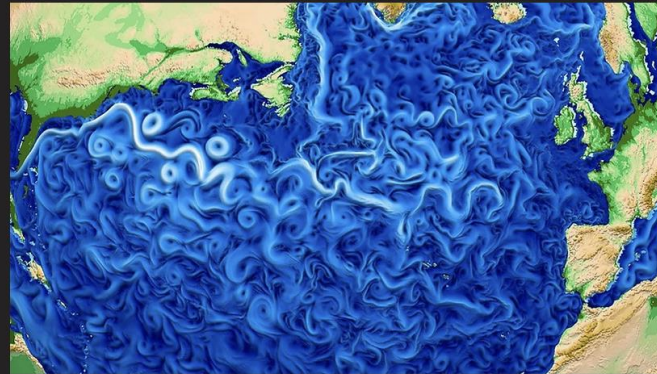
## DATA & MODELS



Handwritten mathematical equations on a chalkboard, likely representing climate model equations. The equations include terms like  $\frac{dS}{dt}$ ,  $\frac{dN}{dt}$ , and  $\frac{S}{N}$ , along with various constants and variables such as  $q_{\text{fact}}$ ,  $g_0(N-N_0)$ ,  $(1-\epsilon_S)S$ ,  $\frac{1-\epsilon_e}{\tau_n}$ ,  $\tau_{\text{top}}$ ,  $\frac{q_{\text{top}}}{V_{\text{top}}}$ , and  $\frac{1}{V_{\text{top}}}$ .

**A Linear Inverse Modeling  
Toolbox for Pacific Climate**

[GIT SITE DOWNLOAD](#)



**New E3SMv1 20-Member  
Large-Ensemble**

[ACCESS DATA](#)



[www.pdv-tools.org](http://www.pdv-tools.org)