Pacific Decadal Variability in a Changing Climate

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B. Anderson and D. Vimont

NOAA Collaborators: Alexander M. and M. Newman

DOE Meeting, September 20, 2011

QUESTION:

Is Pacific decadal variability altered by *climate change* and how?

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Data we can use:

- AR4/AR5 climate model simulations
- Paleo multi-proxy reconstructions
- Targeted climate model experiments

QUESTION:

Is Pacific decadal variability altered by *climate change* and how?

Hypothesis **or a** ***working model***

of the dynamics that explain most of the

Pacific decadal variance

Model for explaining Pacific decadal dynamics

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Extra-tropics [Ocean forced by Atmosphere]

Tropics [Ocean-Atmosphere Coupled System]

Model for explaining Pacific decadal dynamics

Extra-tropics [Ocean forced by Atmosphere]

Meridional Mode
2nd tropical mode

Zonal Mode
1st tropical mode

Tropics [Ocean-Atmosphere Coupled System]

Model for explaining Pacific decadal dynamics

Extra-tropics [Ocean forced by Atmosphere]

CPW

Central Pacific Warming

non-Canonical ENSO

(mature)

ENSO

Eastern Pacific

Canonical ENSO

(mature)

Tropics [Ocean-Atmosphere Coupled System]

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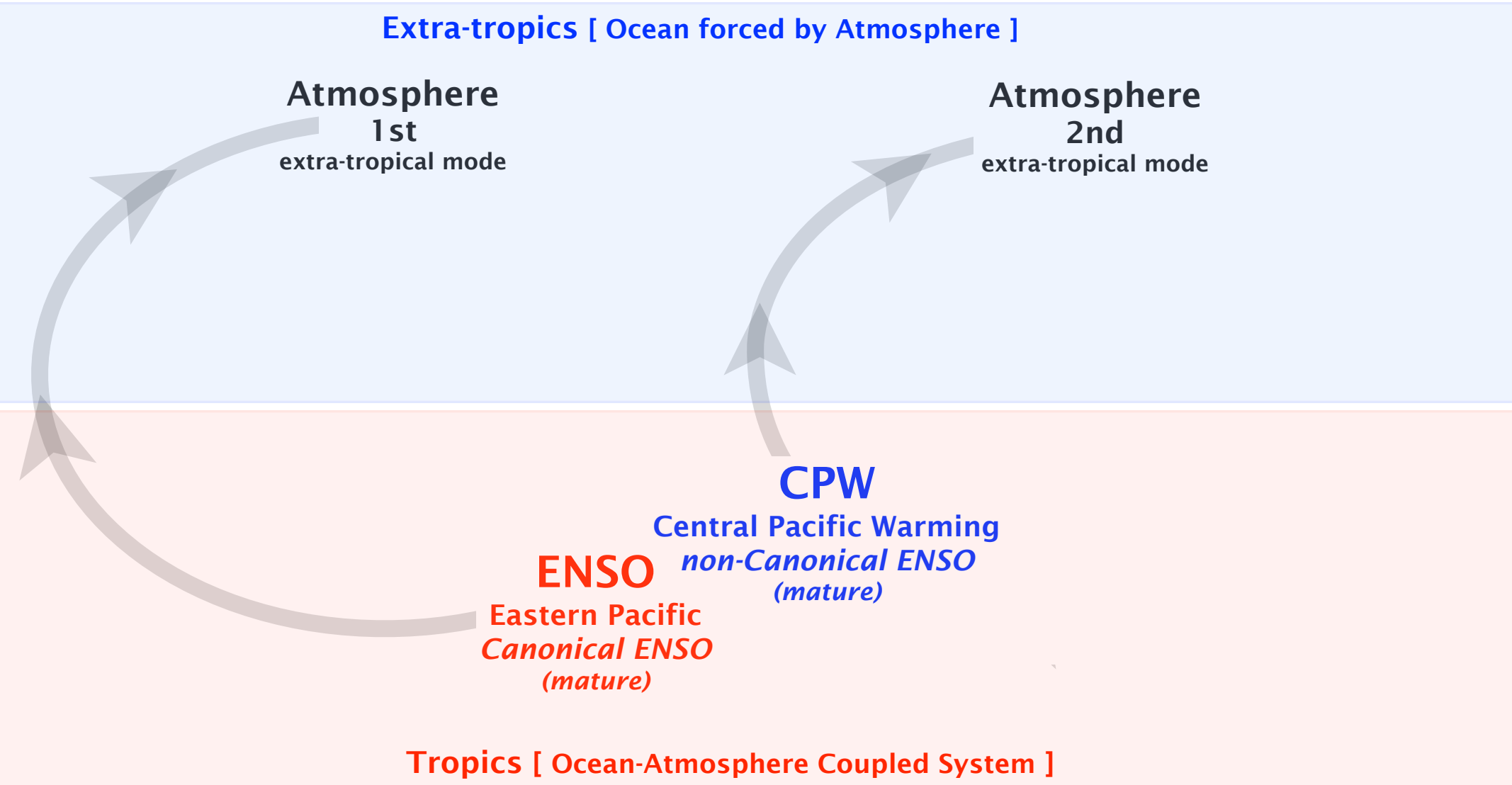

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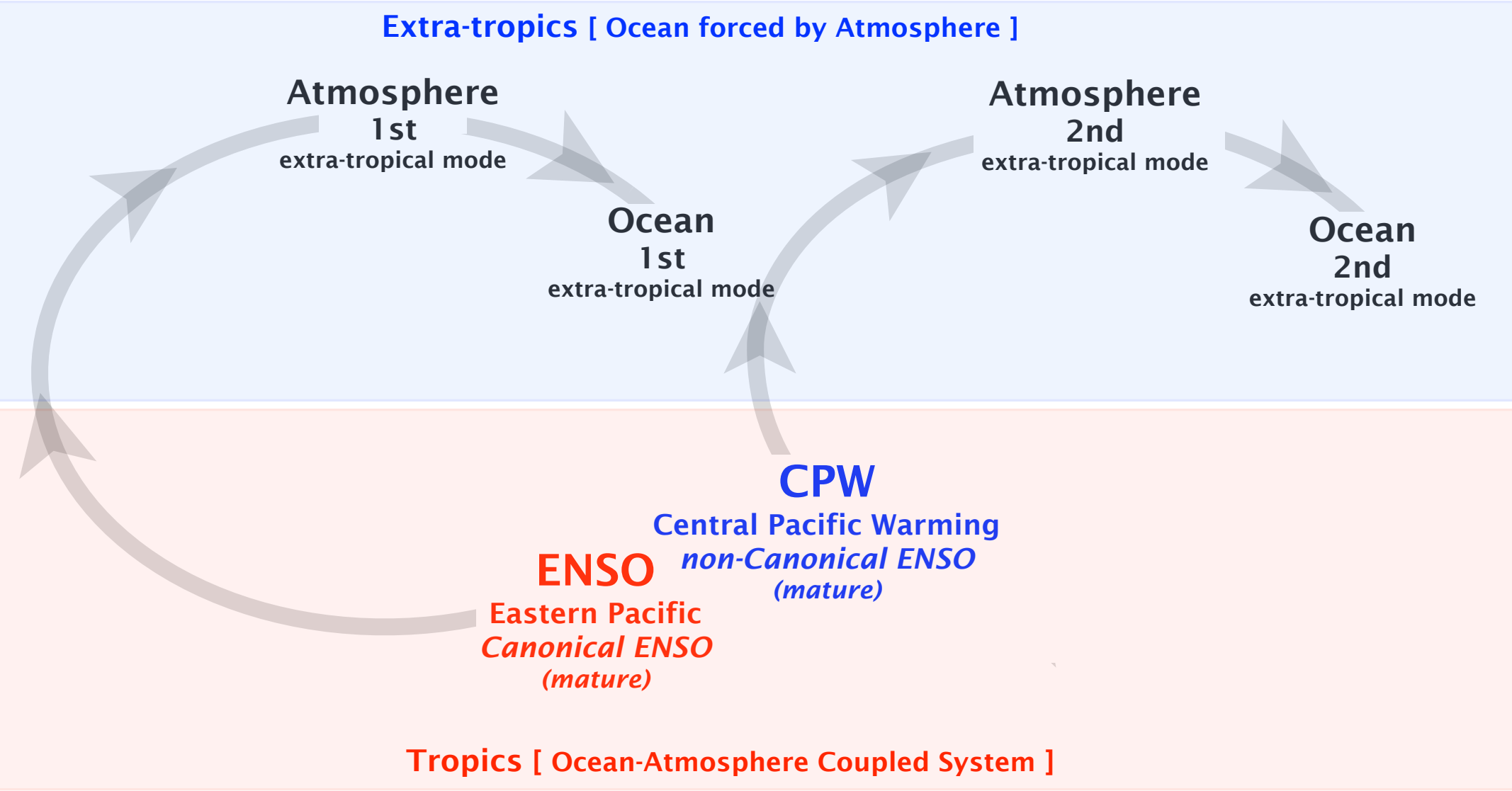

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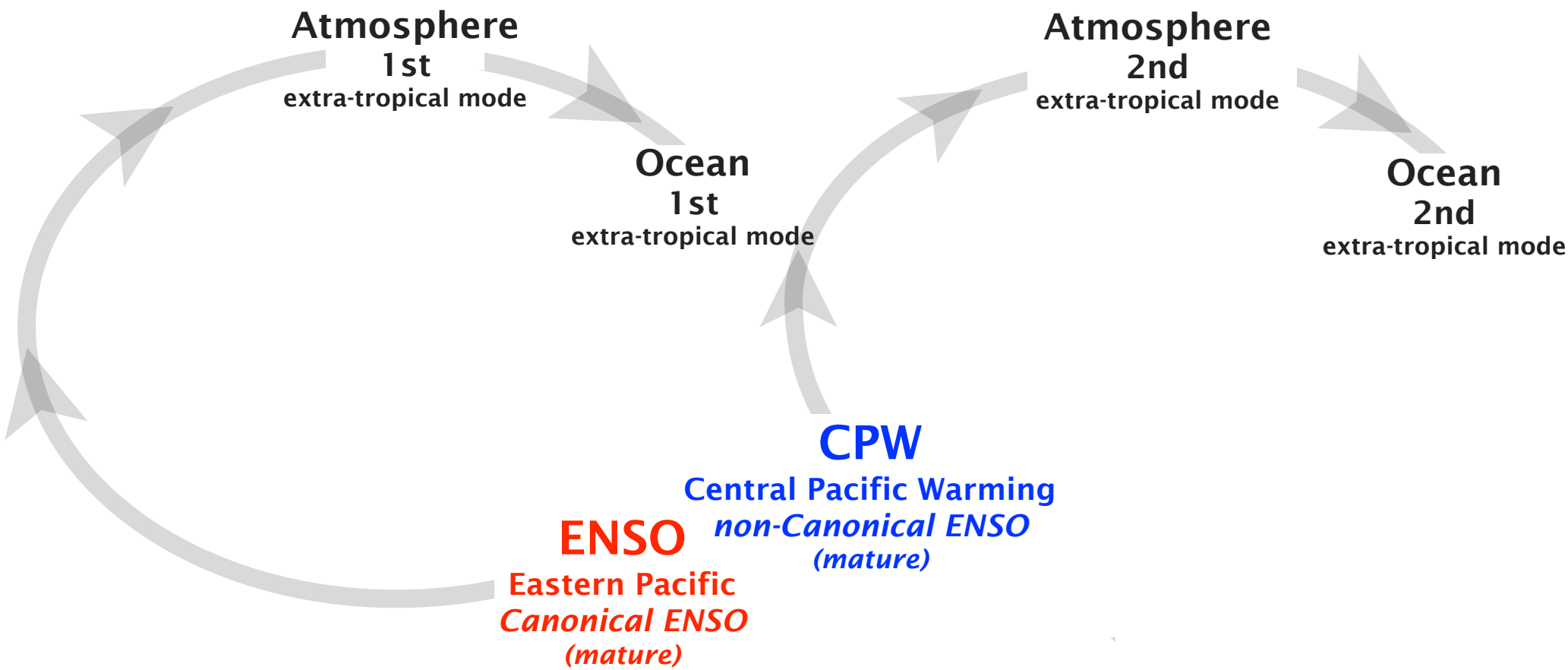

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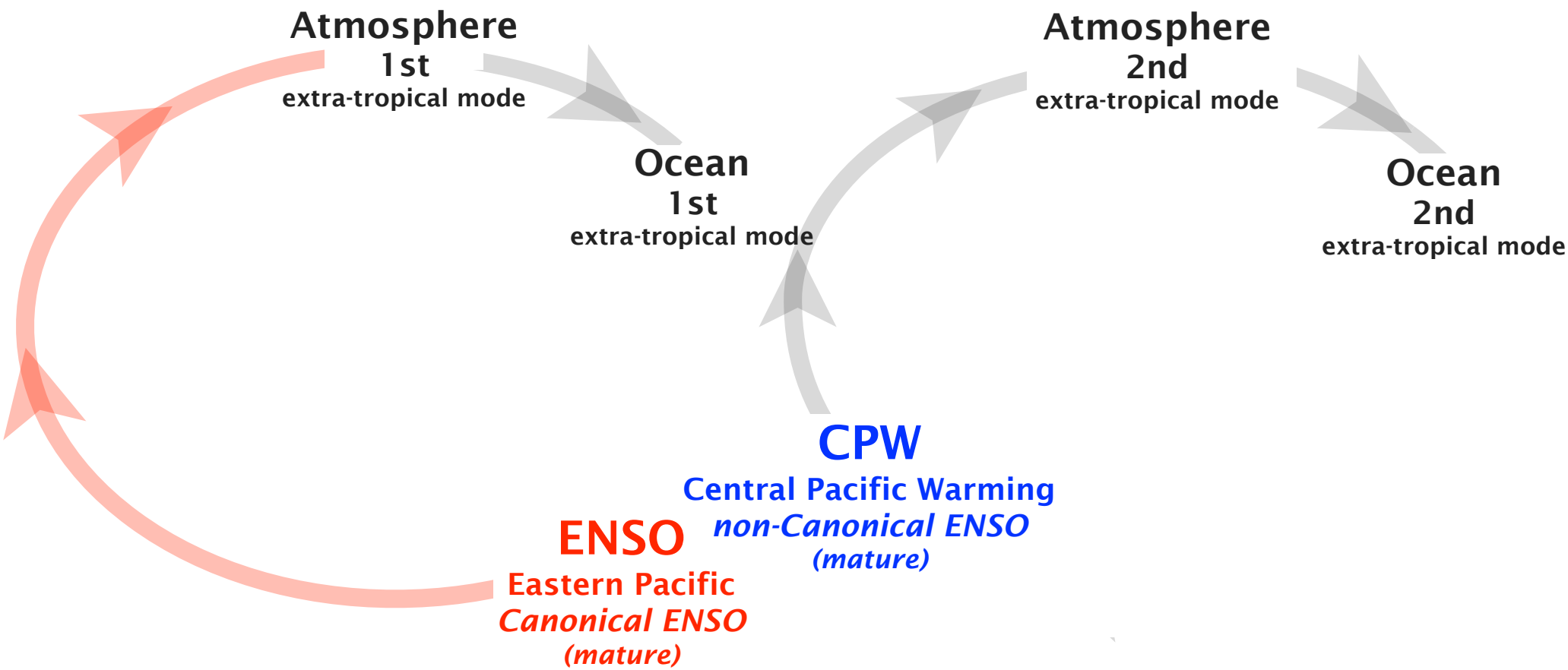

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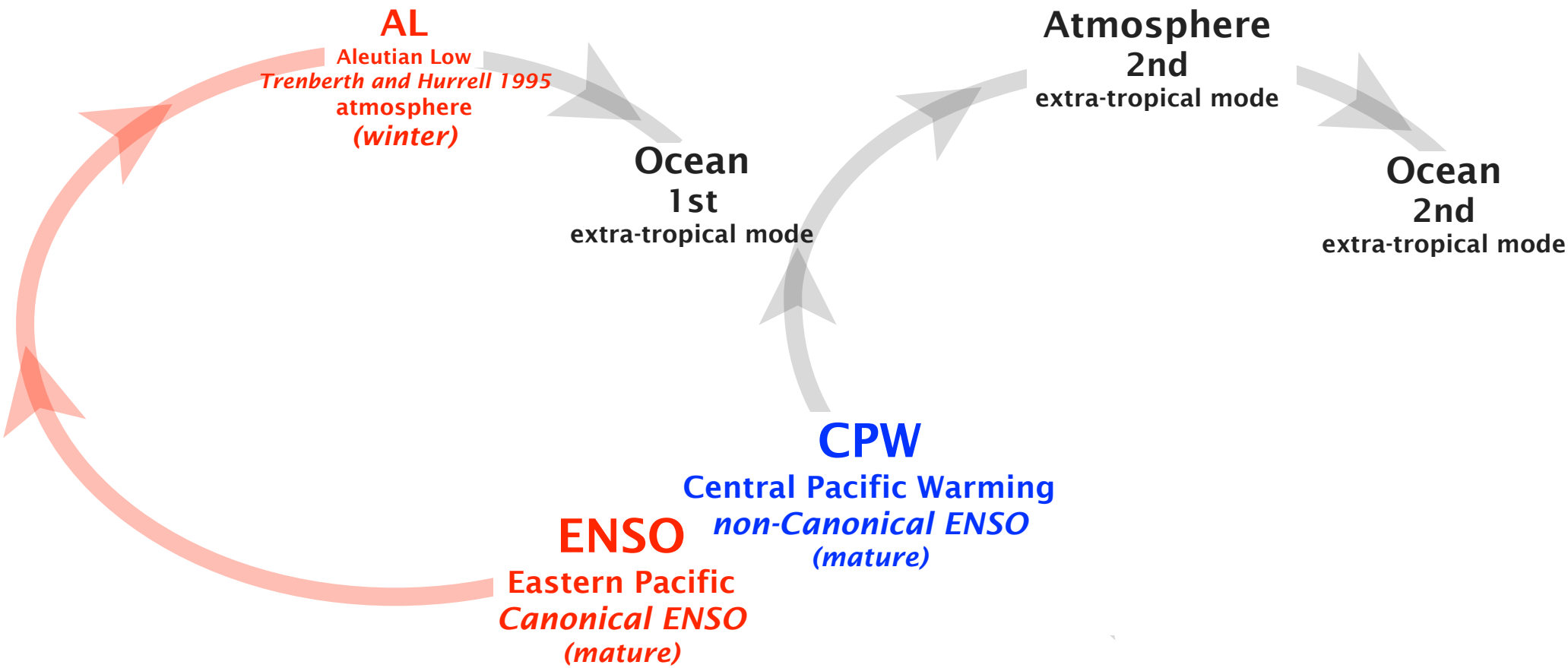

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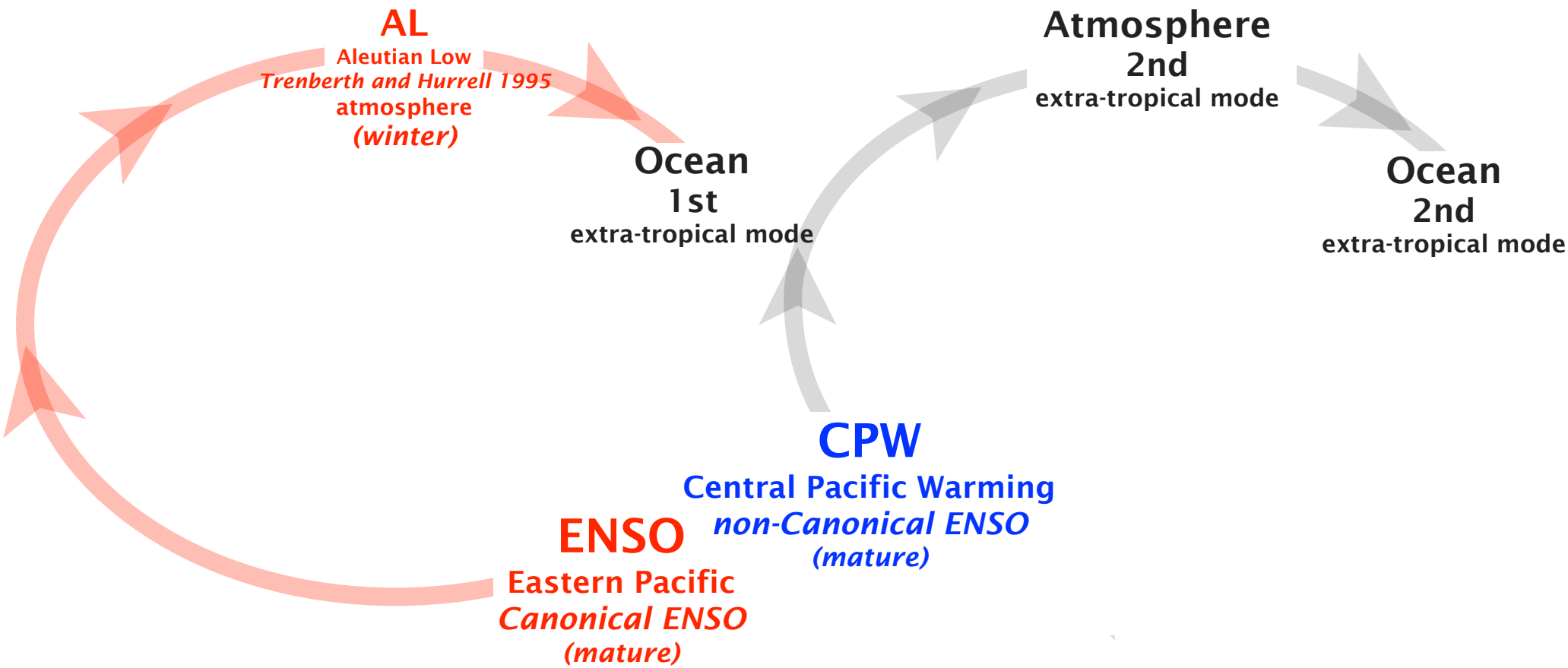

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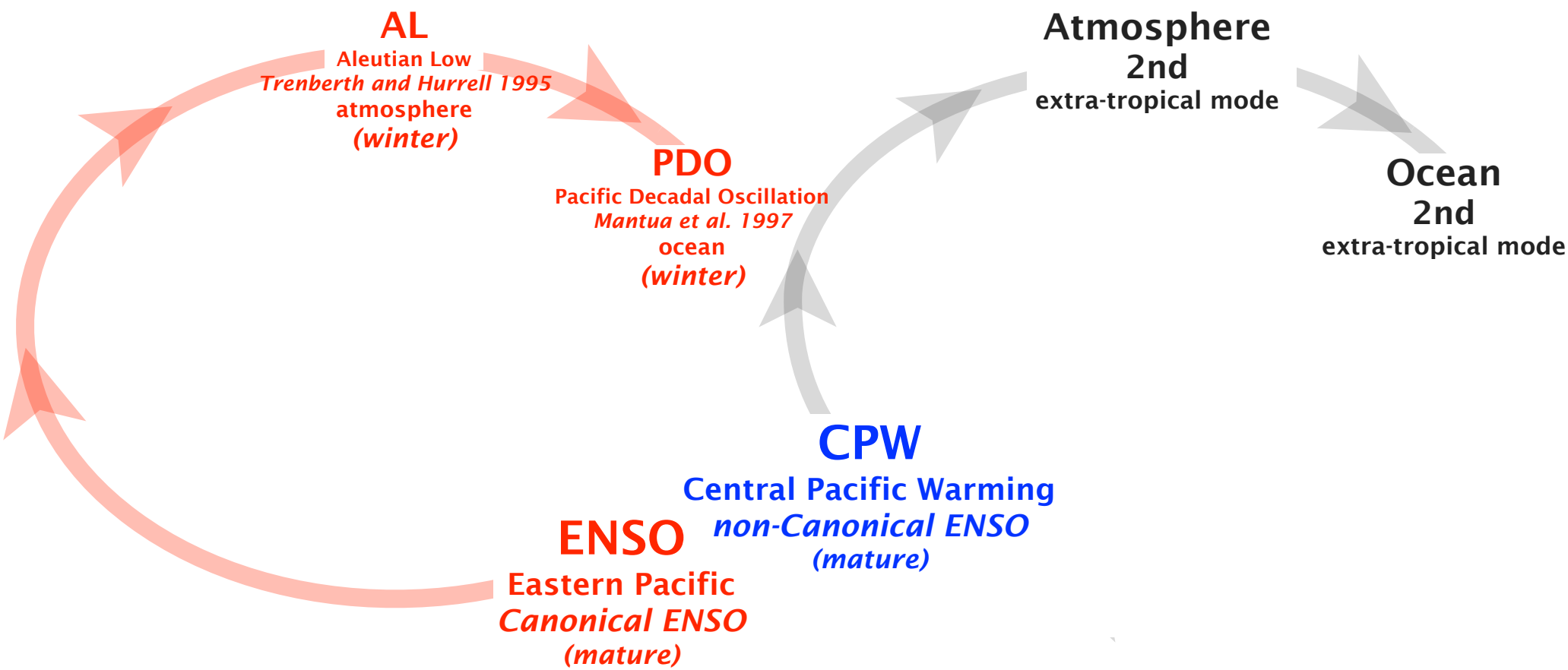

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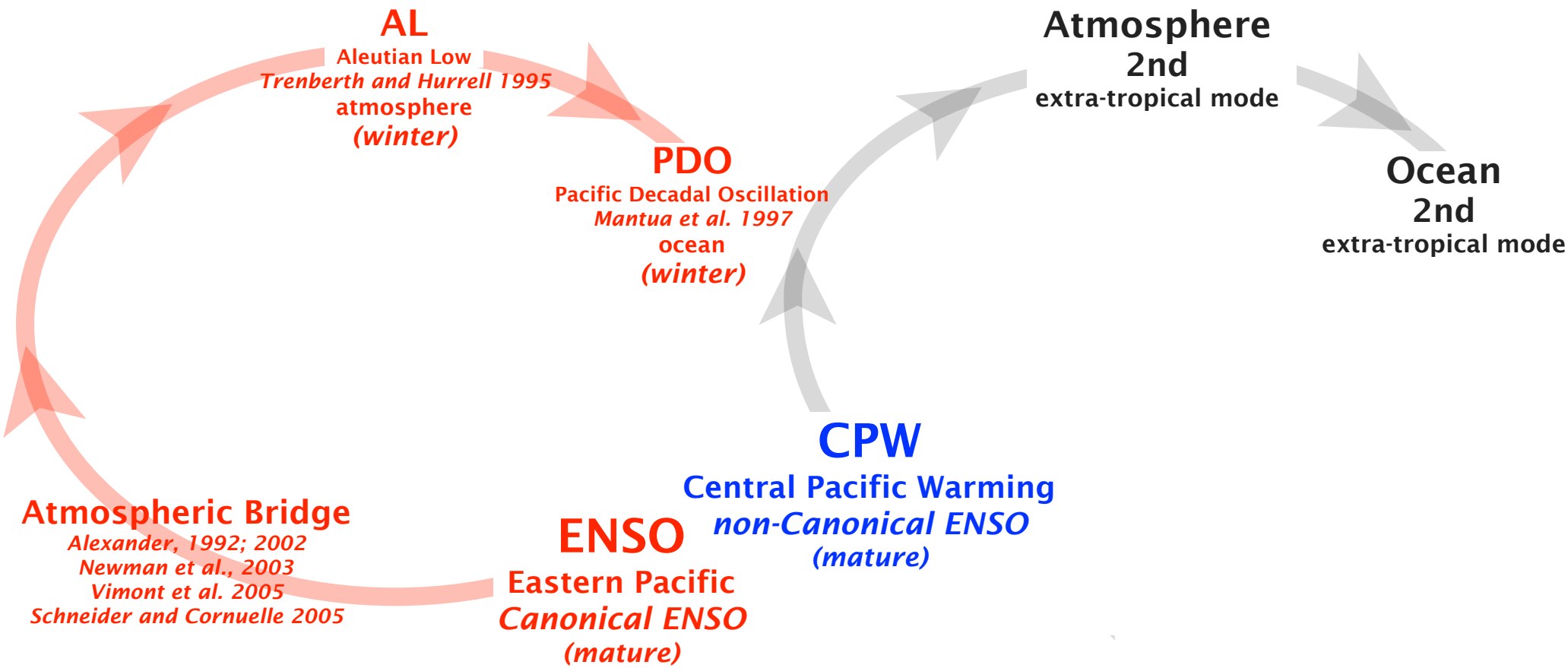

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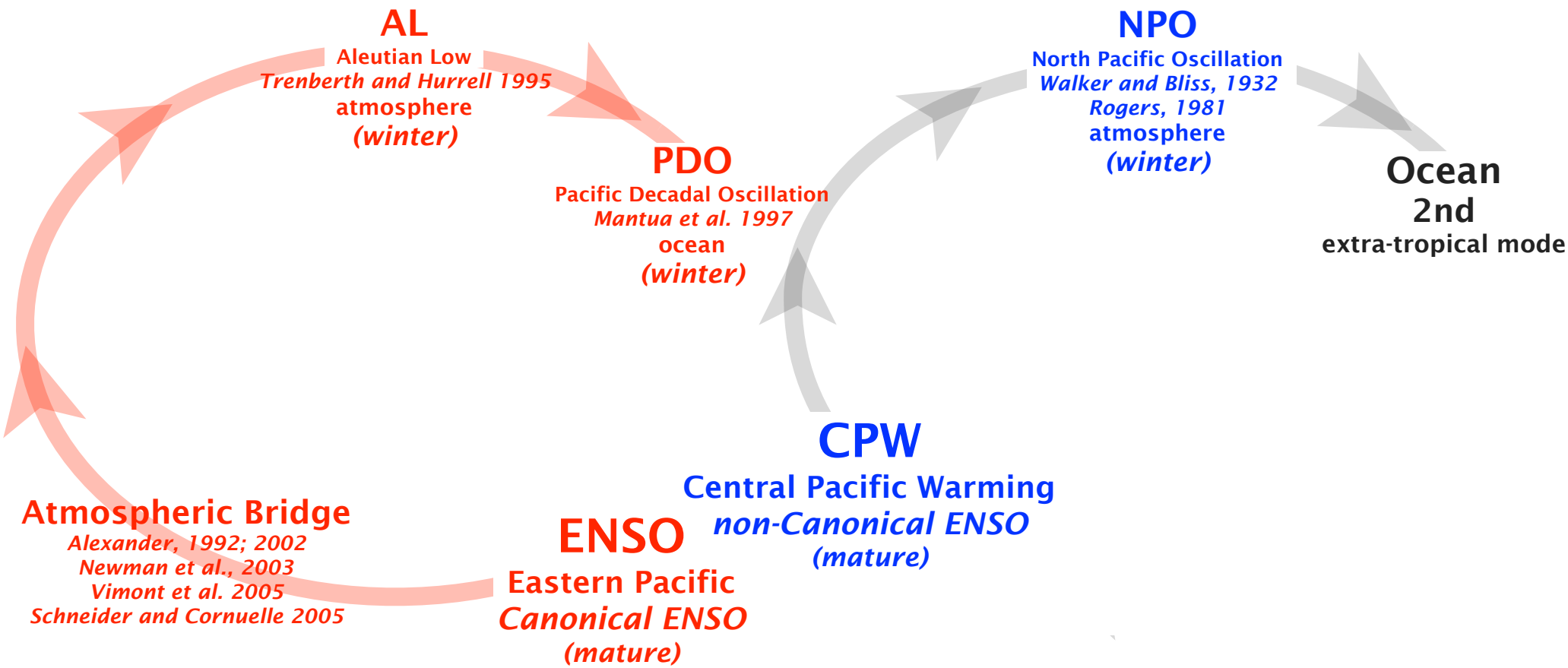

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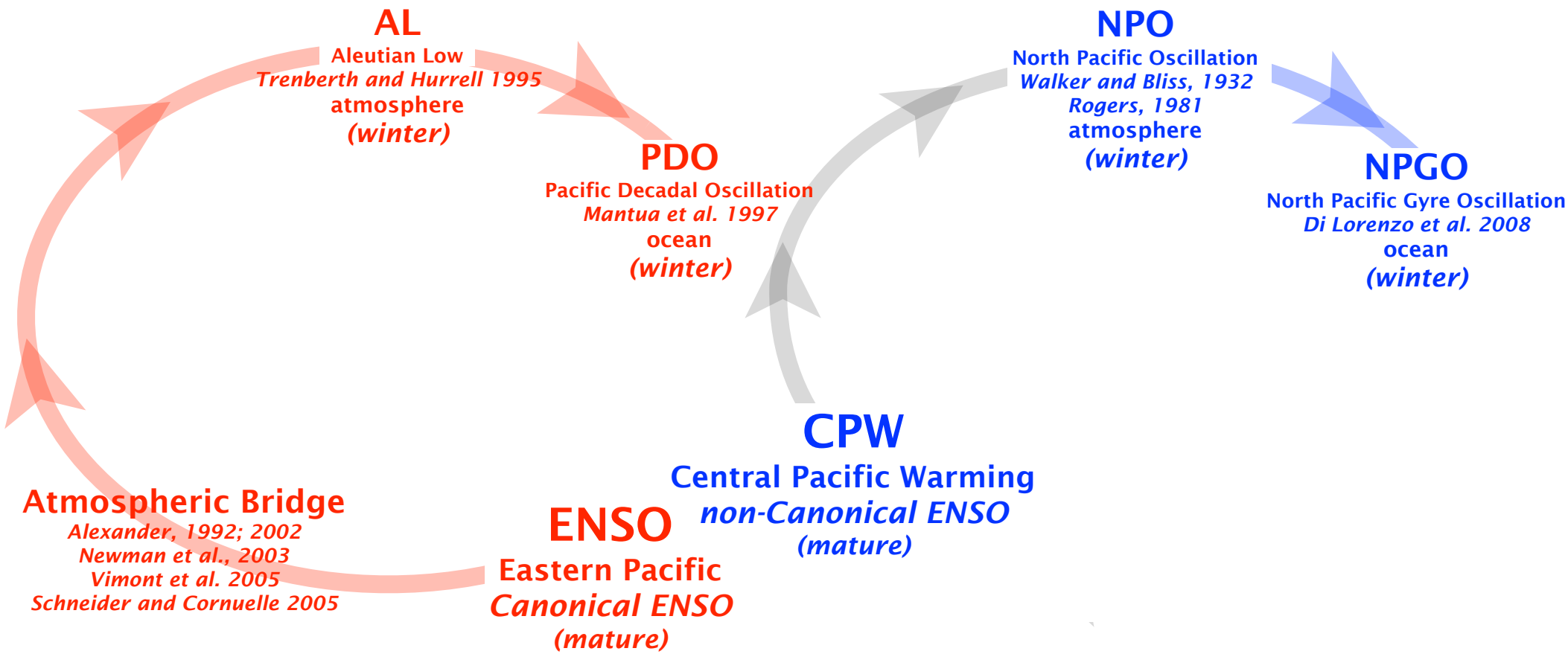

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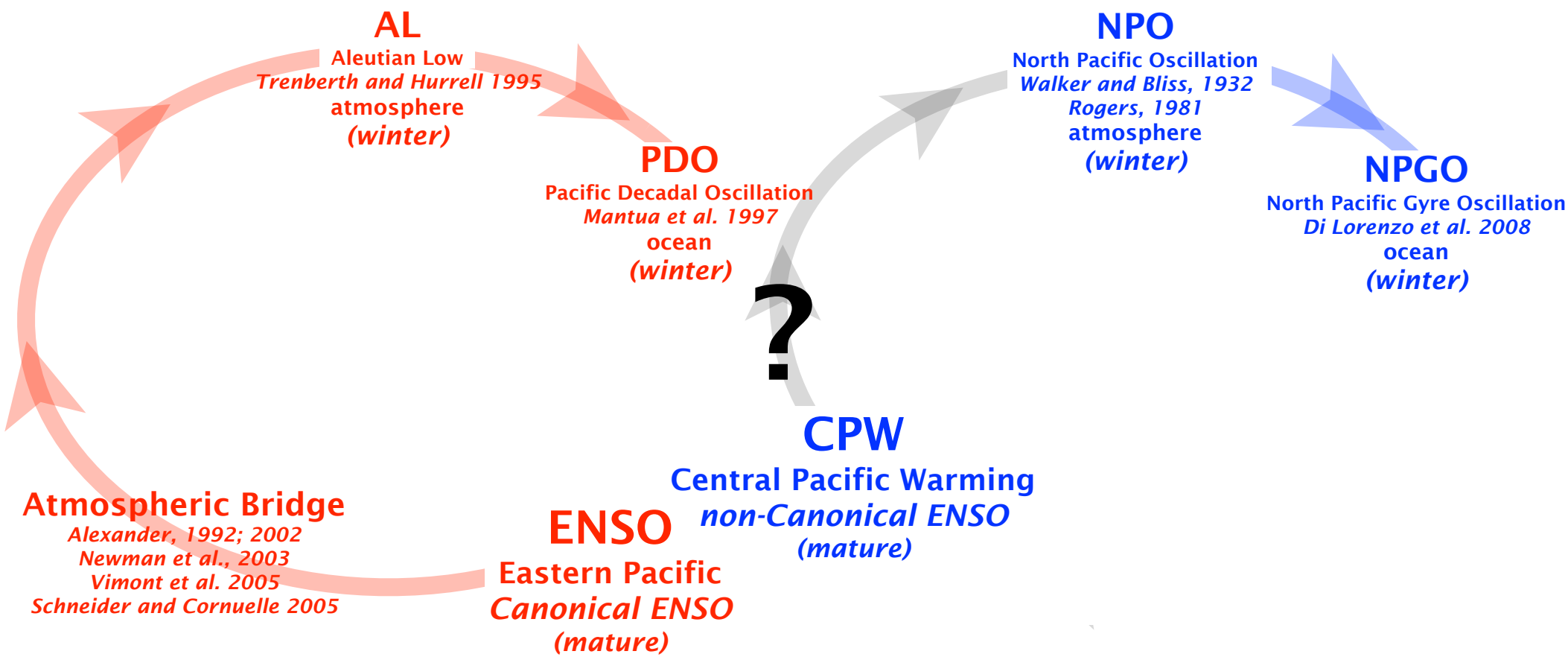

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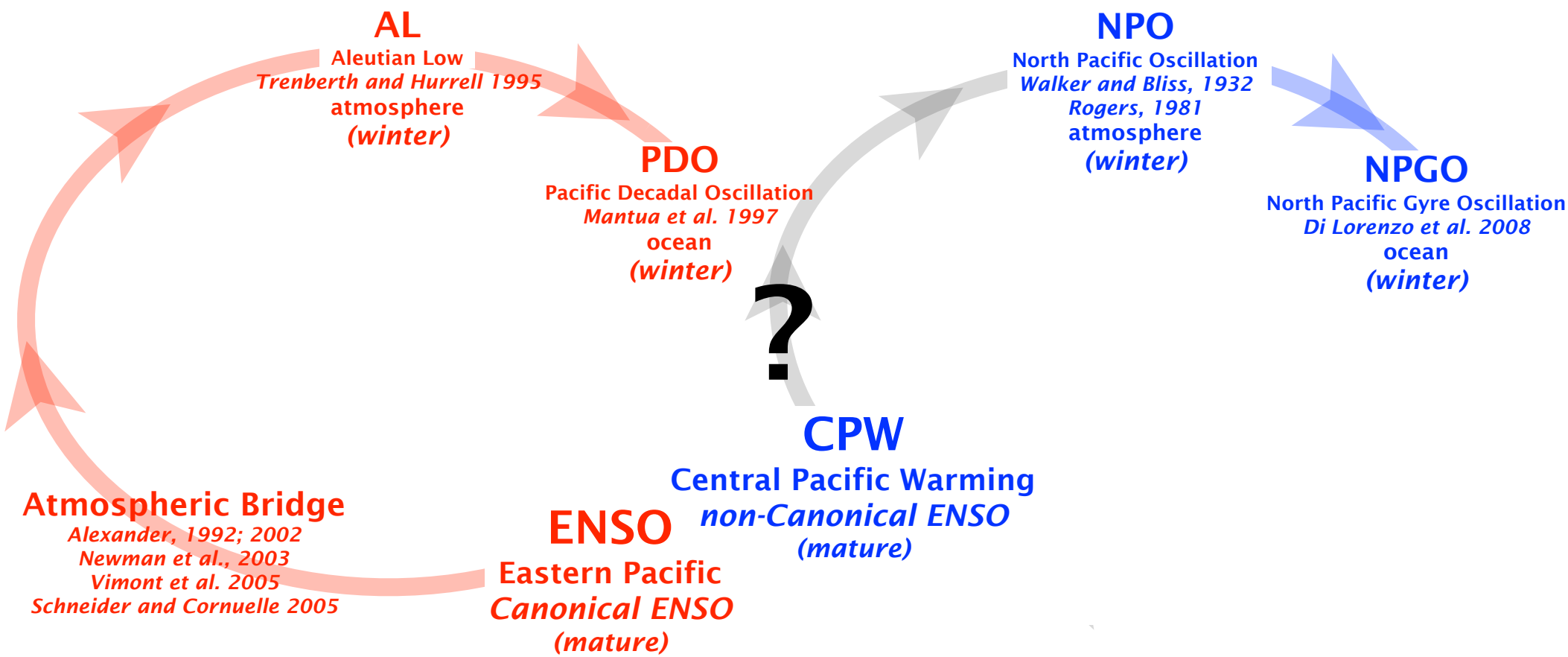
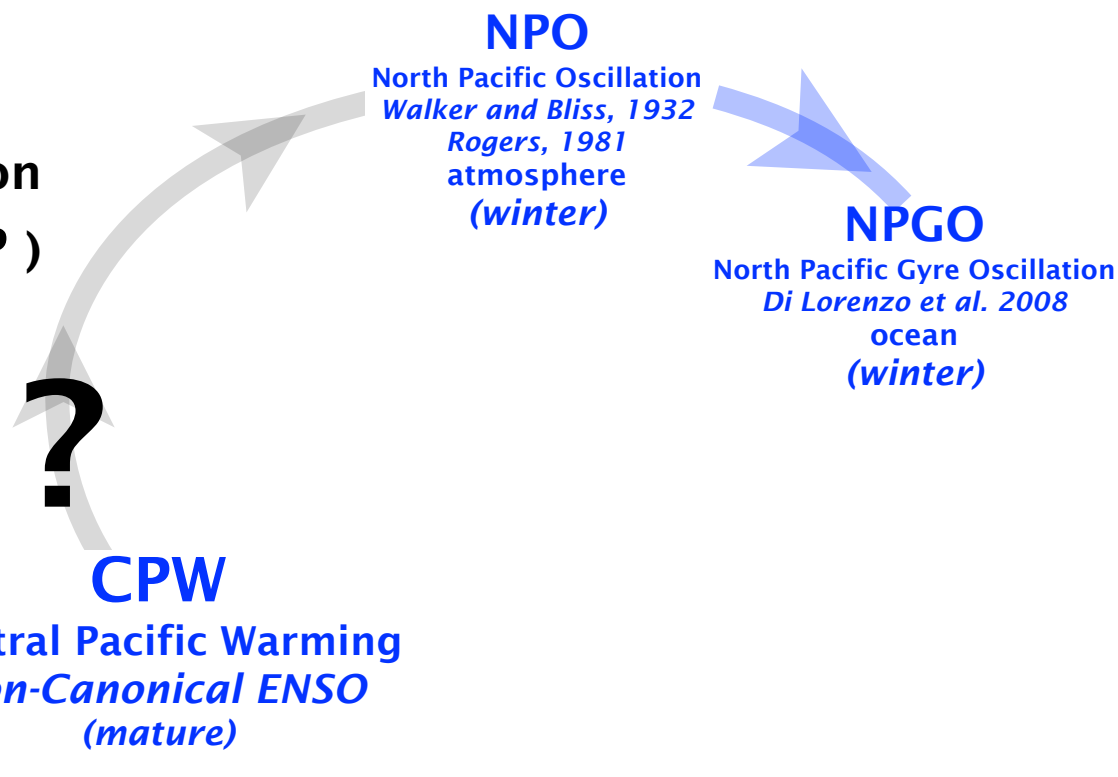


Questions:

Is NPGO the decadal expression of CPW?

Atmospheric General Circulation Model (AGCM-ICTP)



Atmospheric General Circulation Model (AGCM-ICTP)

NPO
North Pacific Oscillation
Walker and Bliss, 1932
Rogers, 1981
atmosphere
(winter)

NPGO
North Pacific Gyre Oscillation
Di Lorenzo et al. 2008
ocean
(winter)

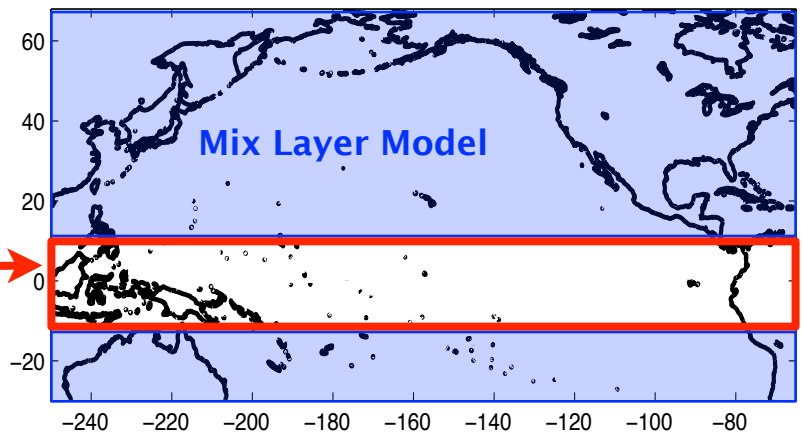
?

CPW
Central Pacific Warming
non-Canonical ENSO
(mature)

Forcing:

Time dependent SSTa 1950-2008 in the tropics [12S - 12N]

Forcing



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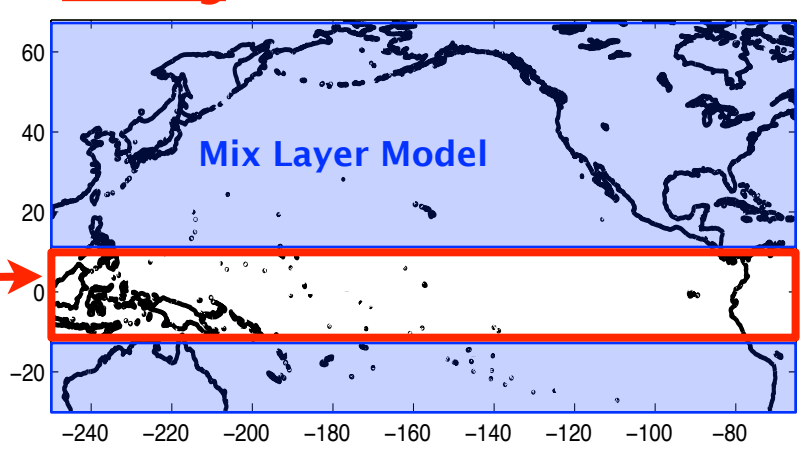
Forcing cycle is repeated 40 times to generate an ensemble

Forcing



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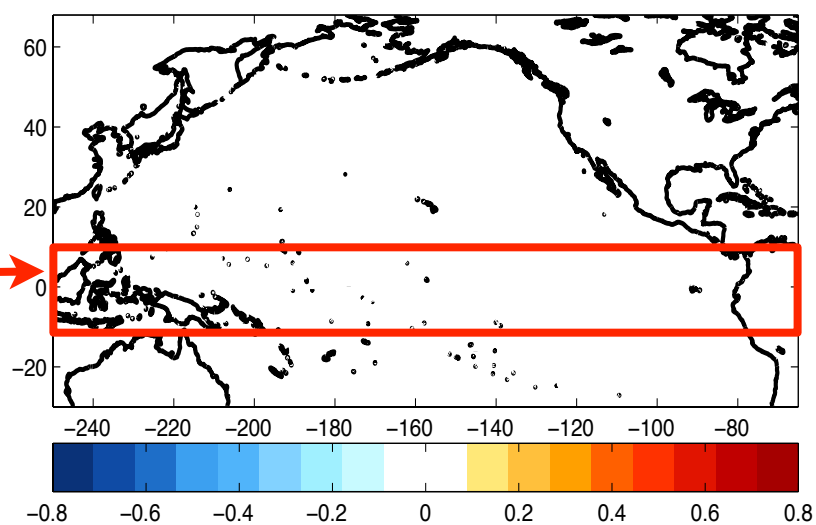

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NPO SSTa Forcing pattern

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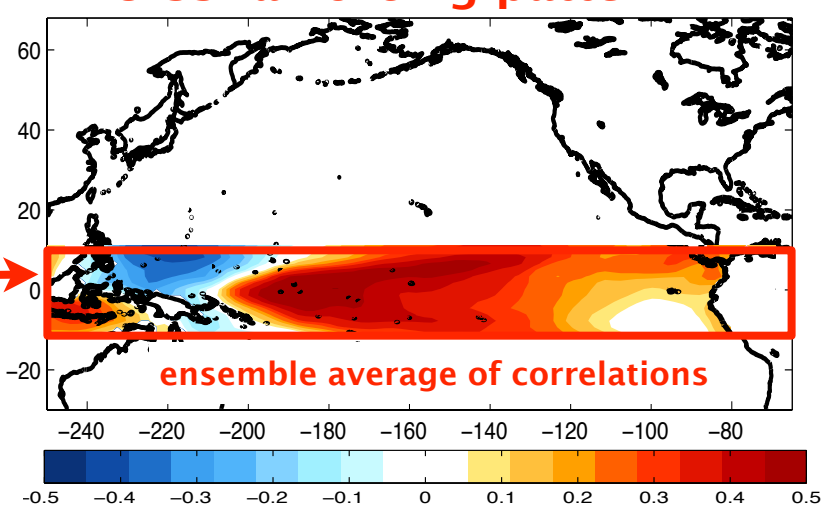

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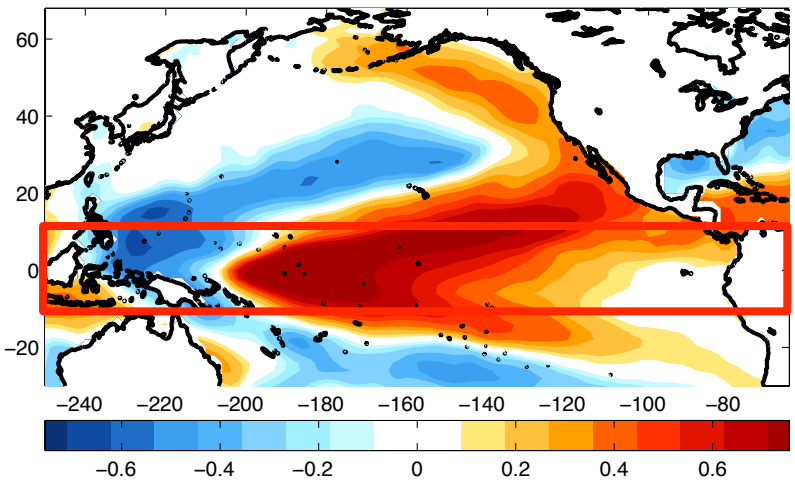
CPW *Non*-Canonical ENSO



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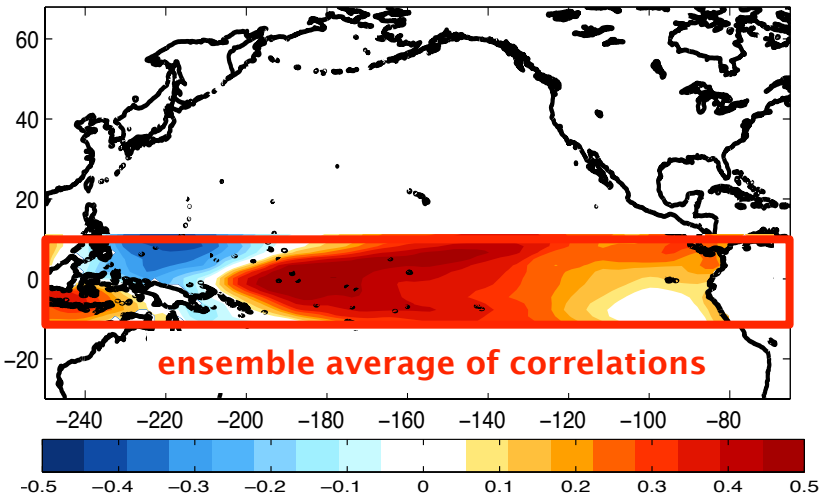

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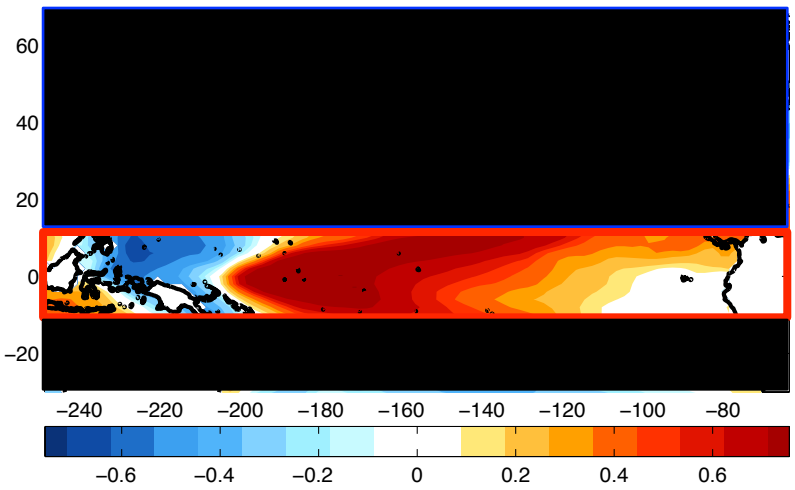

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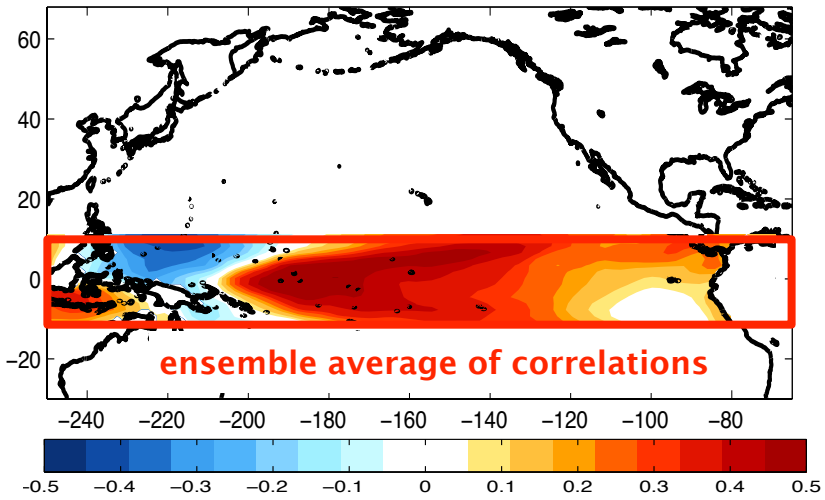

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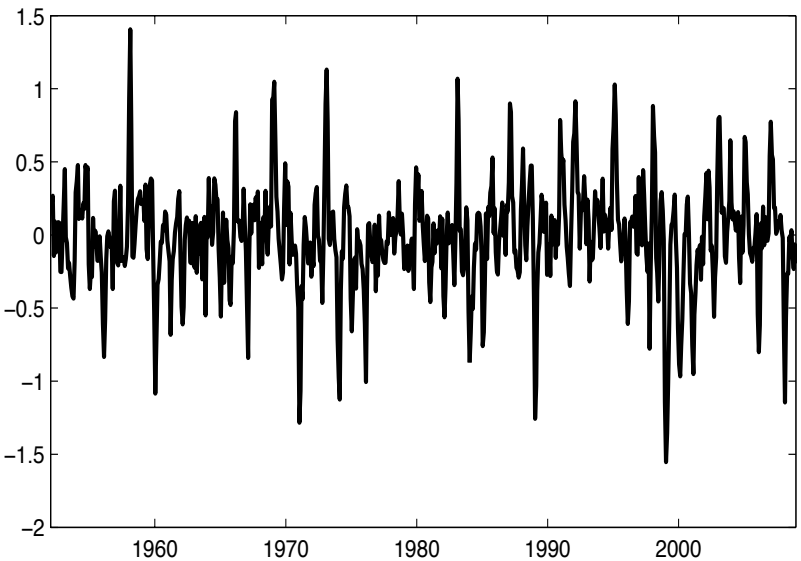

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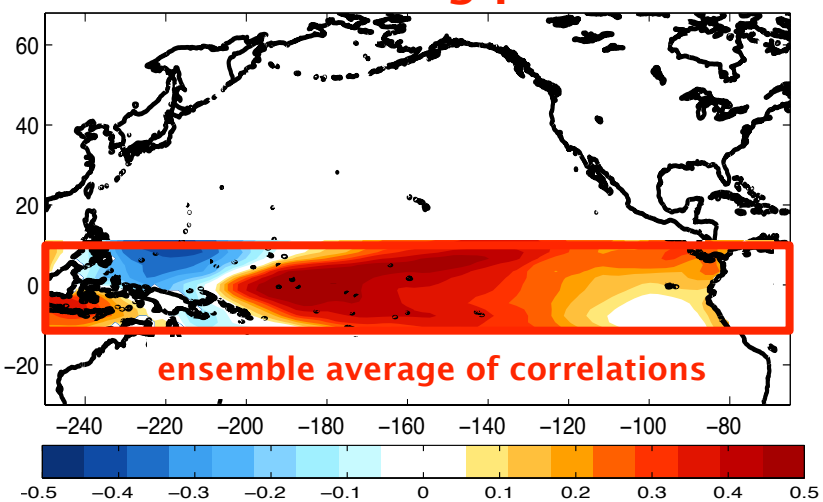

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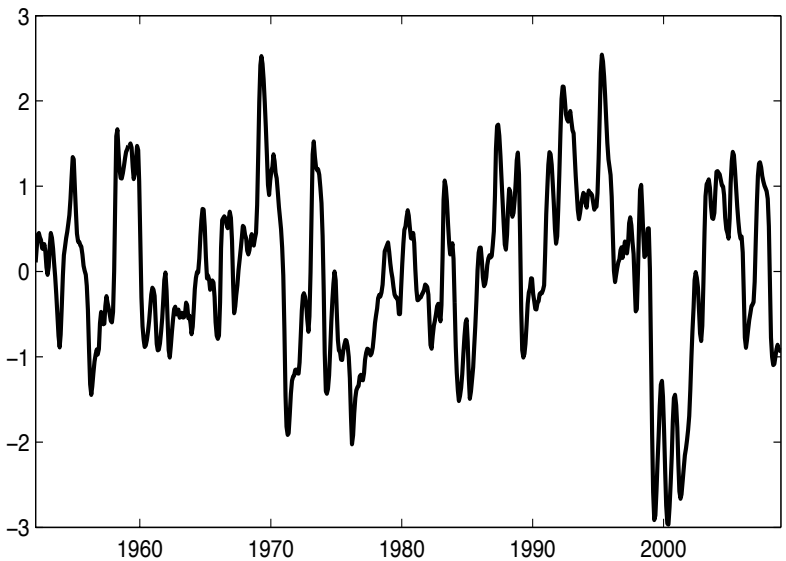
Integrated NPO Index ensemble average



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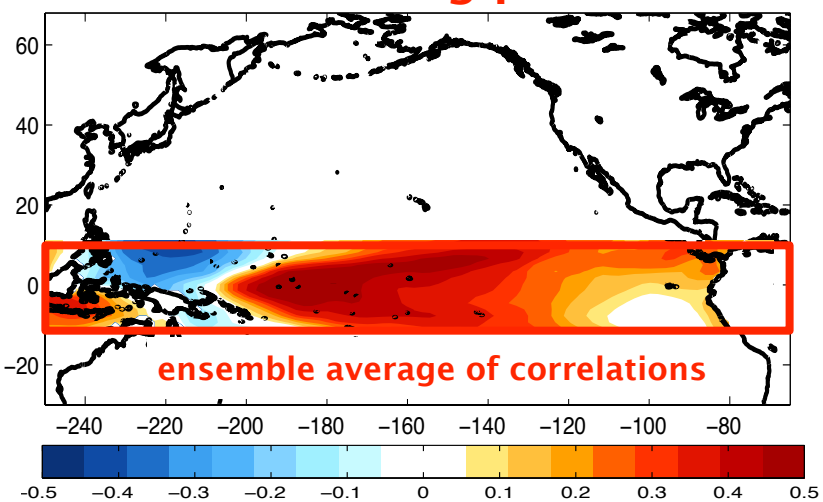

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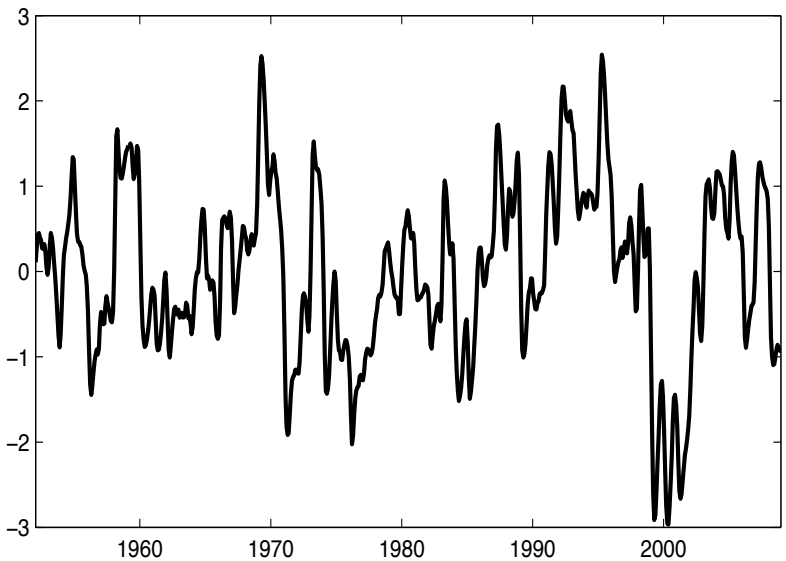
Reconstructed NGPO Index ensemble average



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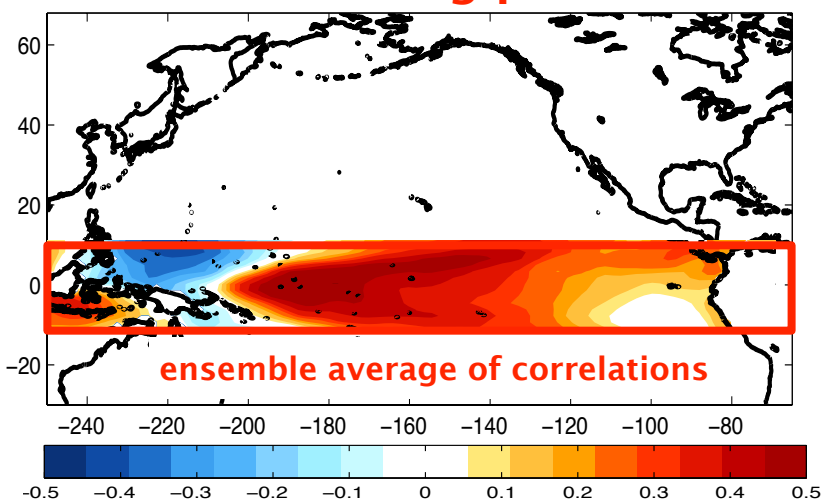

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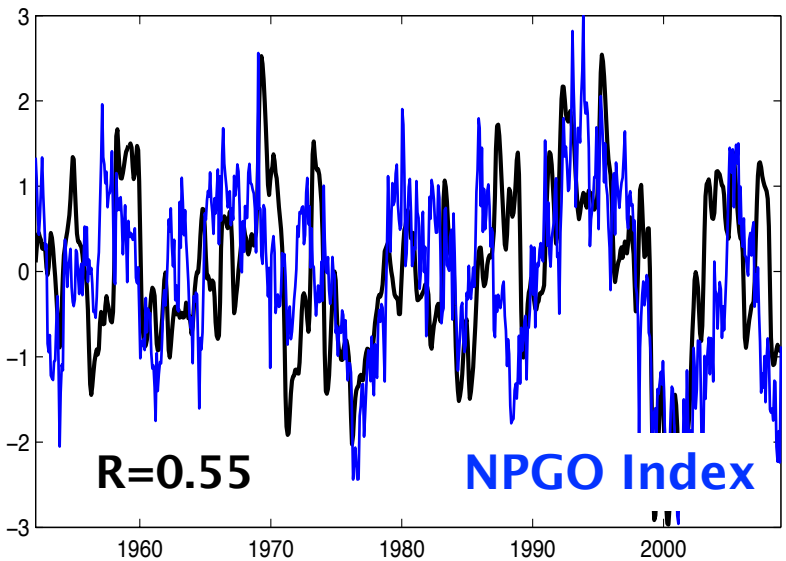

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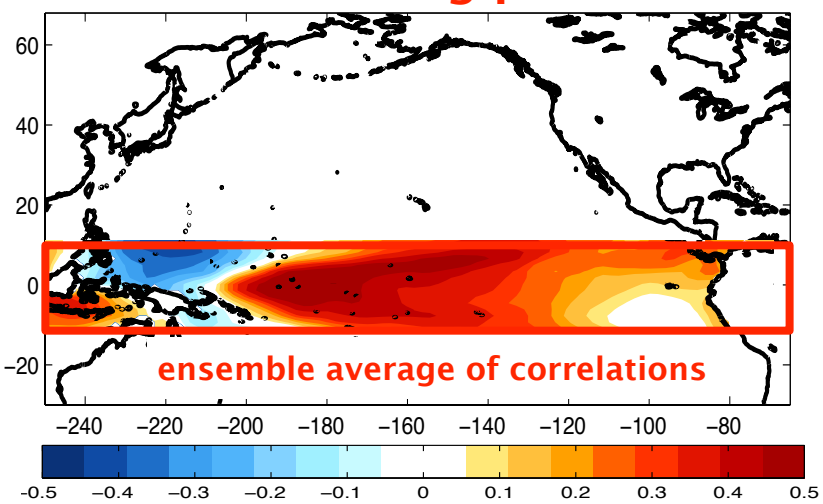

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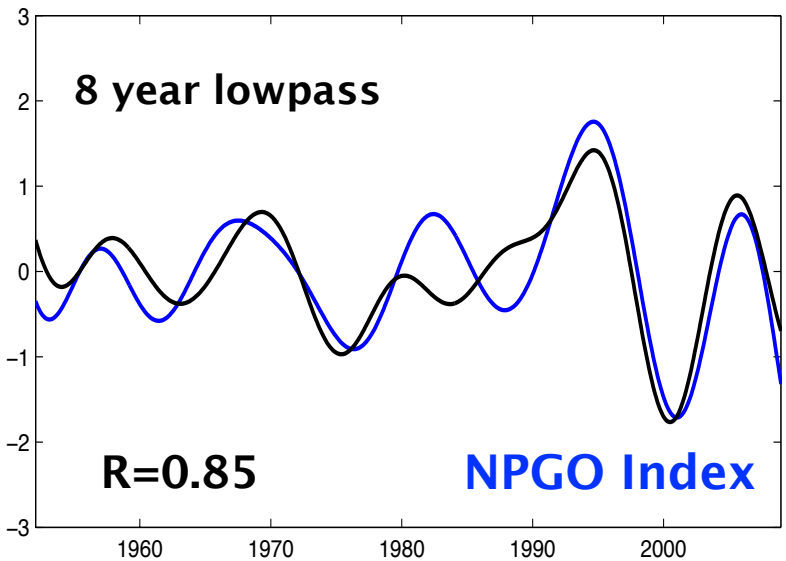

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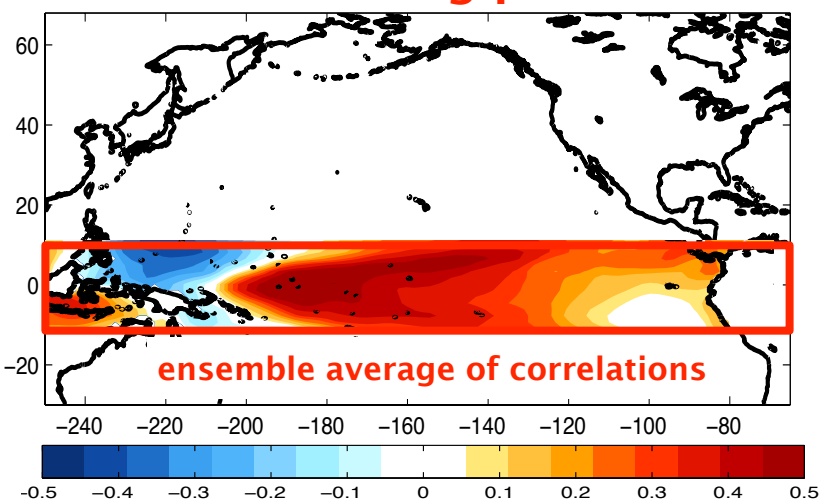
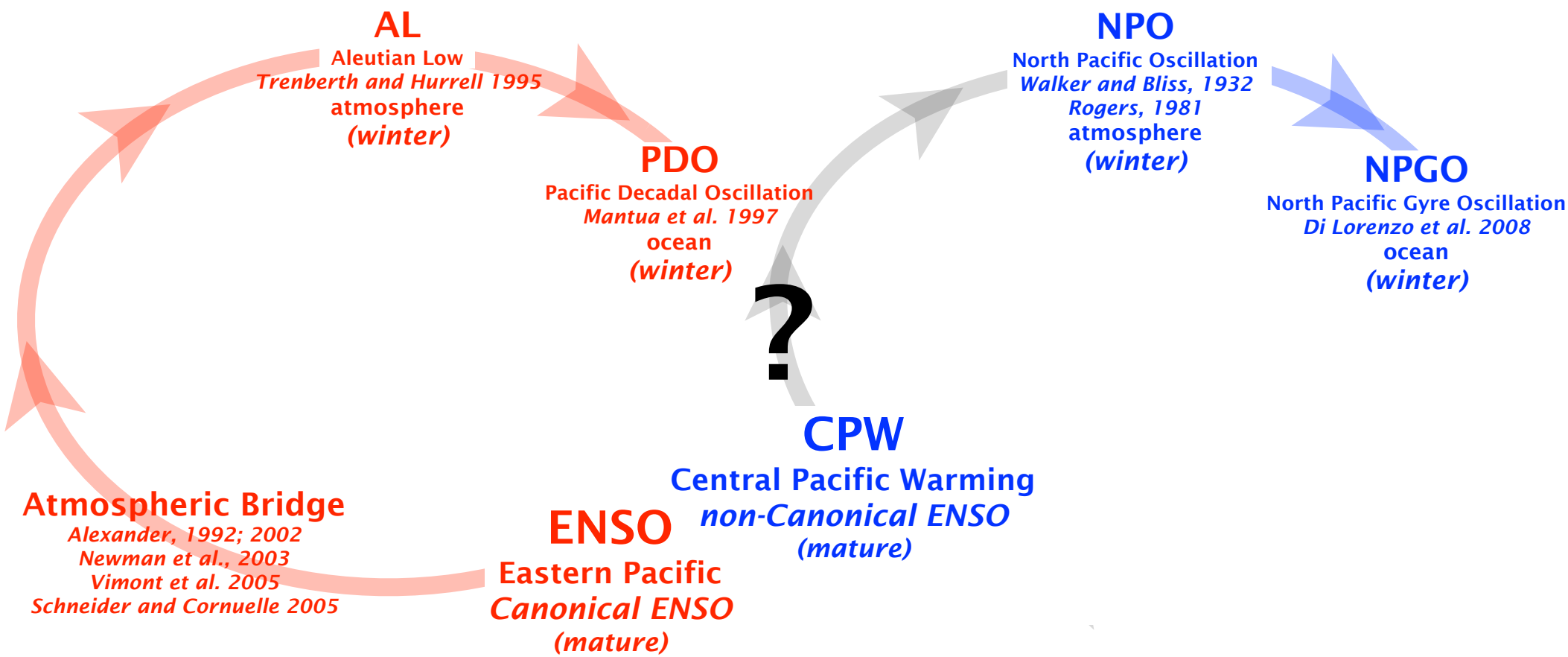


Model for explaining Pacific decadal dynamics



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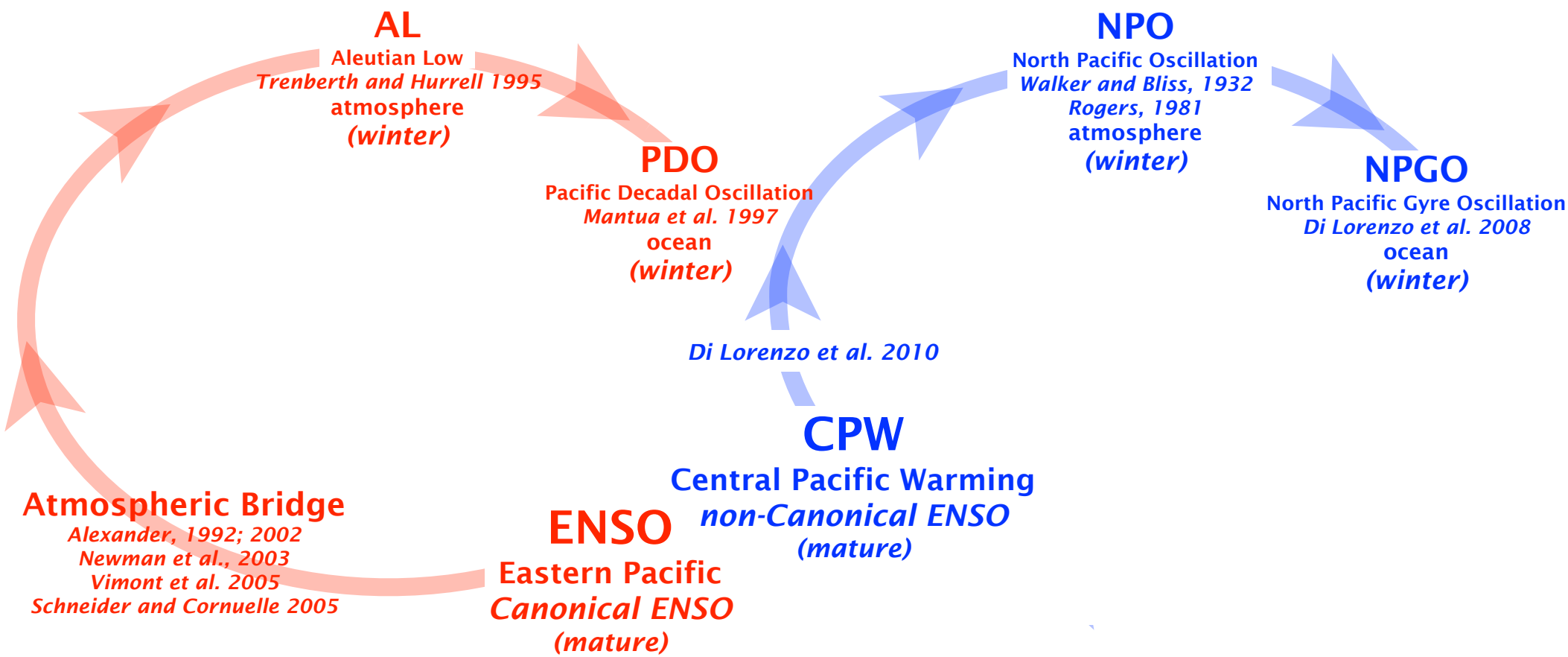

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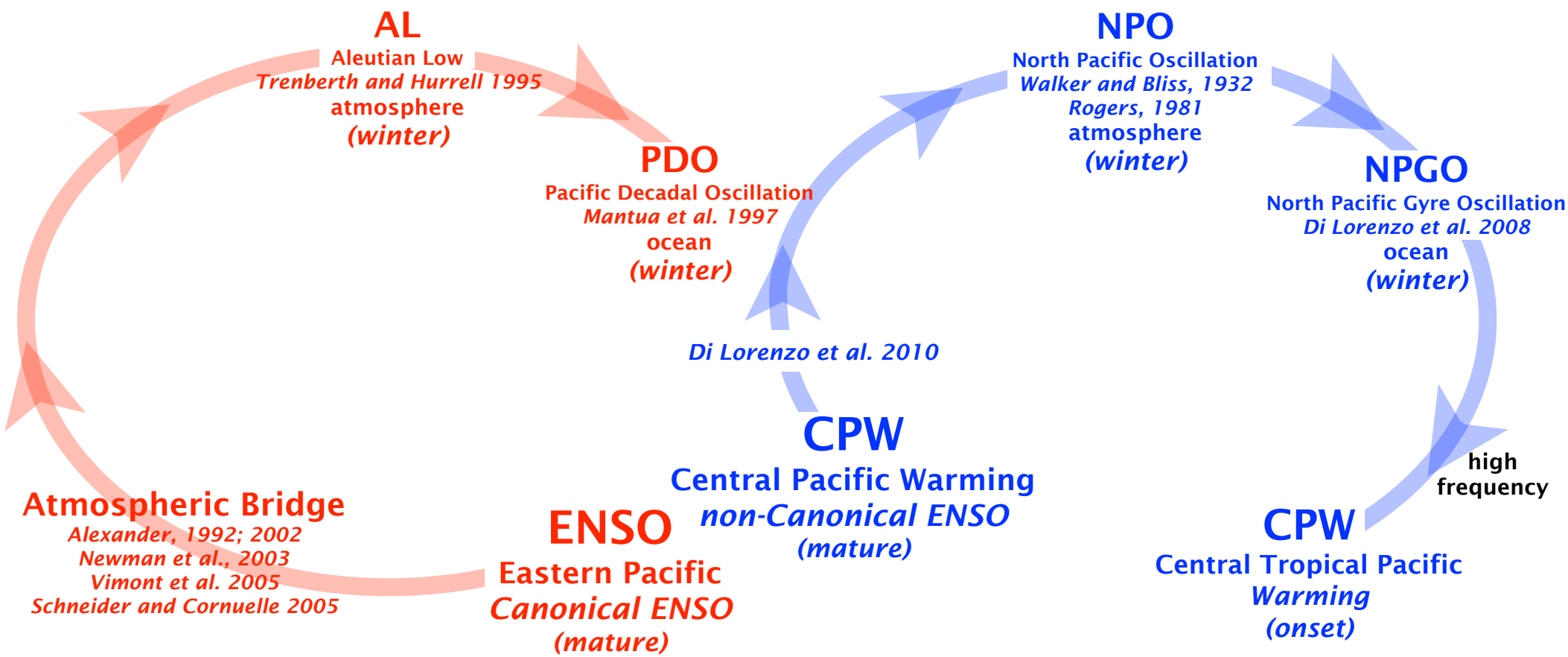

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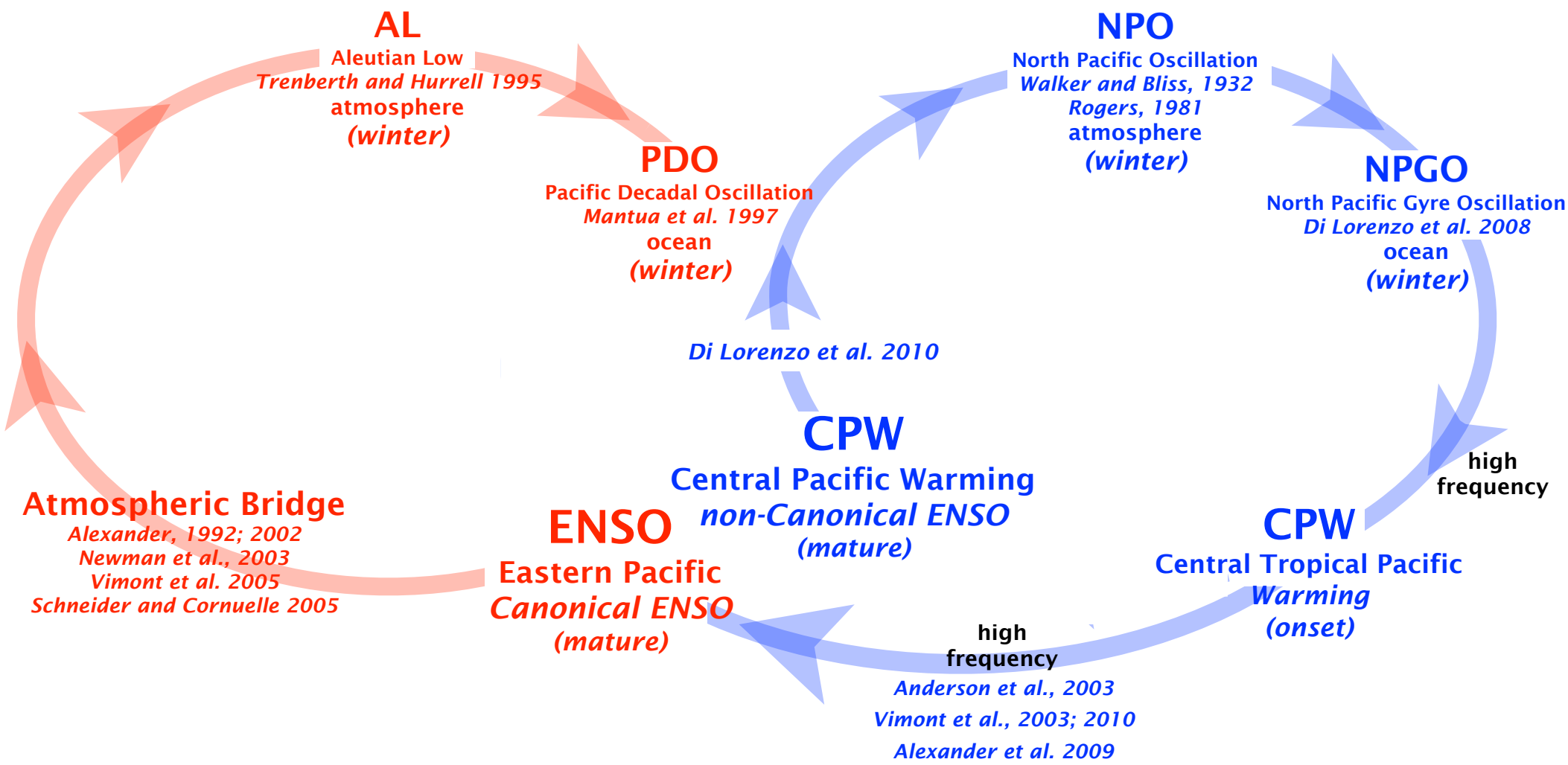

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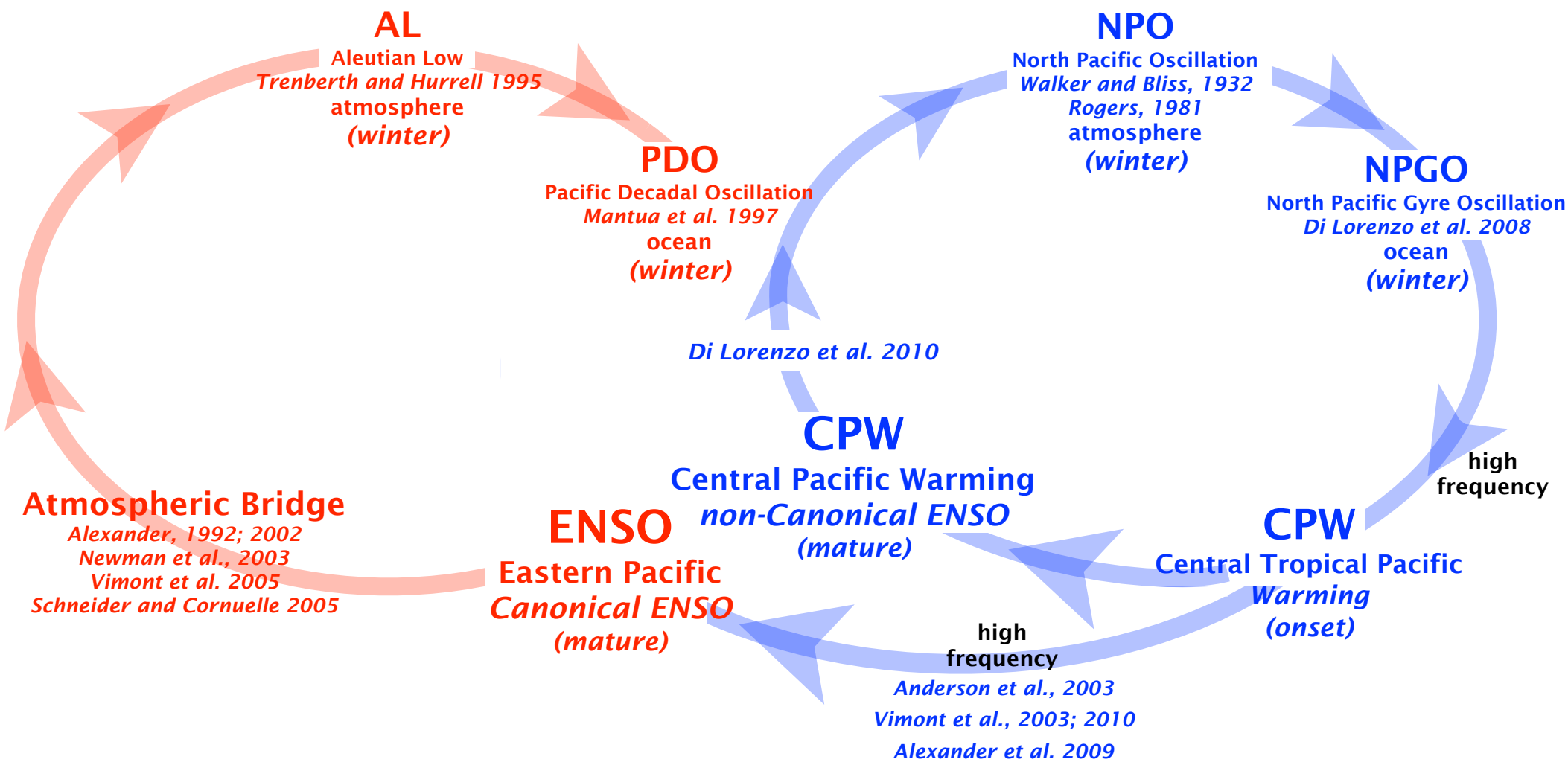

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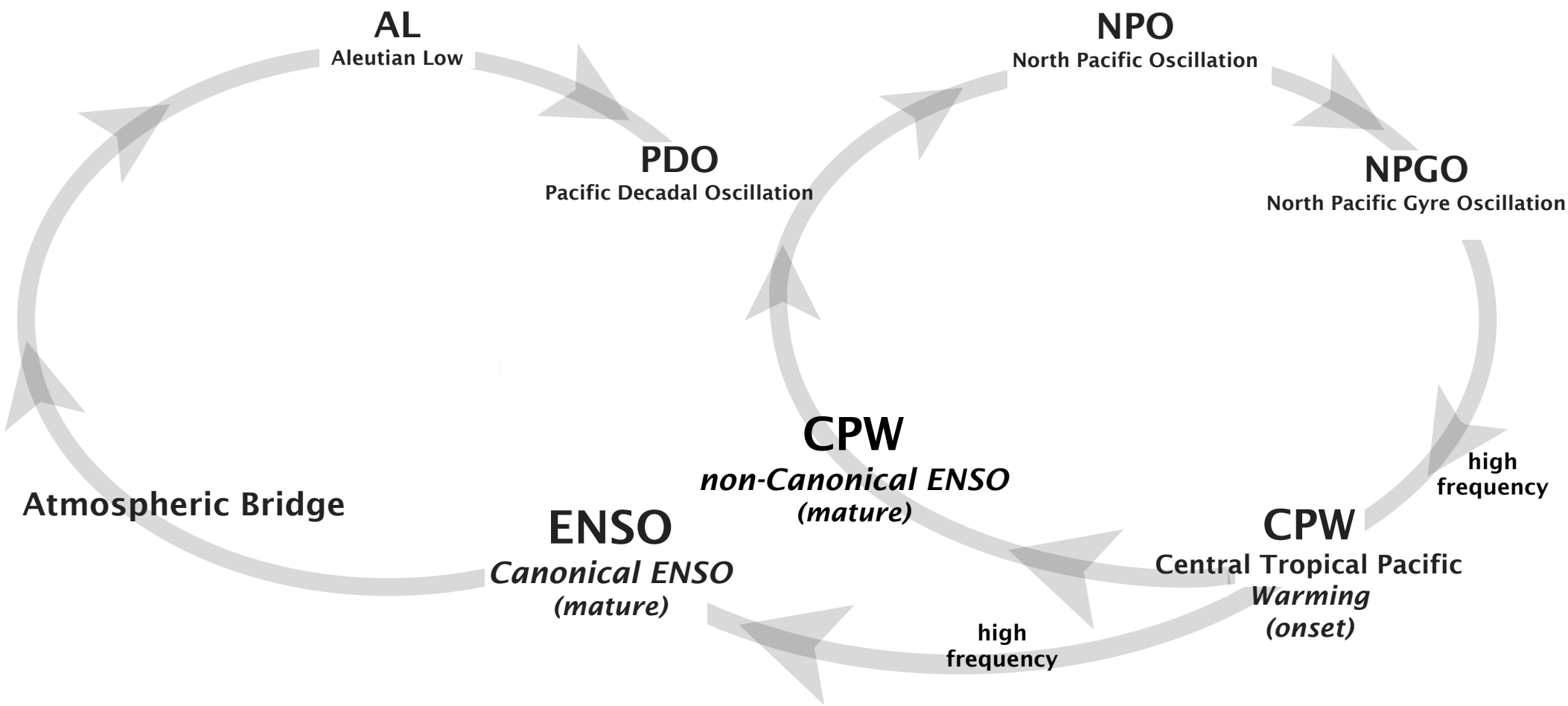
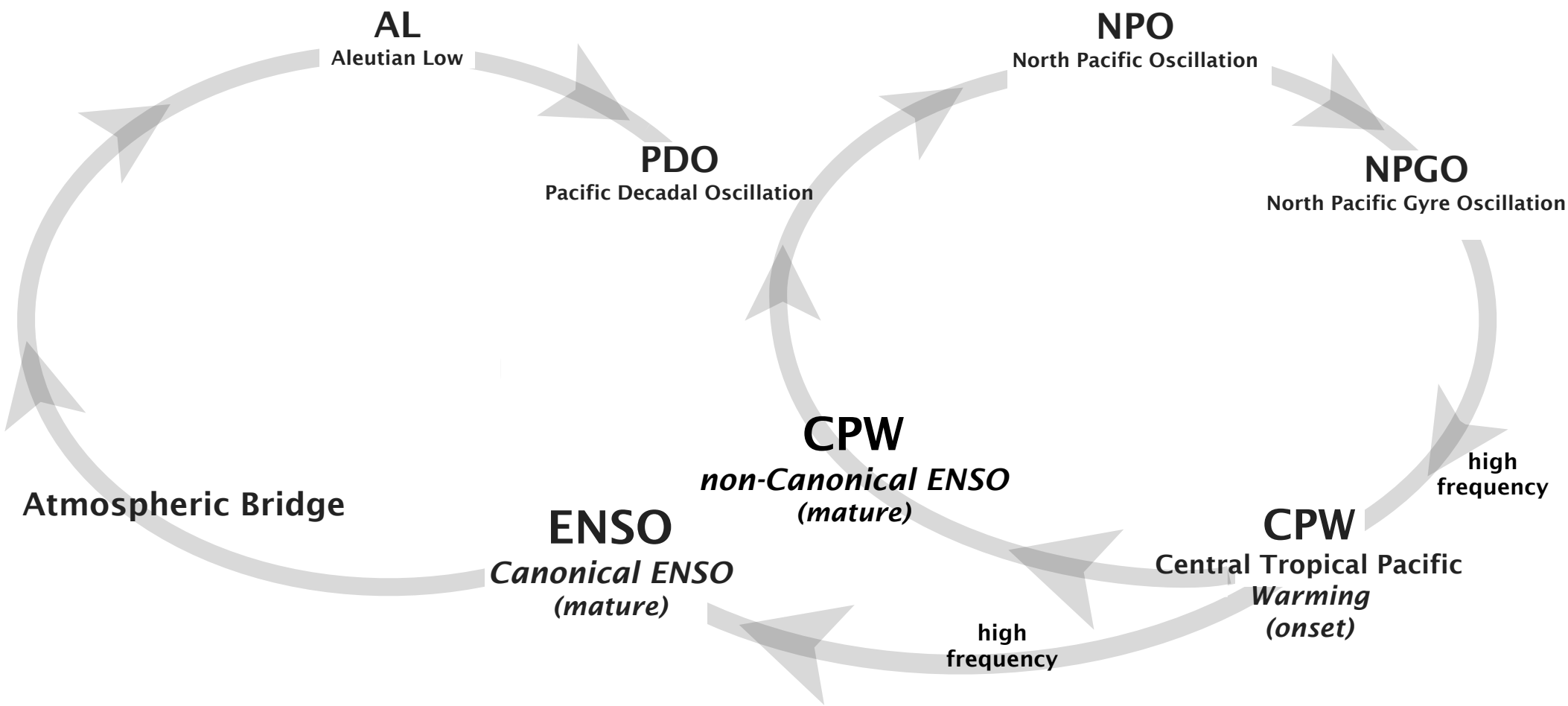


QUESTION:

How do AR4 models capture these Pacific decadal modes and their connections in the control simulations (1800-2000) ?

Test the AR4 models Pacific decadal dynamics 1800-2000



Furtado et al., 2011

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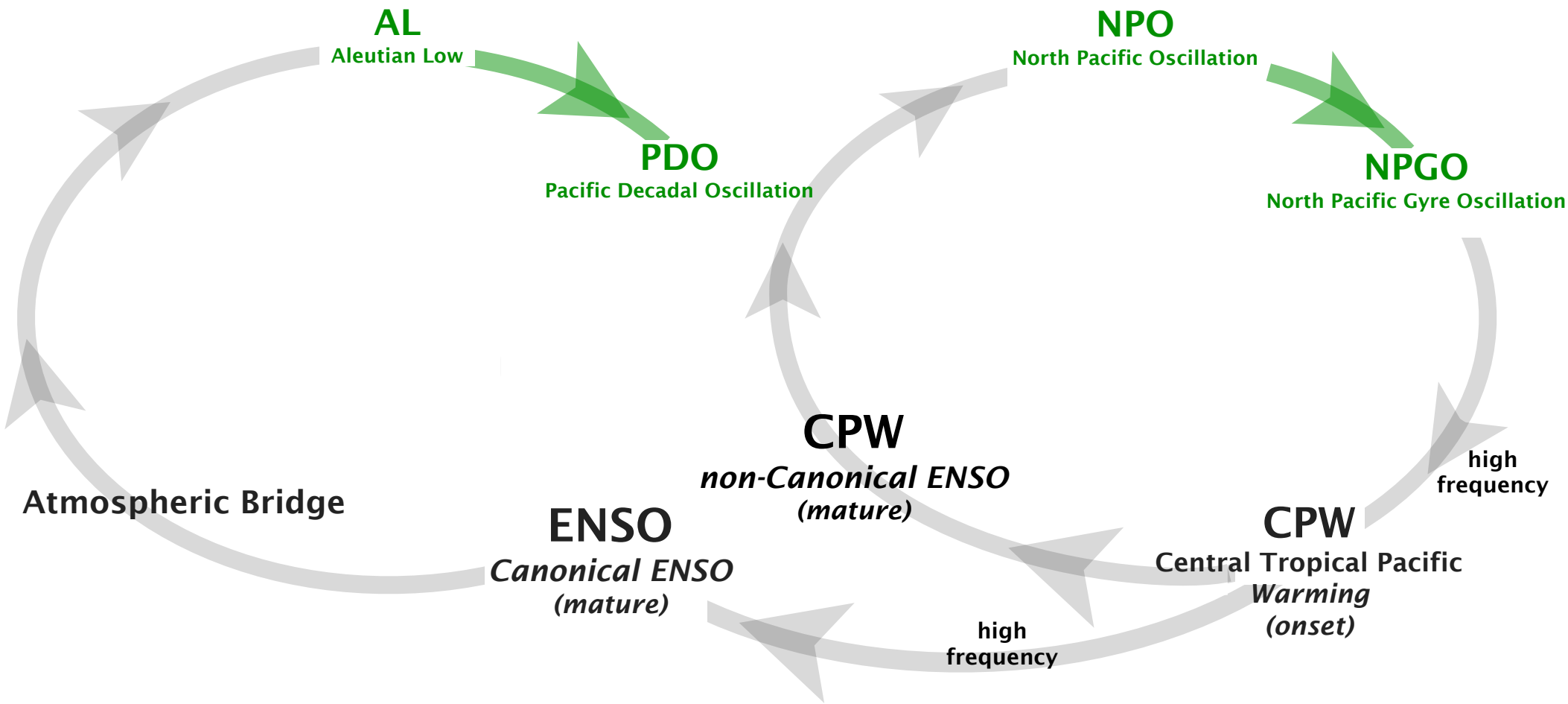

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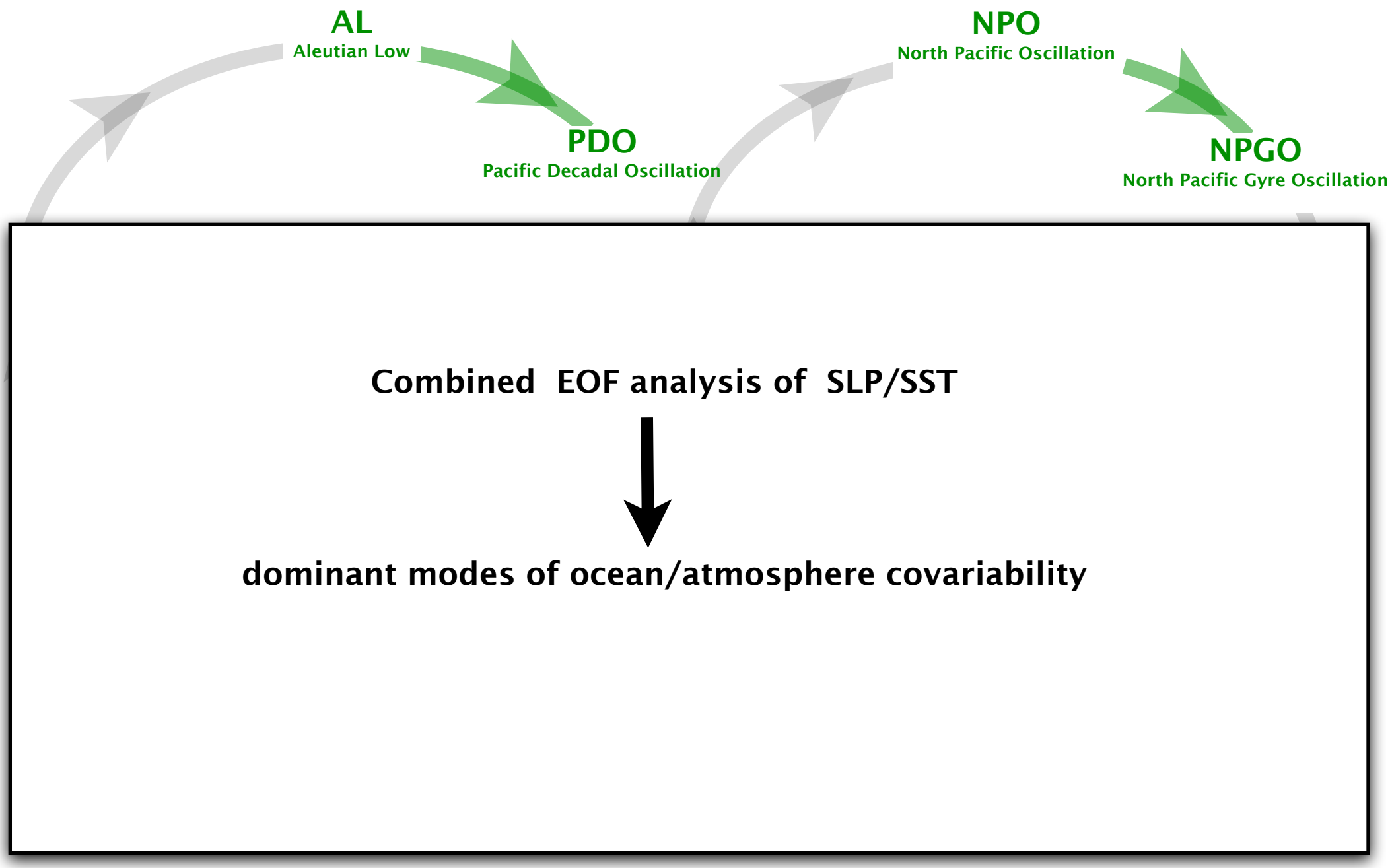

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Test the AR4 models Pacific decadal dynamics 1800-2000

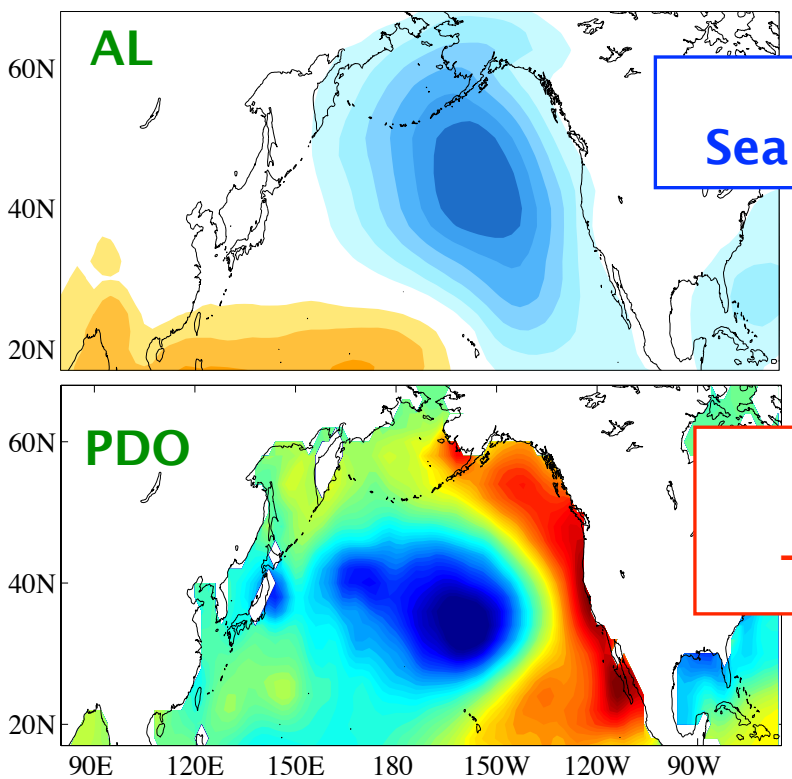
AL
Aleutian Low

PDO
Pacific Decadal Oscillation

NPO
North Pacific Oscillation

NPGO
North Pacific Gyre Oscillation

Observations



Atmosphere
Sea Level Pressure

Ocean
Sea Surface Temperature

Ocean/Atmosphere Combined EOF Mode 1

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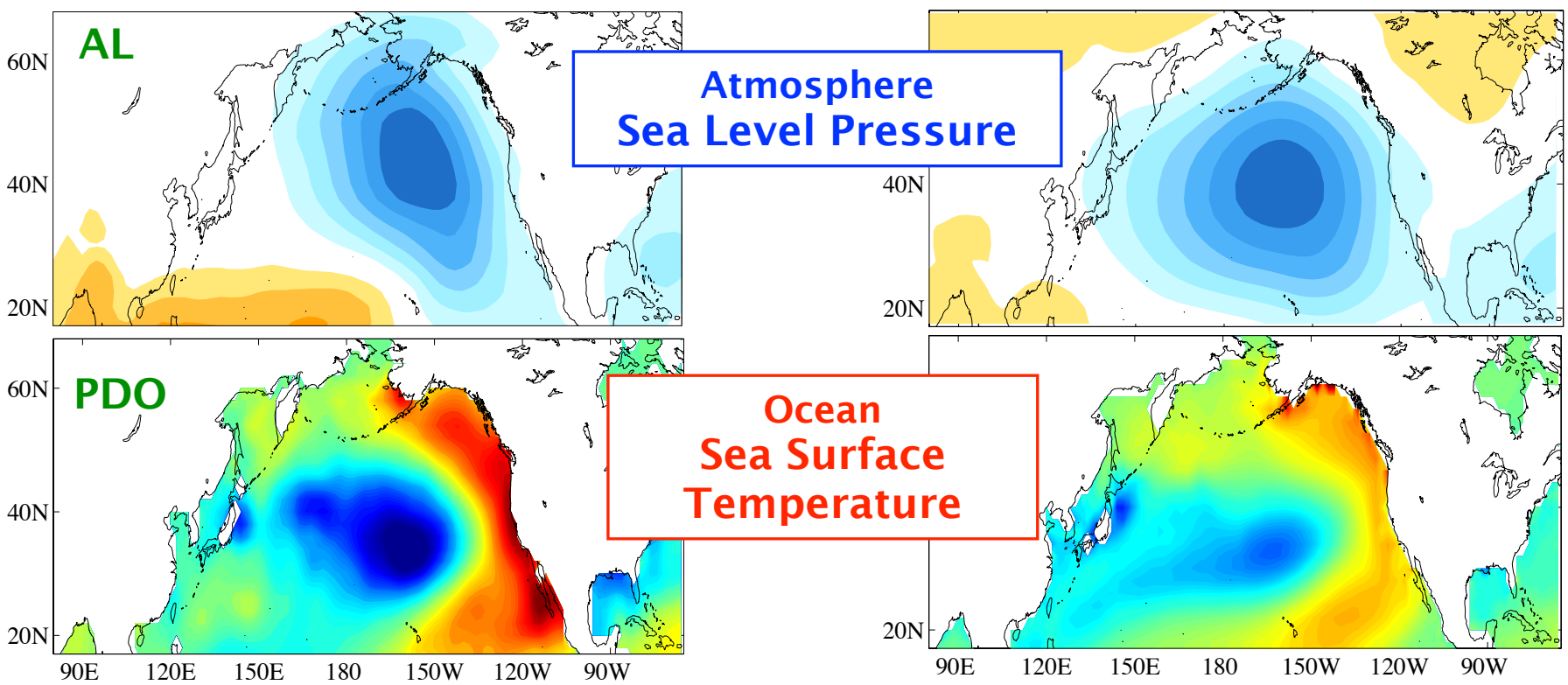
AR4 Models (Ensemble Mean)



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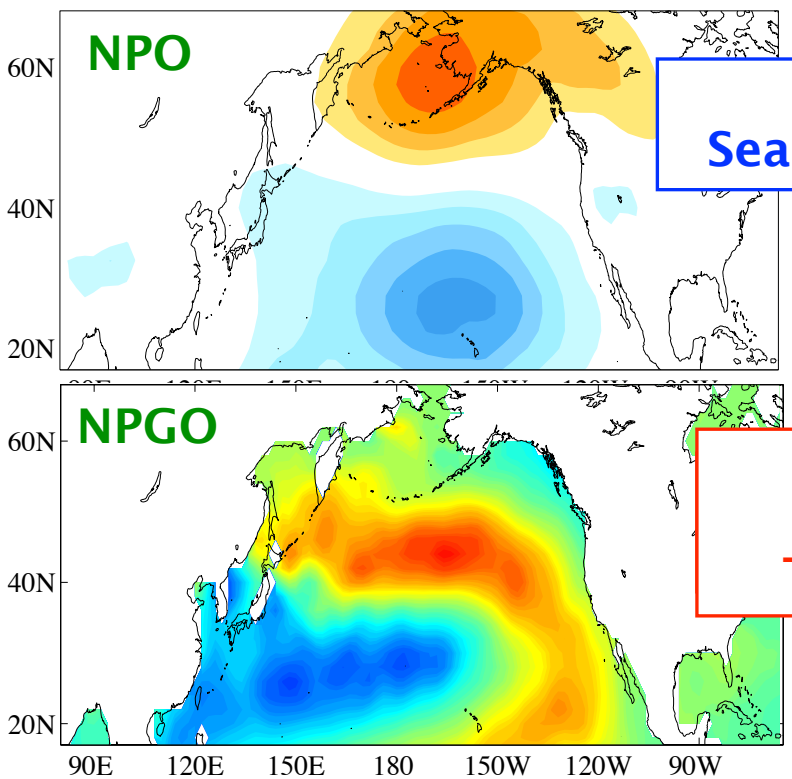

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Furtado et al., 2011

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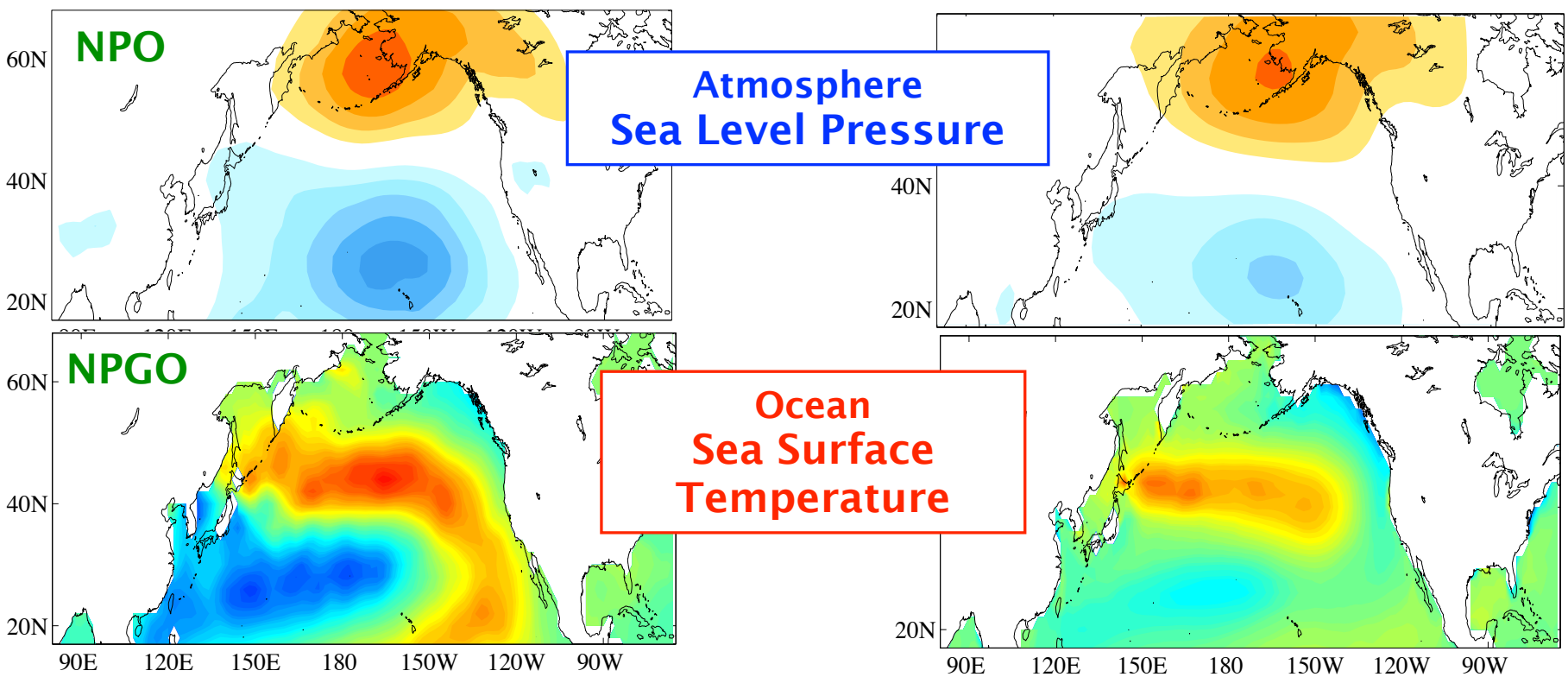
Observations

AR4 Models (Ensemble Mean)



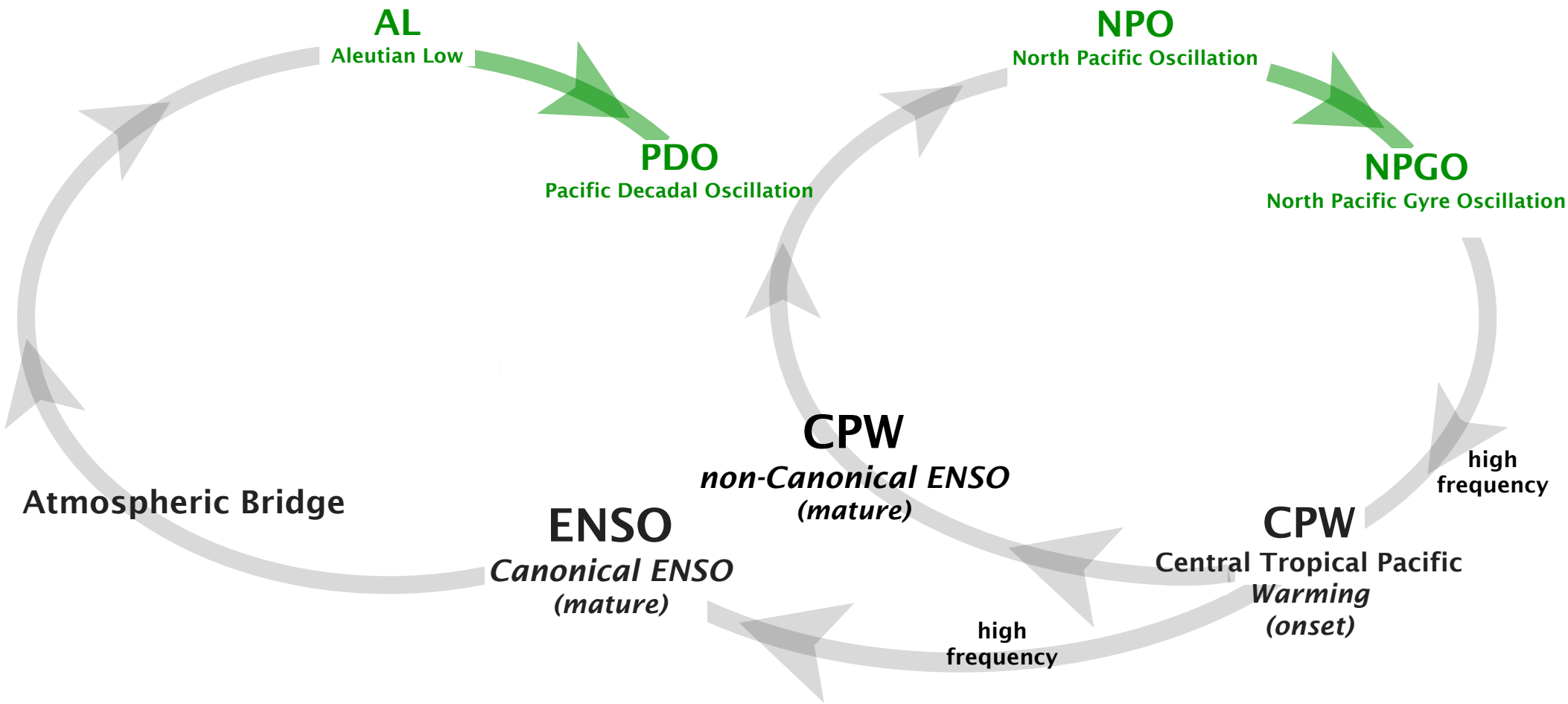
Atmosphere
Sea Level Pressure

Ocean
Sea Surface Temperature

Ocean/Atmosphere Combined EOF Mode 2

Furtado et al., 2011

Test the AR4 models Pacific decadal dynamics 1800-2000



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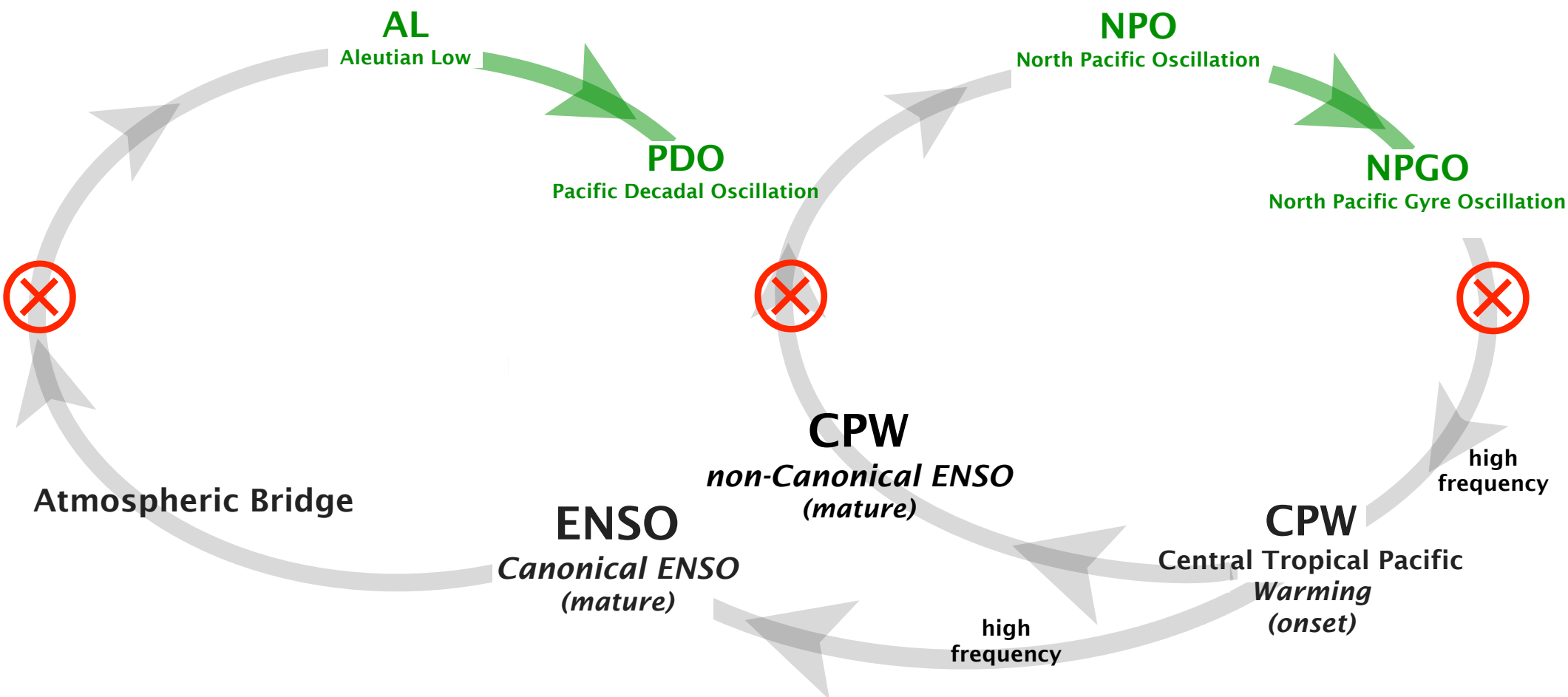

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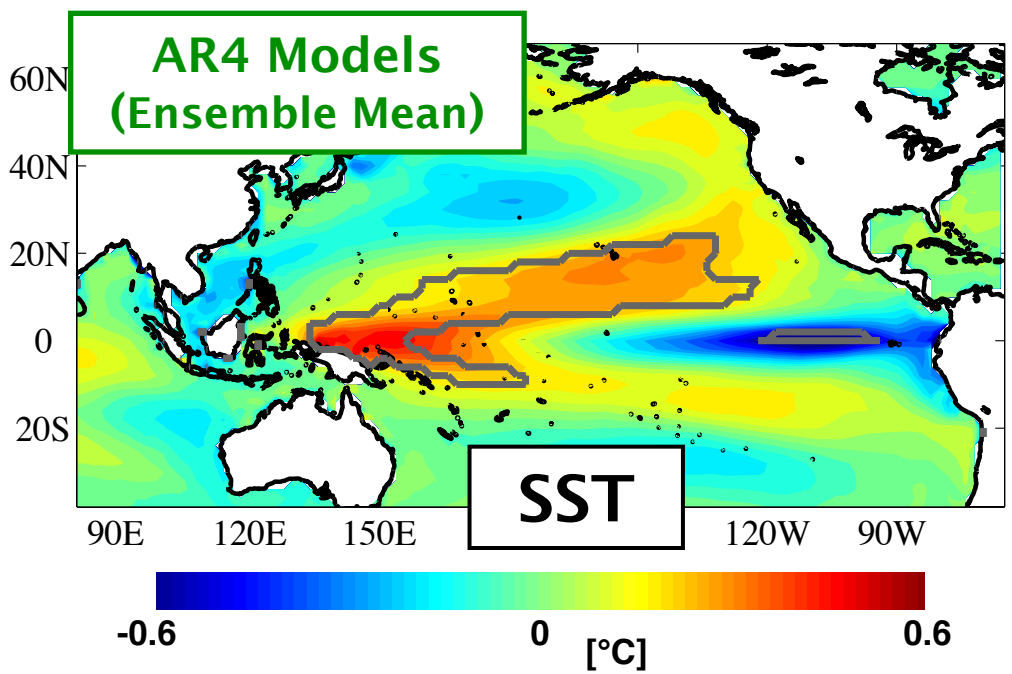

CPW pattern

emerges as

2nd mode

Tropics [12S 12N]

Ocean/Atmosphere Combined EOF Mode 2

Furtado et al., 2011

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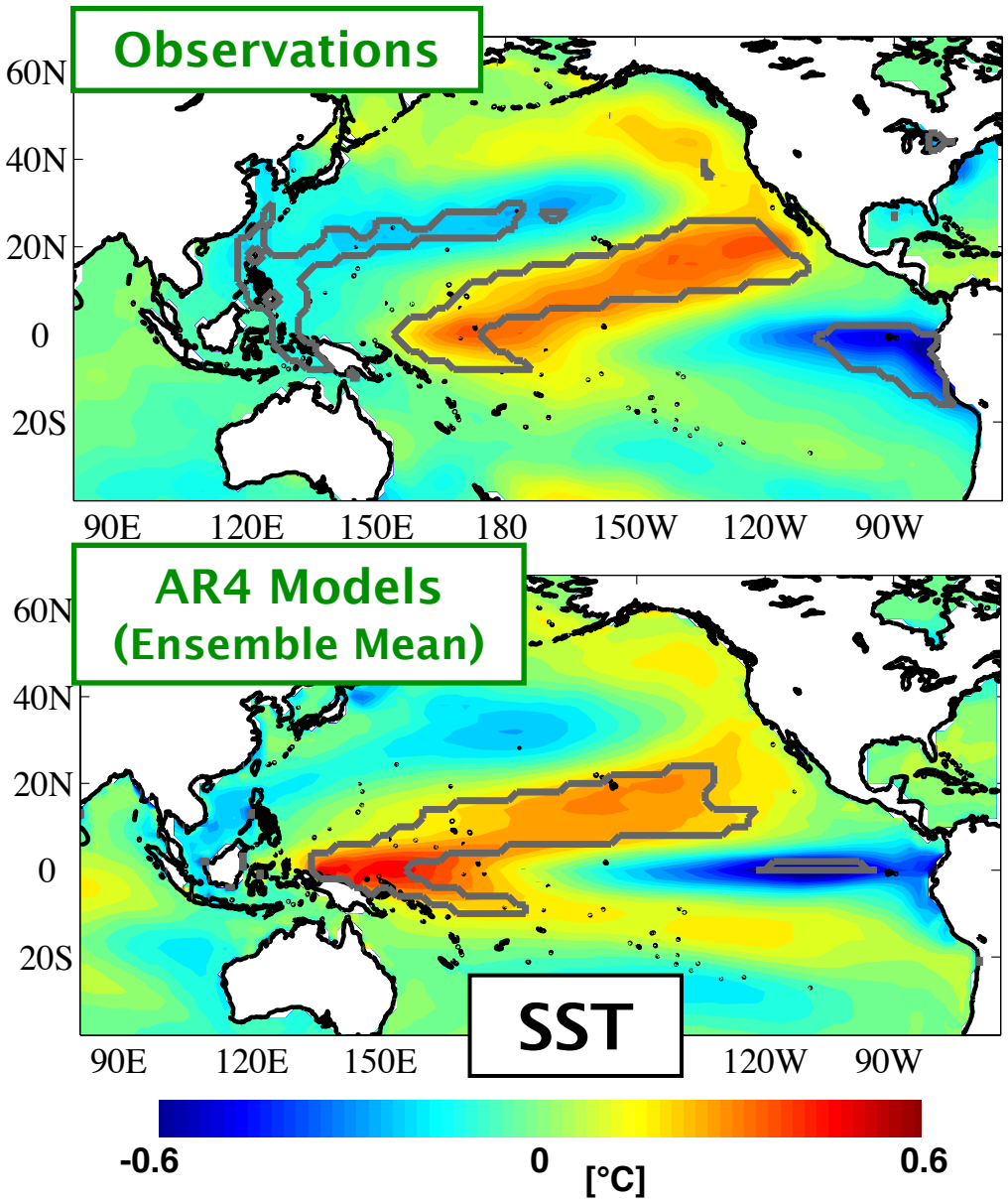

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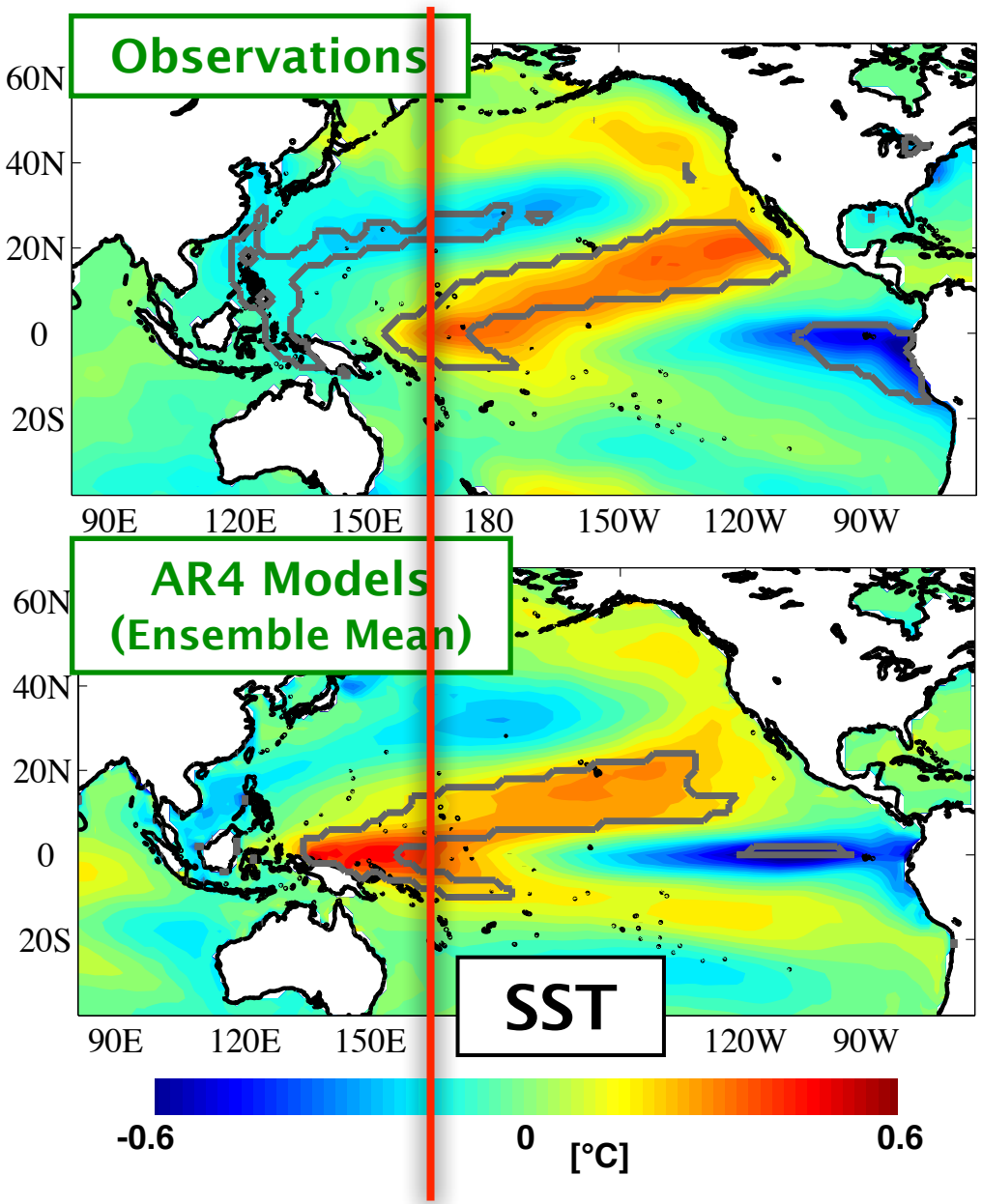

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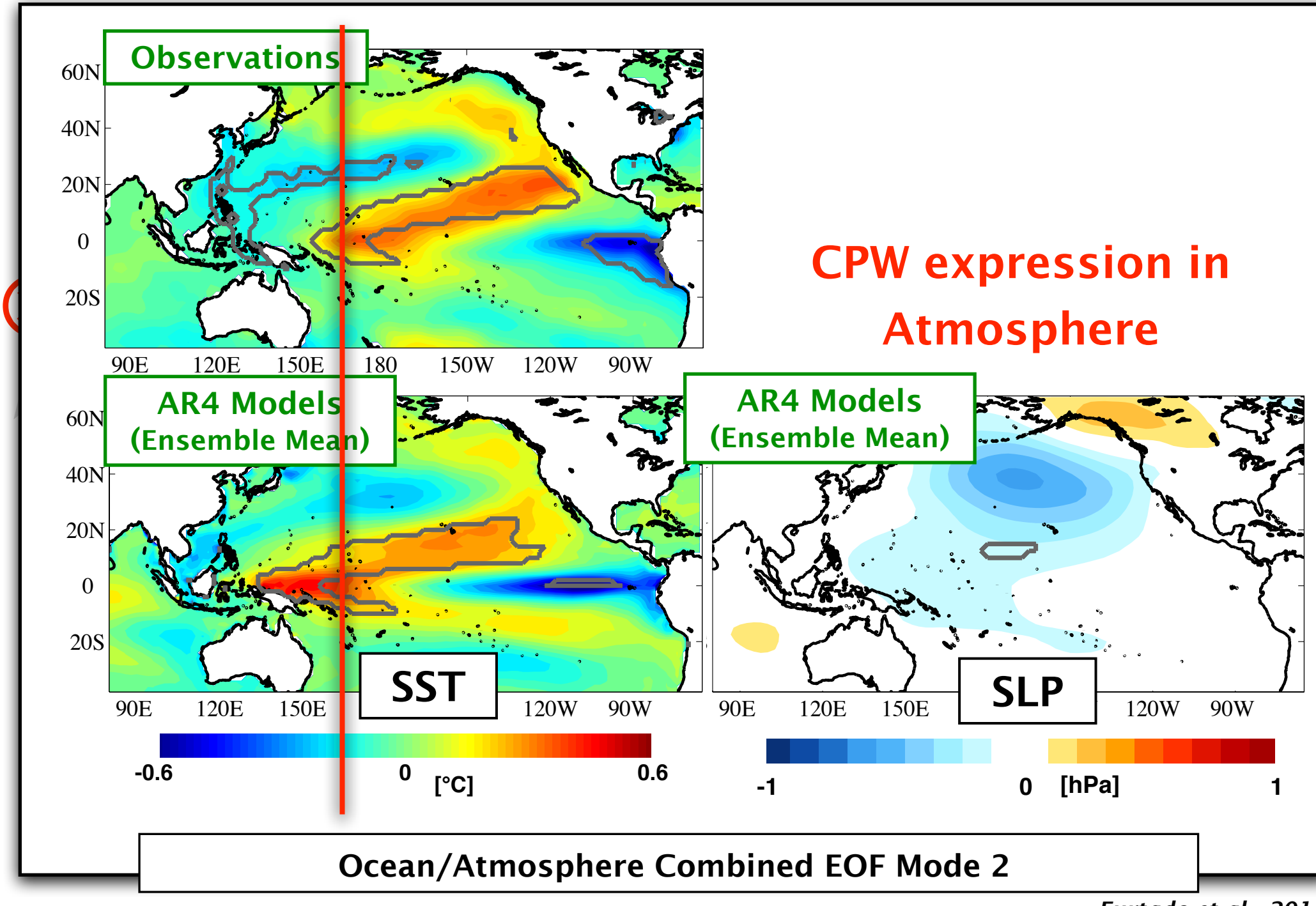

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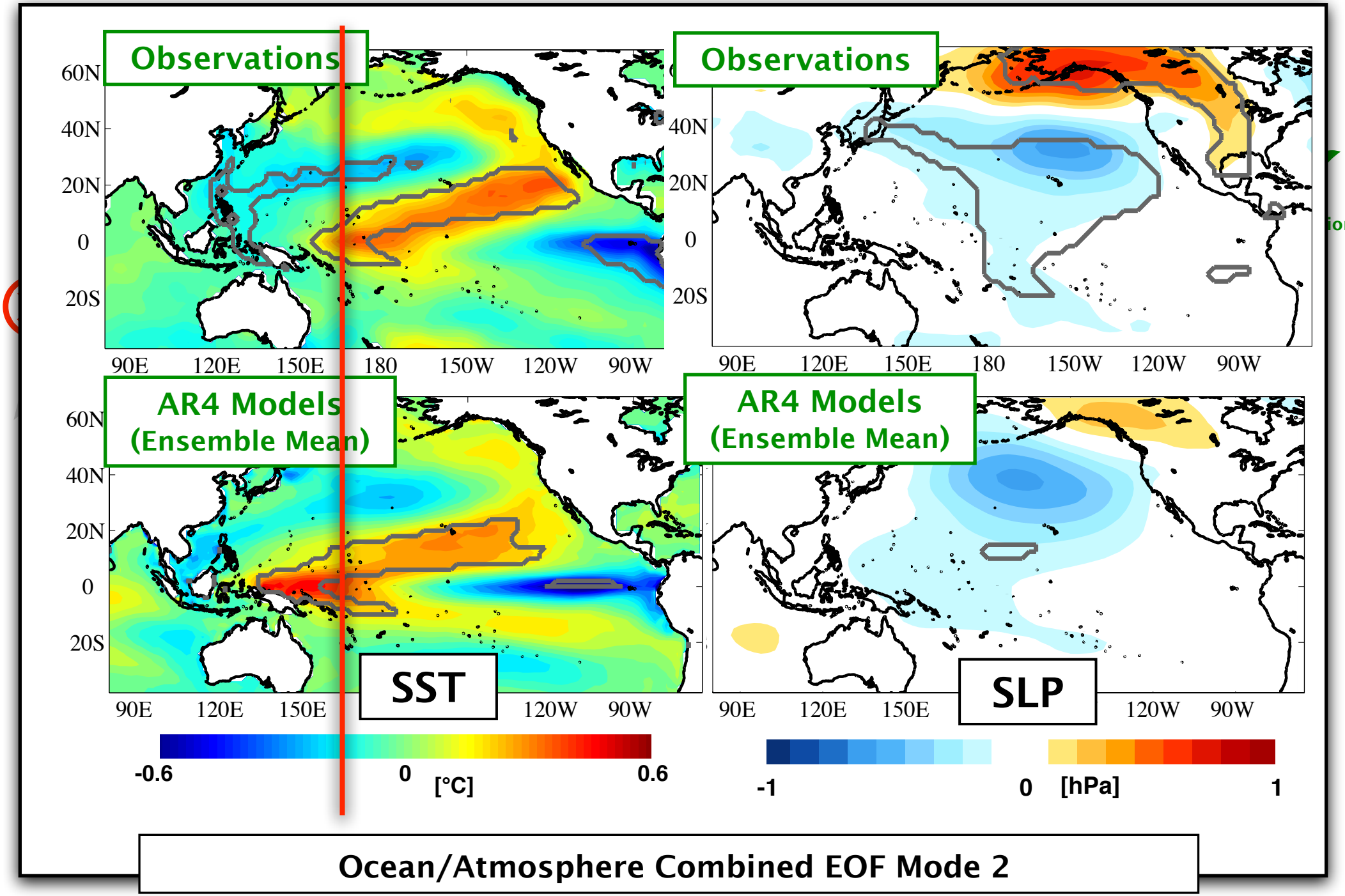

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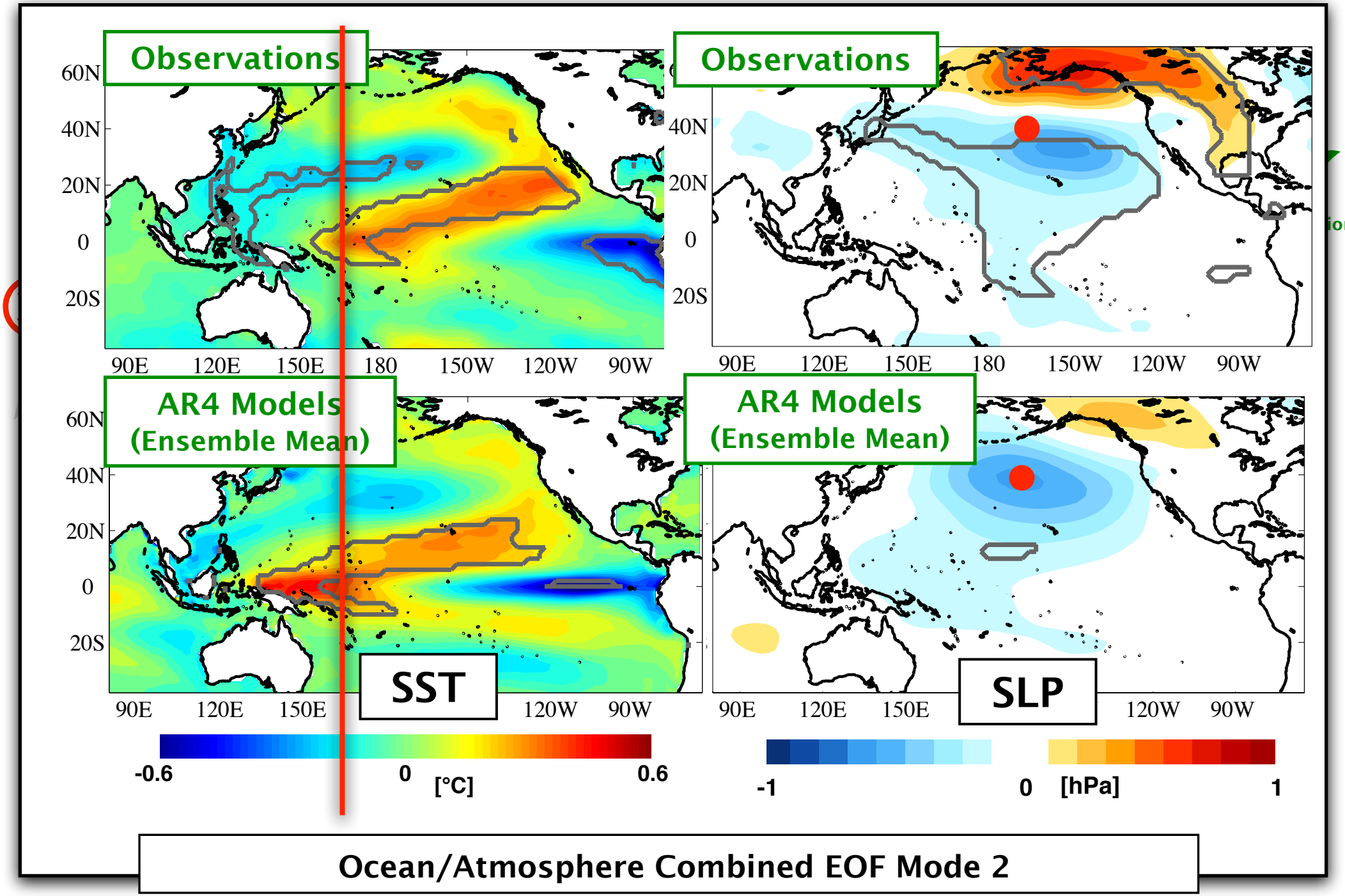

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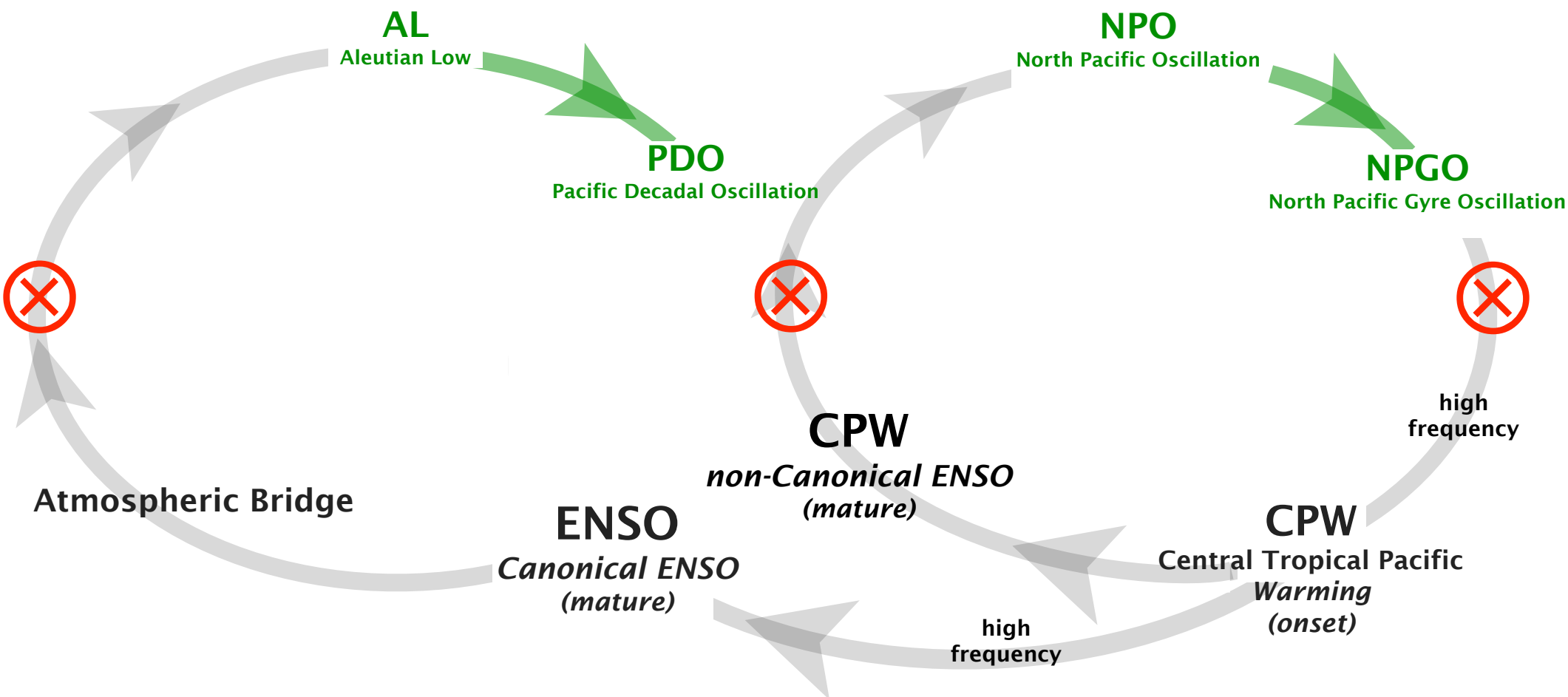

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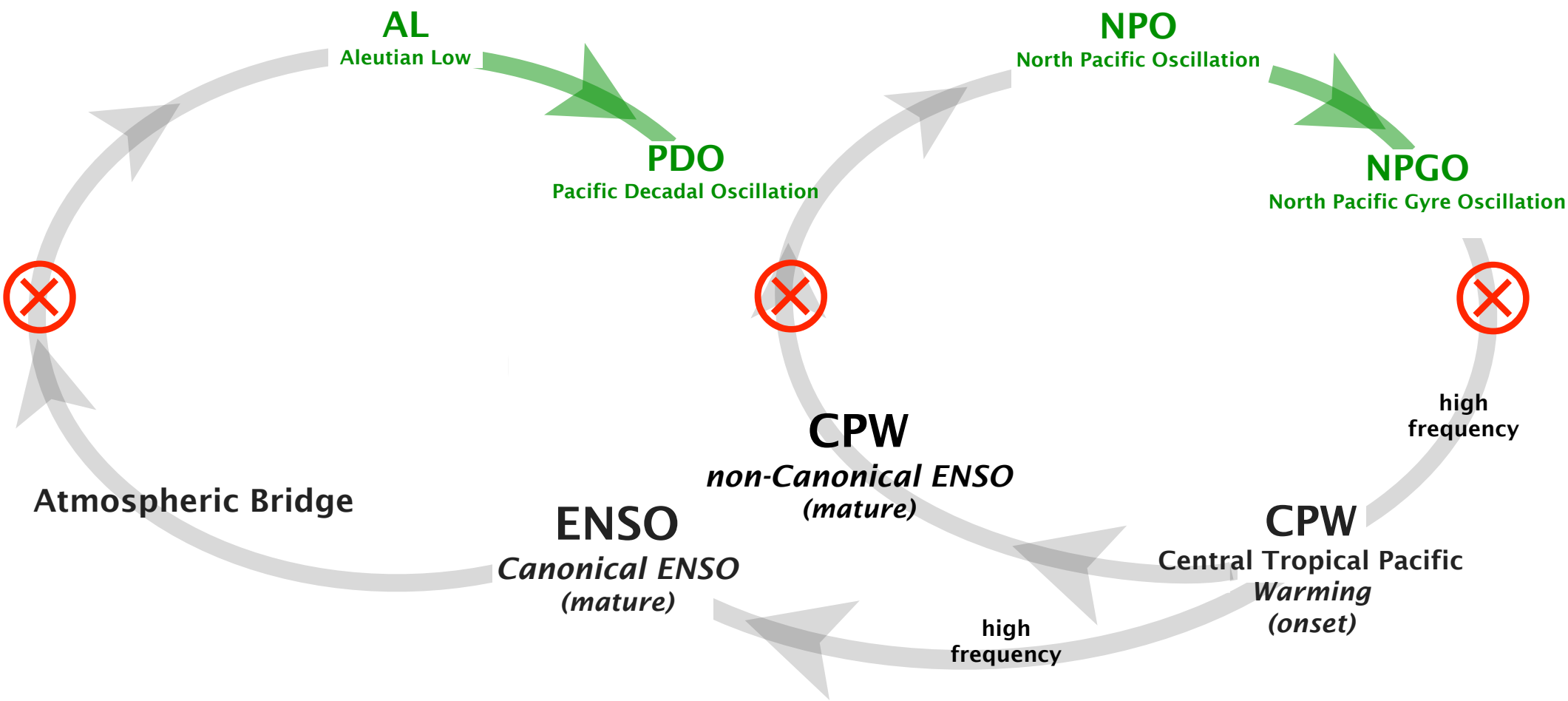
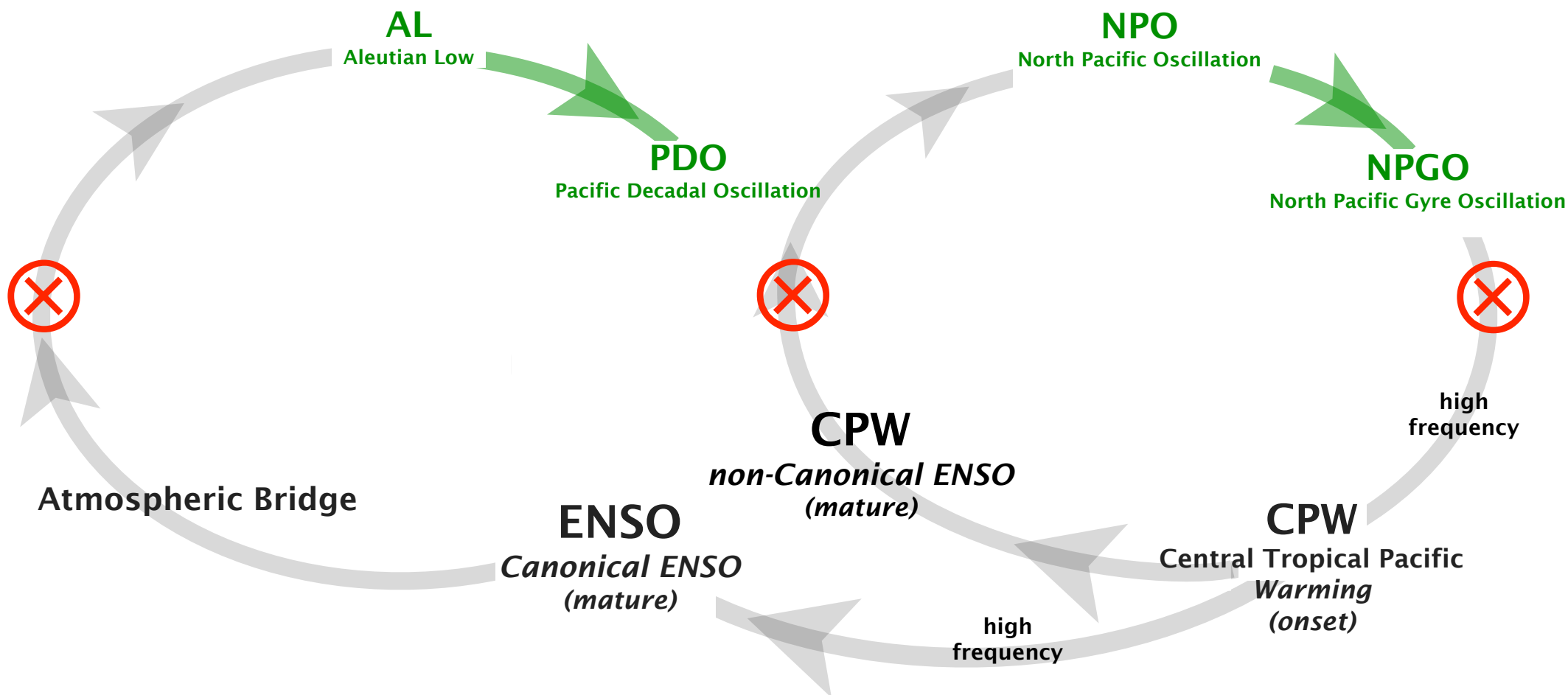


QUESTION:

What changes do the AR4 models predict in the future (A1B scenario)?

Furtado et al., 2011

Test the AR4 models Pacific decadal dynamics 1800-2000



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models are inconsistent in predicting changes in the decadal modes spatial structure and frequency

Furtado et al., 2011

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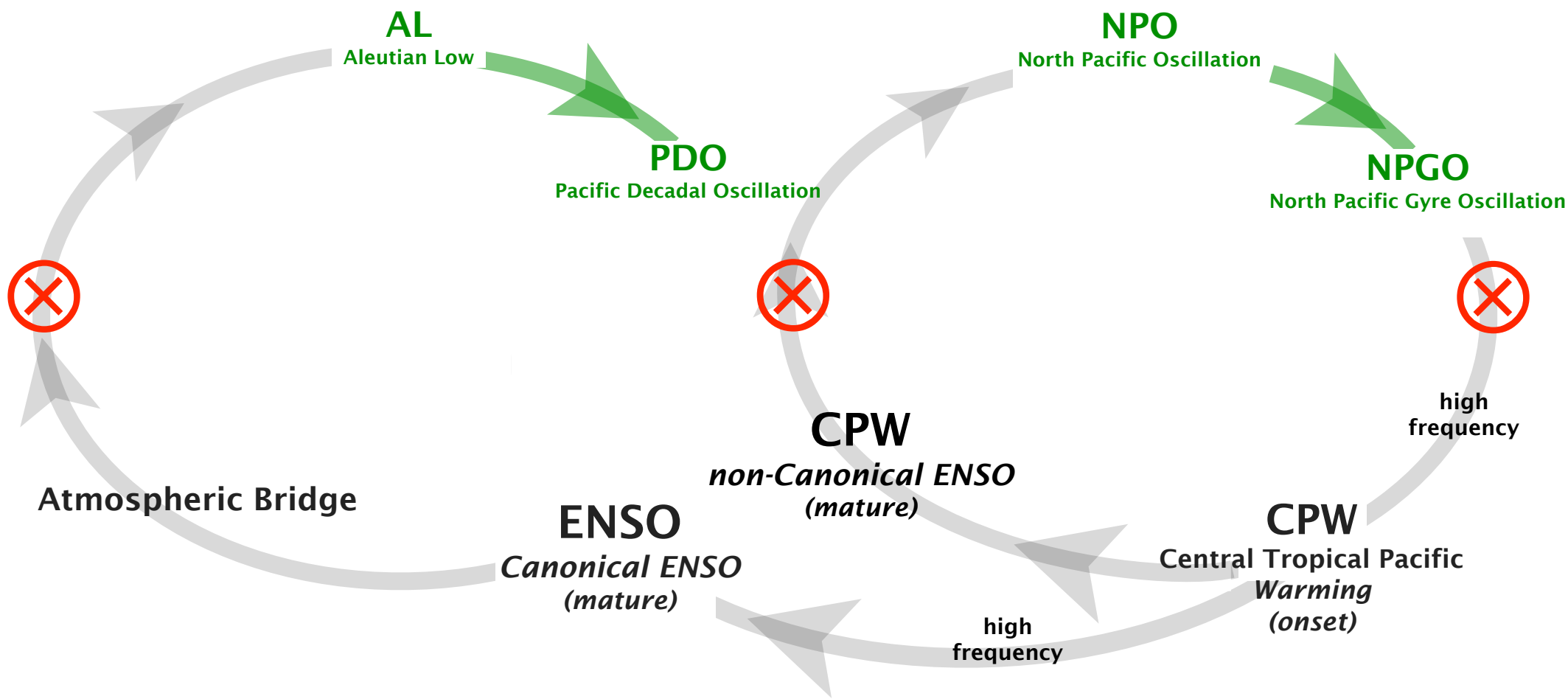

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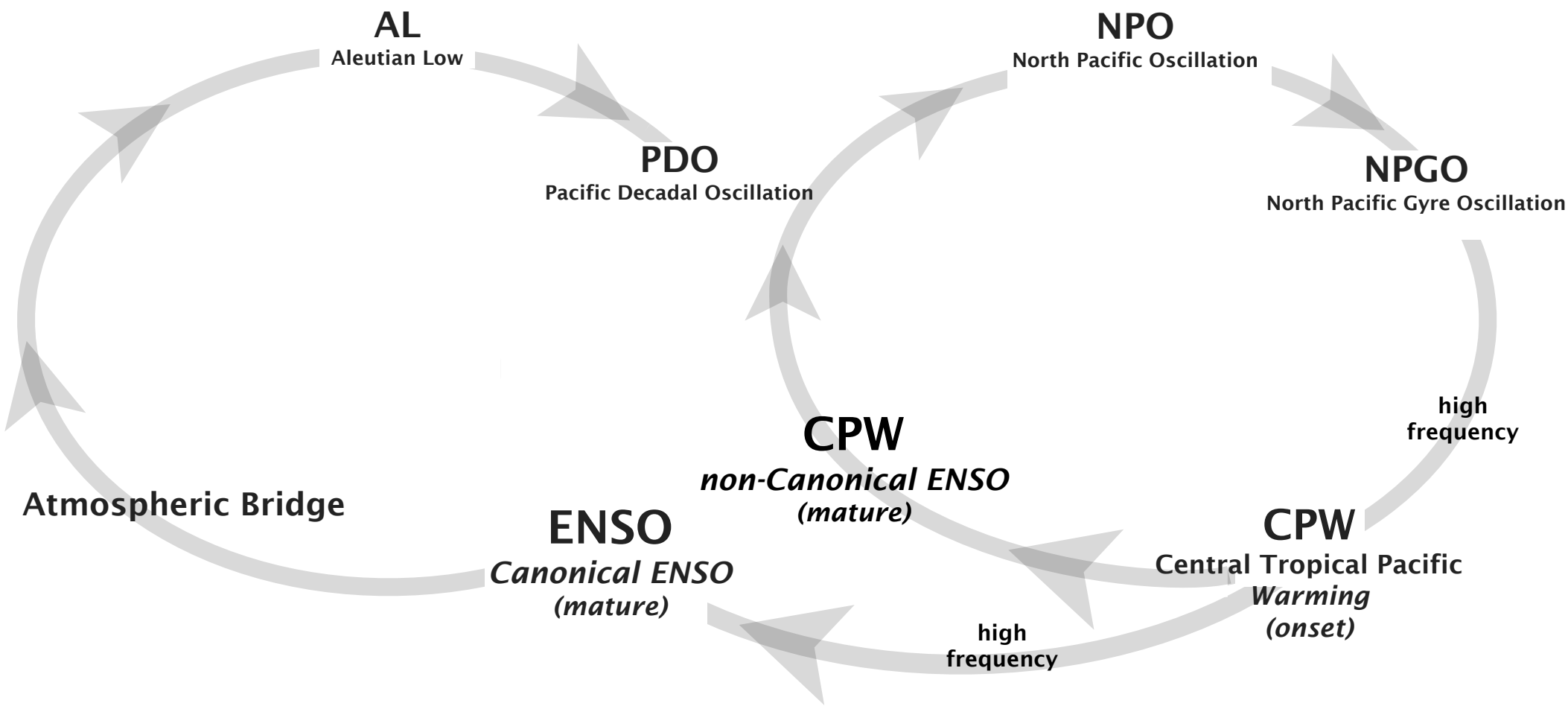
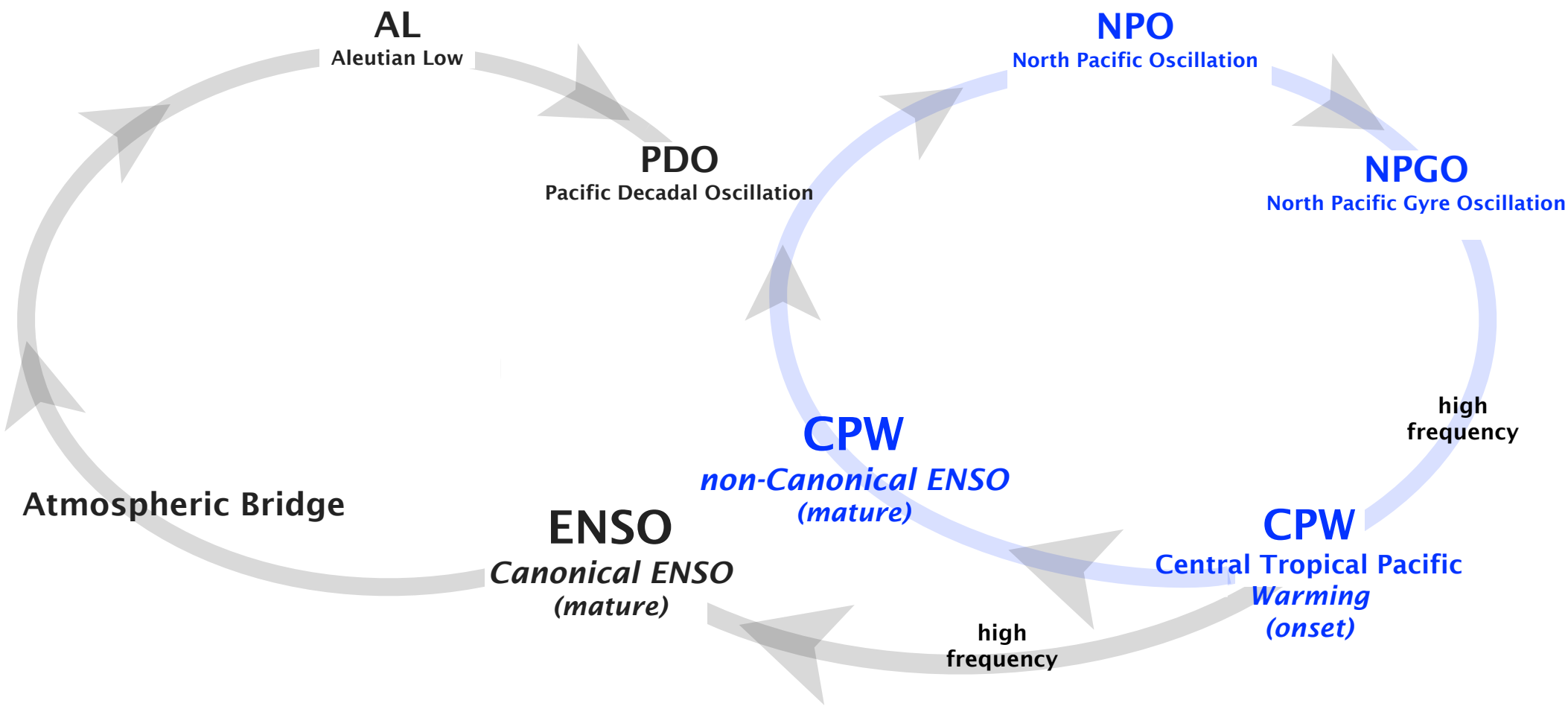
... however it is unclear if these predictions are meaningful

Furtado et al., 2011

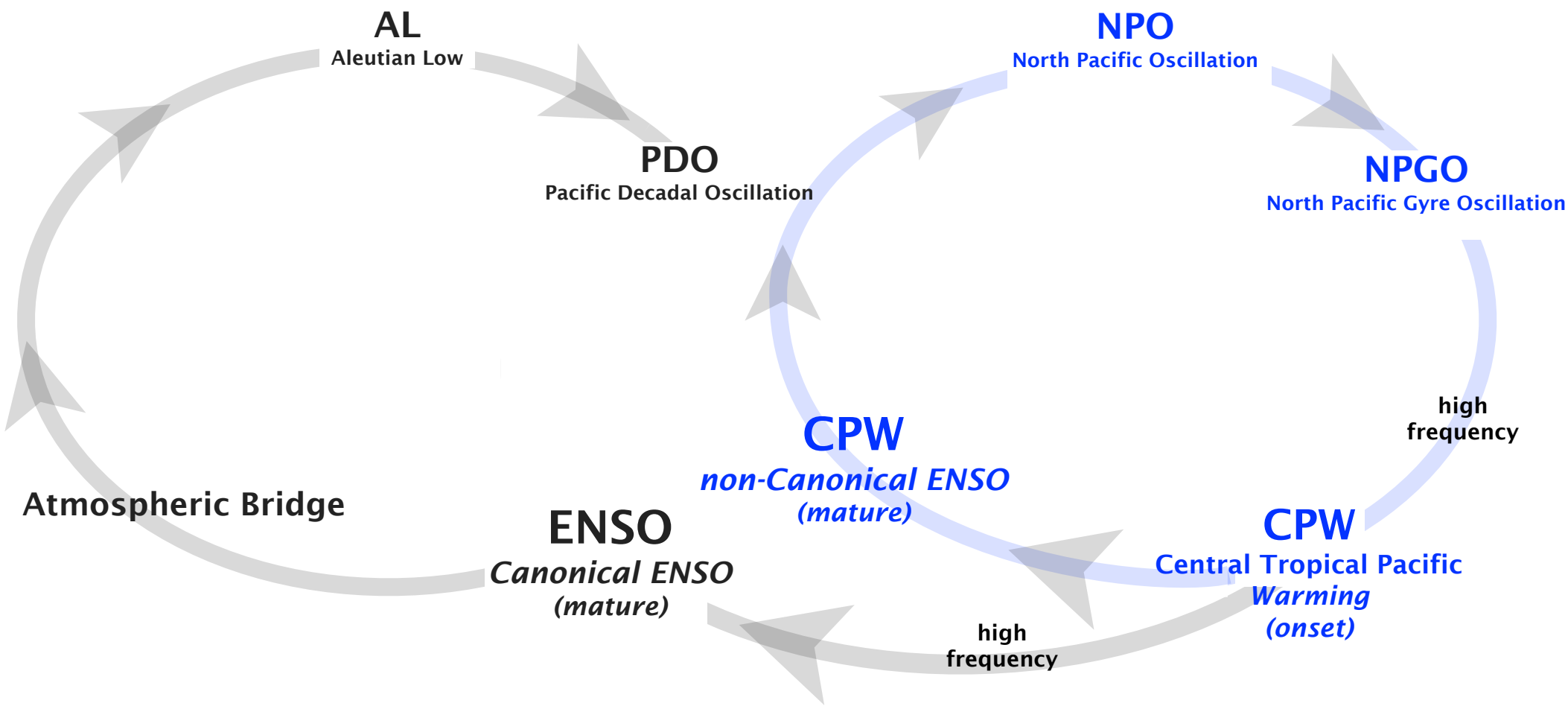


QUESTION:

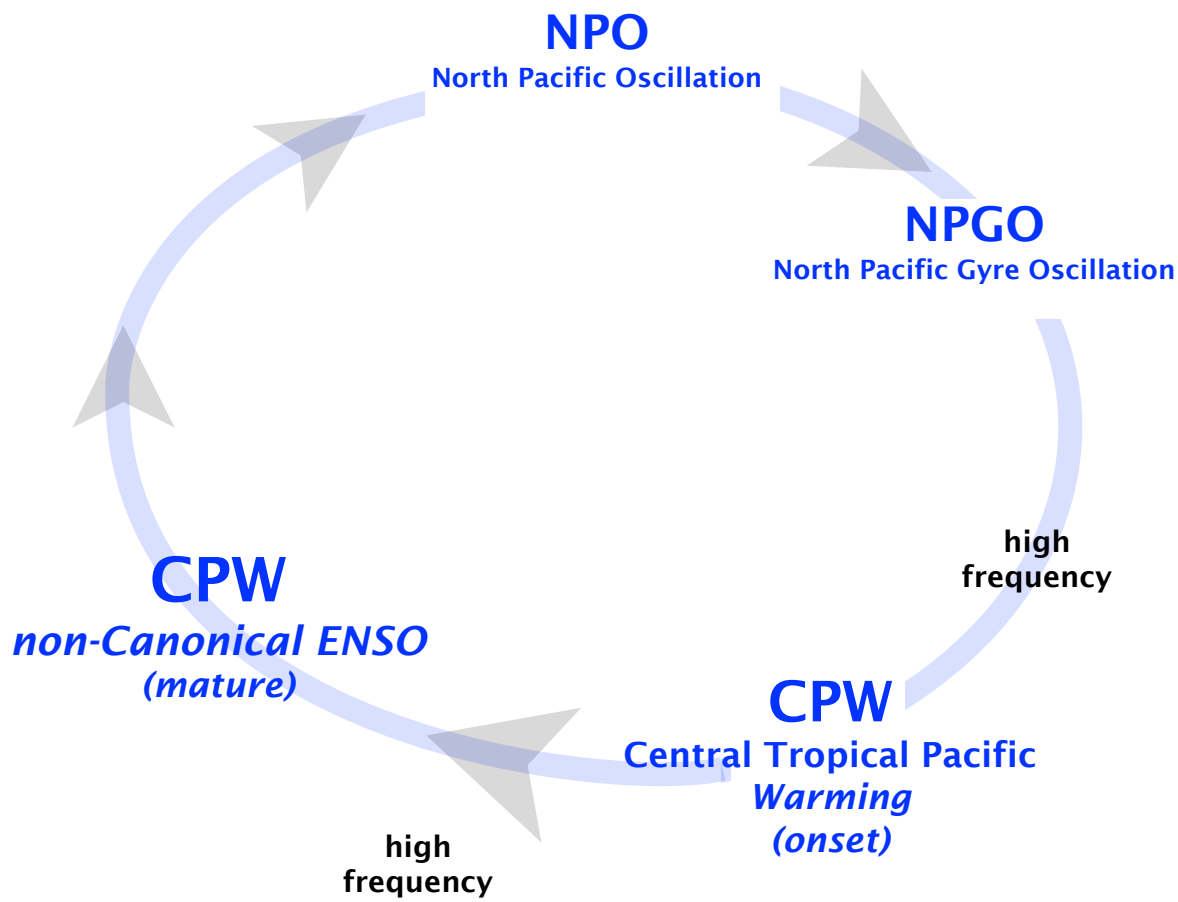
What do observations tell us about the impact of climate change on the decadal modes?



The low-frequency variance explained by the CPW/NPO/NPGO system has increased since the 1980s.



Suggestion that CPW variance is increasing as a result of *climate change* (Yeh et al., 2009).



QUESTION:

Is the variance of the CPW/NPO/NPGO

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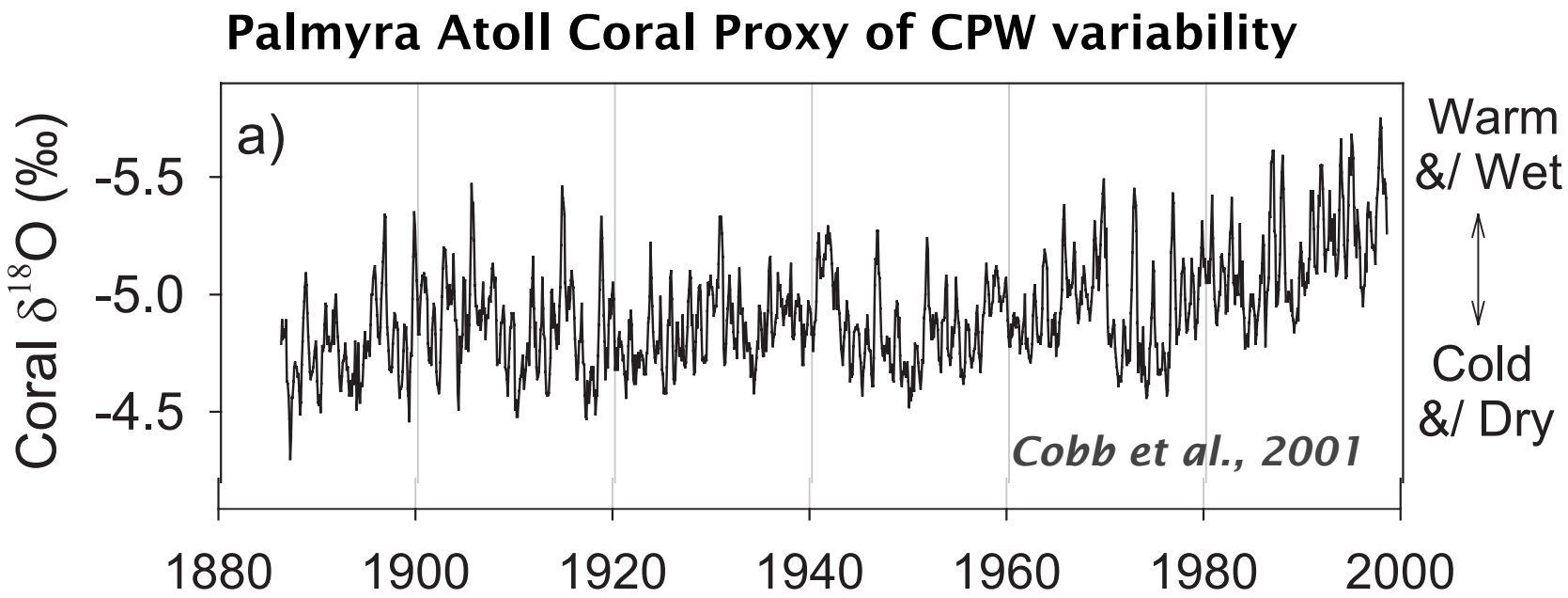

APPROACH:

- ❖ paleo proxy reconstruction of CPW

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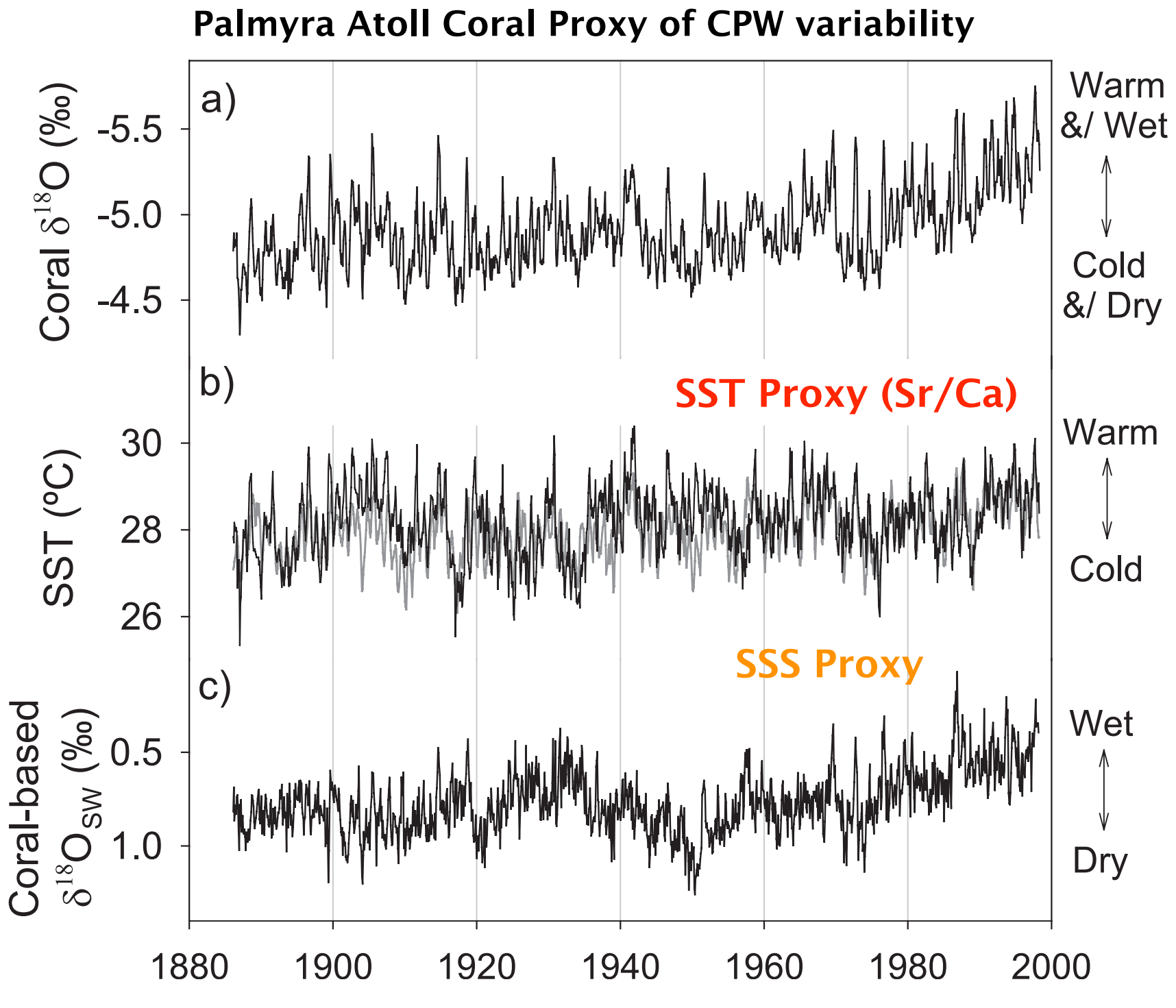
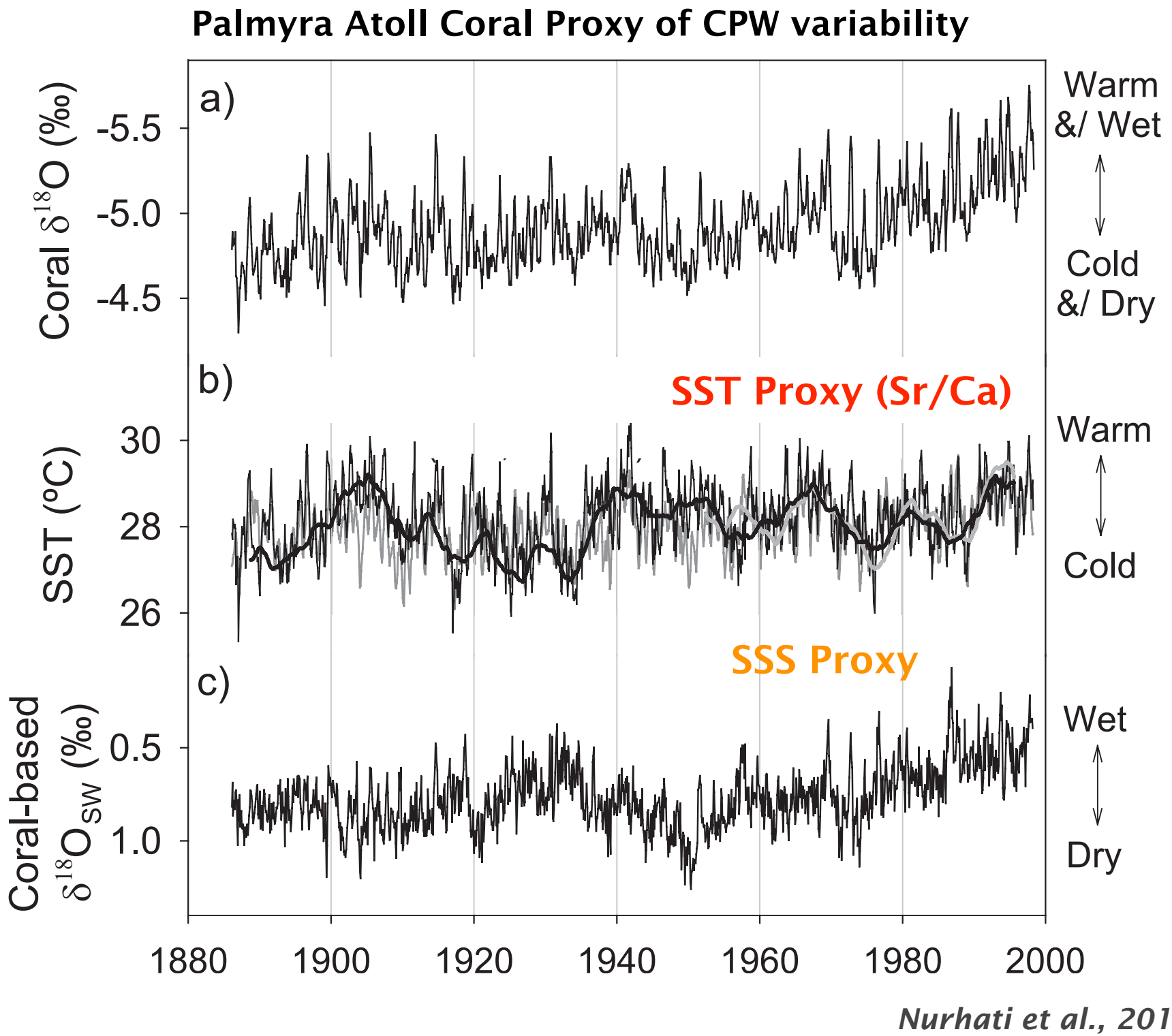

Palmyra Atoll Coral Proxy of CPW variability
a)
Coral δ18O (‰)
-5.5
-5.0
-4.5
Warm
&/ Wet
Cold
&/ Dry
b)
SST Proxy (Sr/Ca)
SST (ºC)
30
28
26
Warm
Cold
c)
SSS Proxy
Coral-based
δ18OSW (‰)
0.5
1.0
Wet
Dry
1880
1900
1920
1940
1960
1980
2000
Nurhati et al., 2011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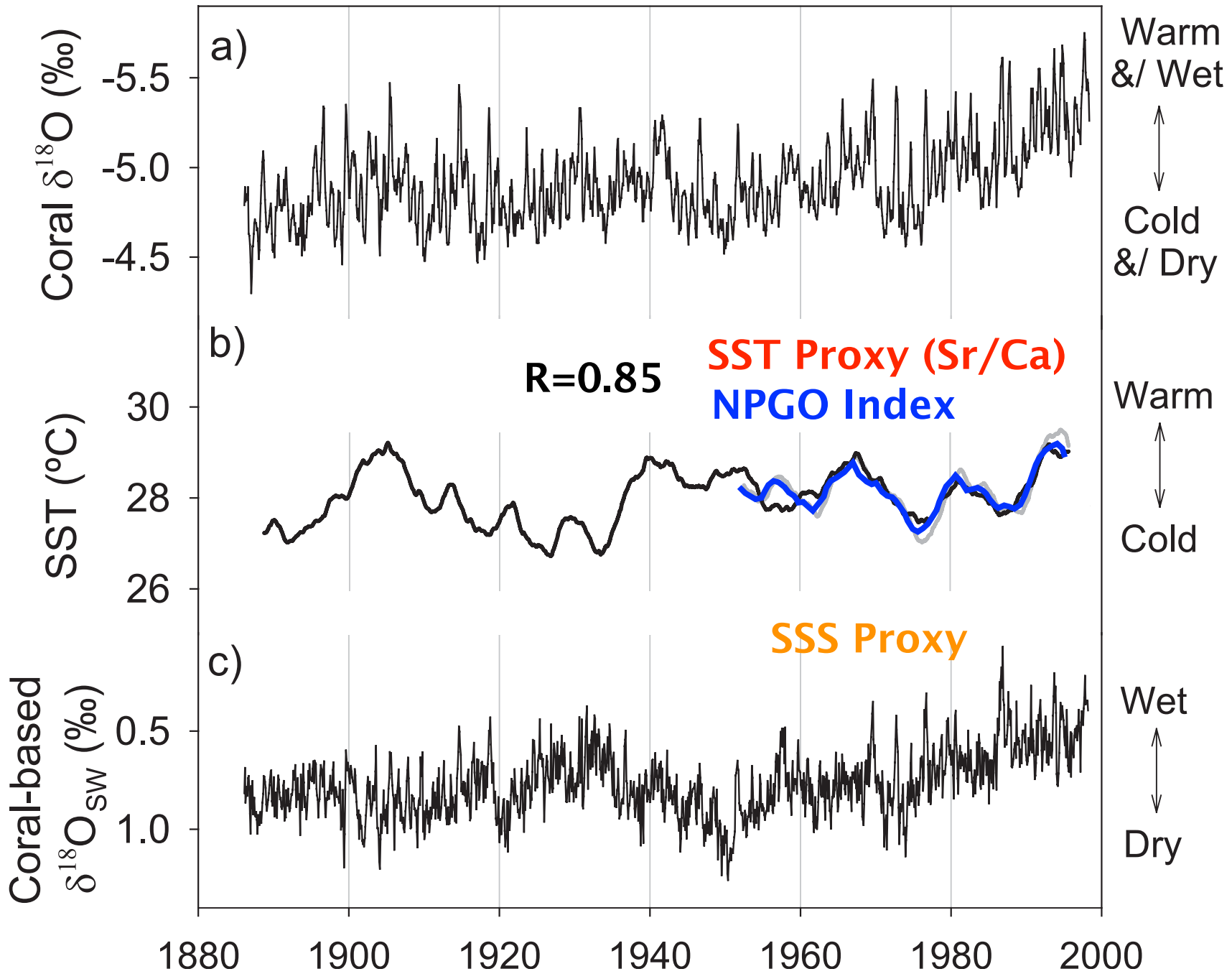

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APPROACH:

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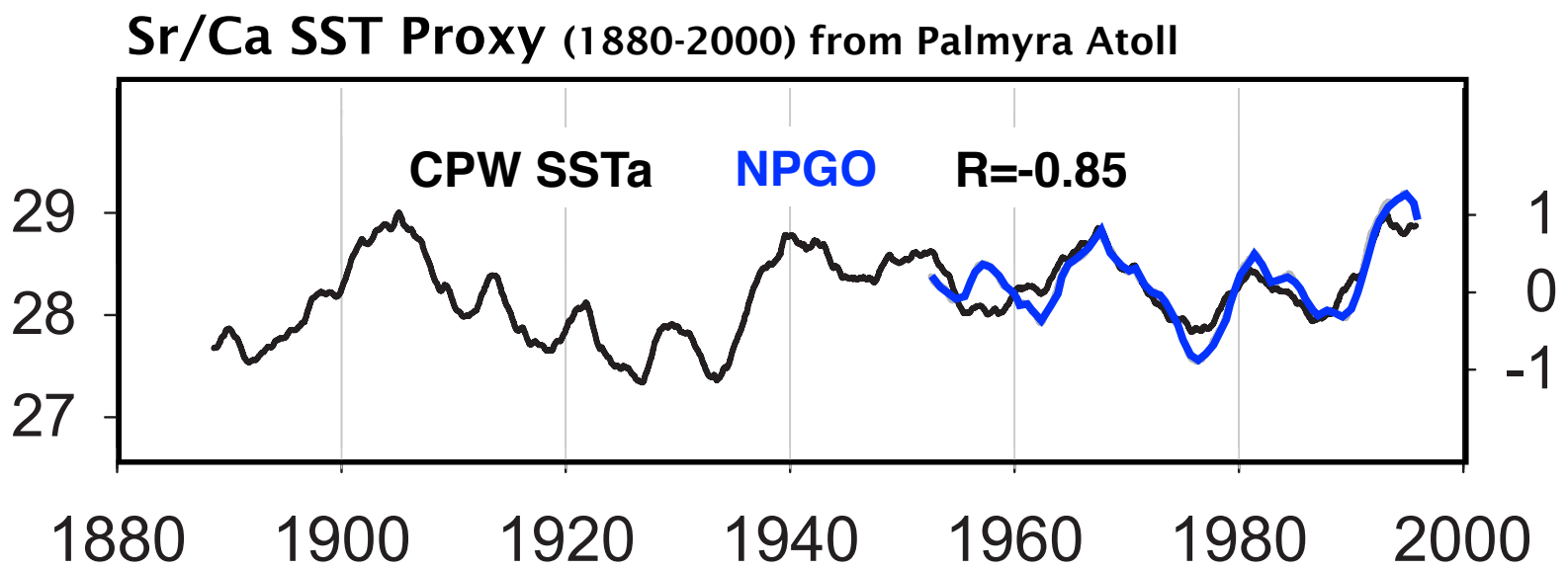
Nurhati et al., 2011



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APPROACH:

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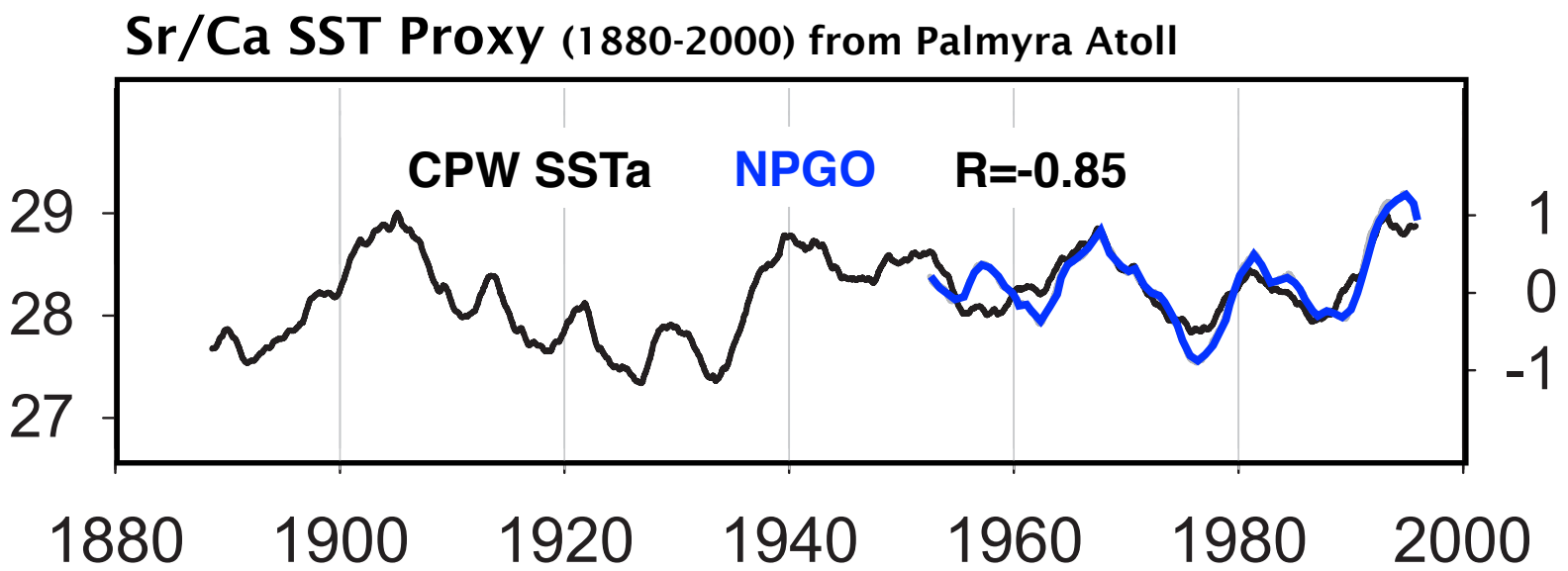
- ❖ **linear modeling multivariate red noise** (*Newman et al., 2011*)

Nurhati et al., 2011



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→ **so far these findings suggest that the increase in CPW/NPO/NPGO variance is not statistically significant**

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Science contributions of PODX:

1. Di Lorenzo et al. 2010: **Central Pacific Warming El Nino and decadal climate change in the North Pacific**. *Nature Geoscience*, DOI: 10.1038/NGEO984.

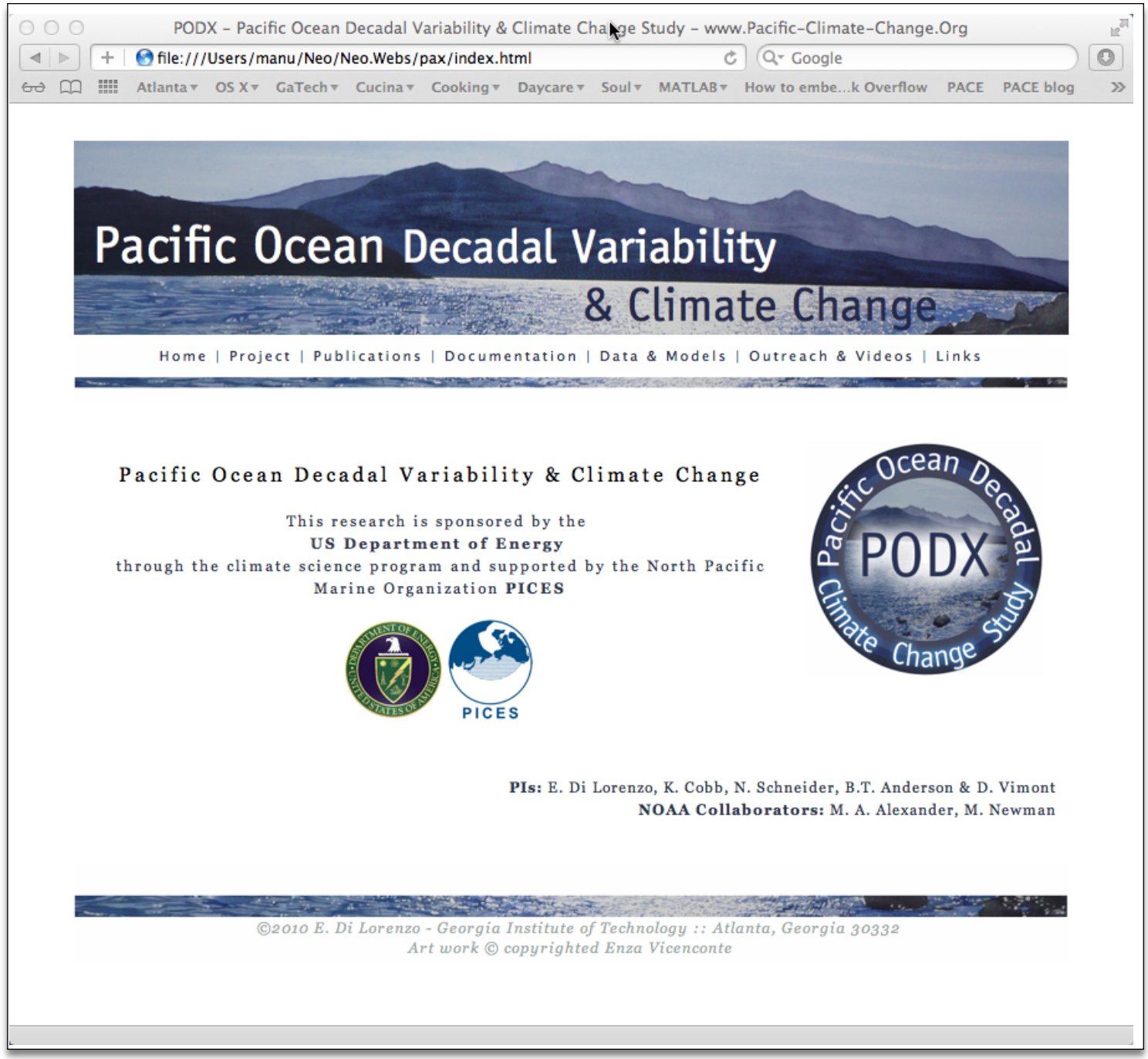
2. Vimont, 2010: **Transient growth of thermodynamically coupled disturbances in the tropics under an equatorially symmetric mean state**. *Journal of Climate* , vol. 23 (21) pp. 5771-5789.

3. Furtado et al. 2011: **North Pacific Decadal Variability and Climate Change in the IPCC AR4 Models**. *Journal of Climate*, doi: 10.1175/2010JCLI3584.1.

4. Nurhati et al. 2011: **Decadal-scale SST and salinity variations in the central tropical Pacific: Signatures of natural and anthropogenic climate change**. *Journal of Climate*, vol. 24 (13) pp. 3294-3308.

5. Newman et al., 2011: **Natural variation in ENSO flavors**. *Geophysical Research Letters* , DOI: 10.1029/2011GL047658.

Project Website

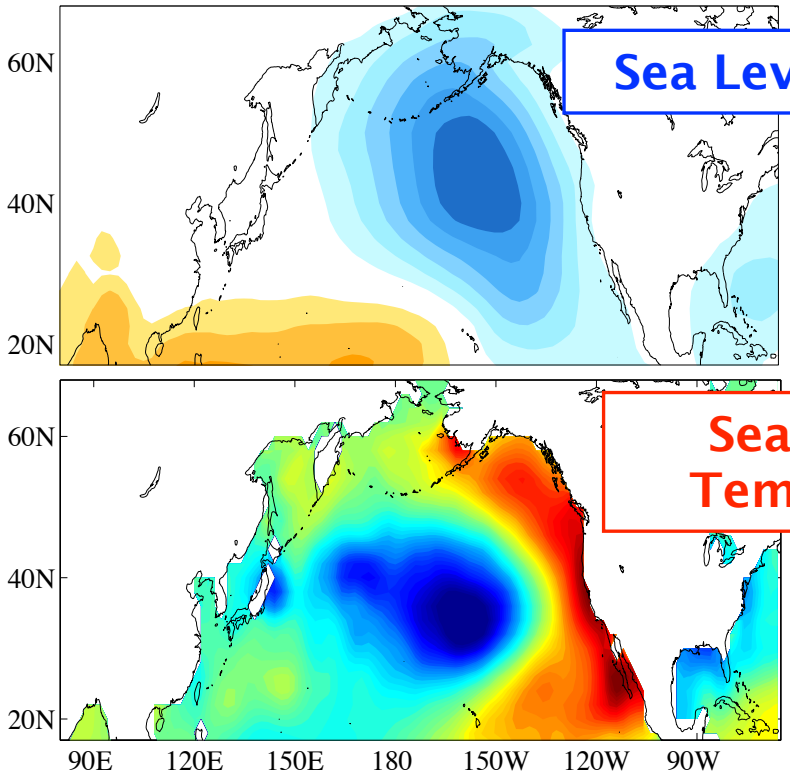


art work by

Enza Viceconte (*Elba Island, Italy*)

www.podx.org

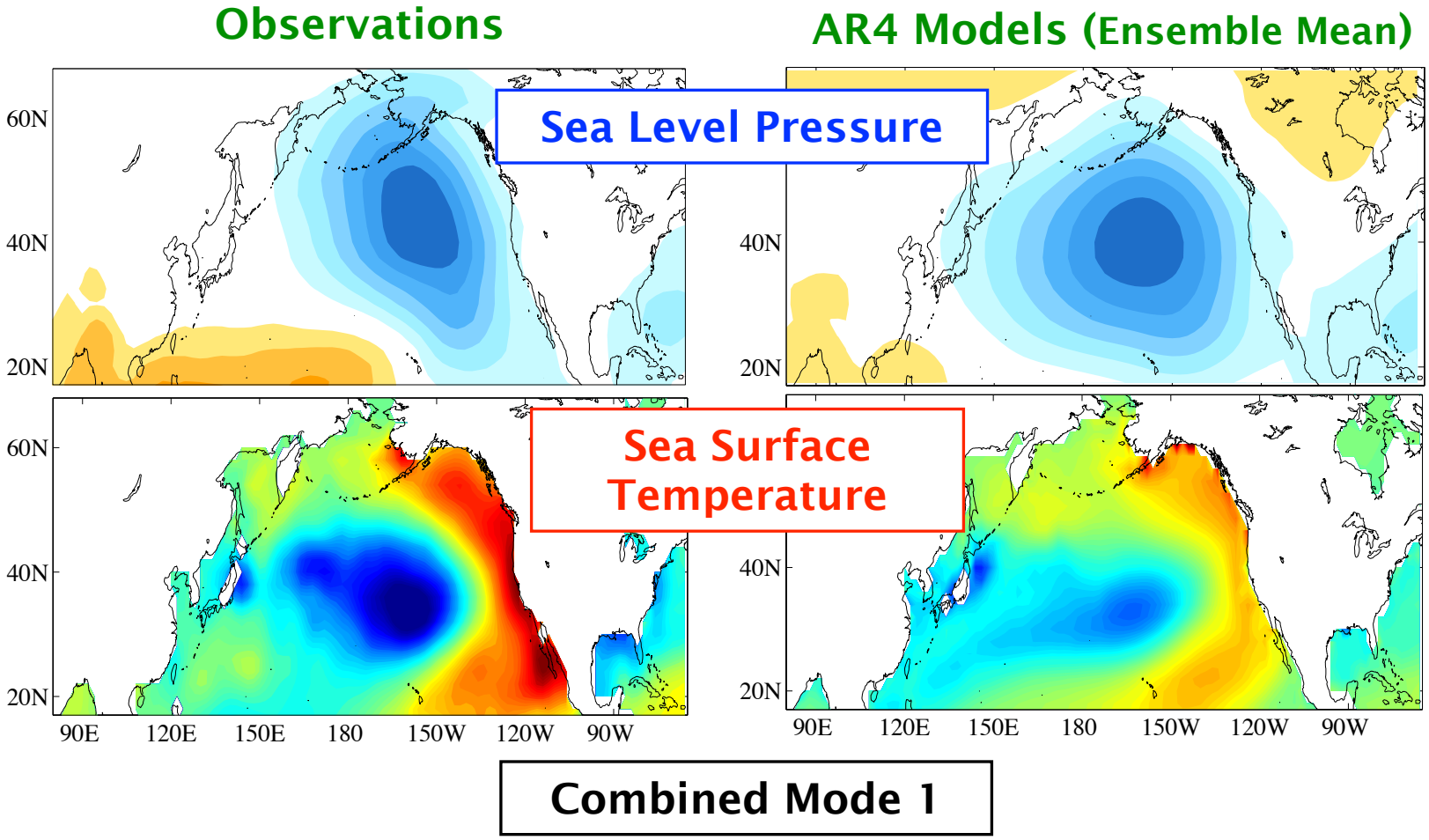
Observations



Sea Level Pressure

Sea Surface Temperature

Combined EOF Mode 1



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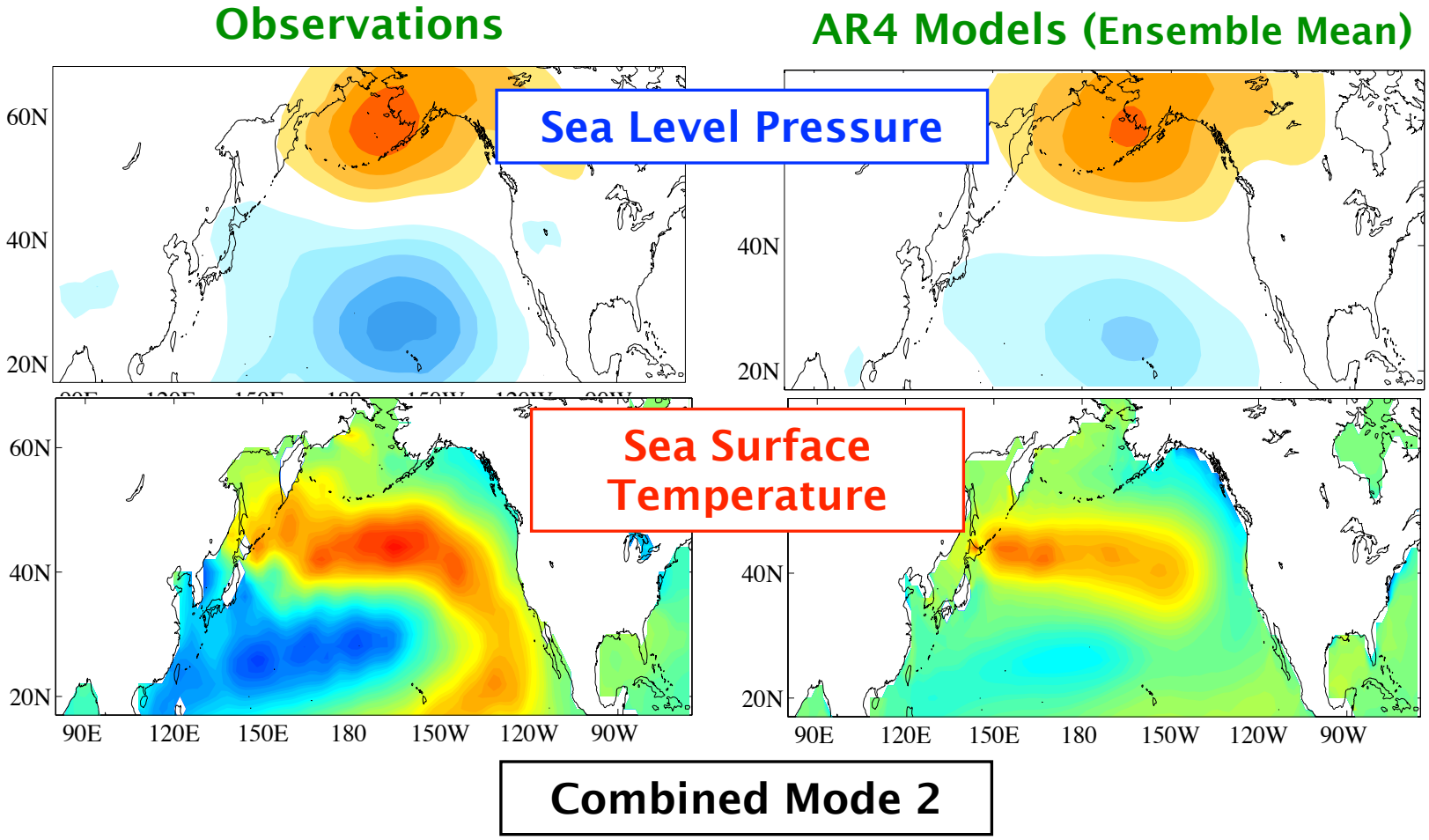
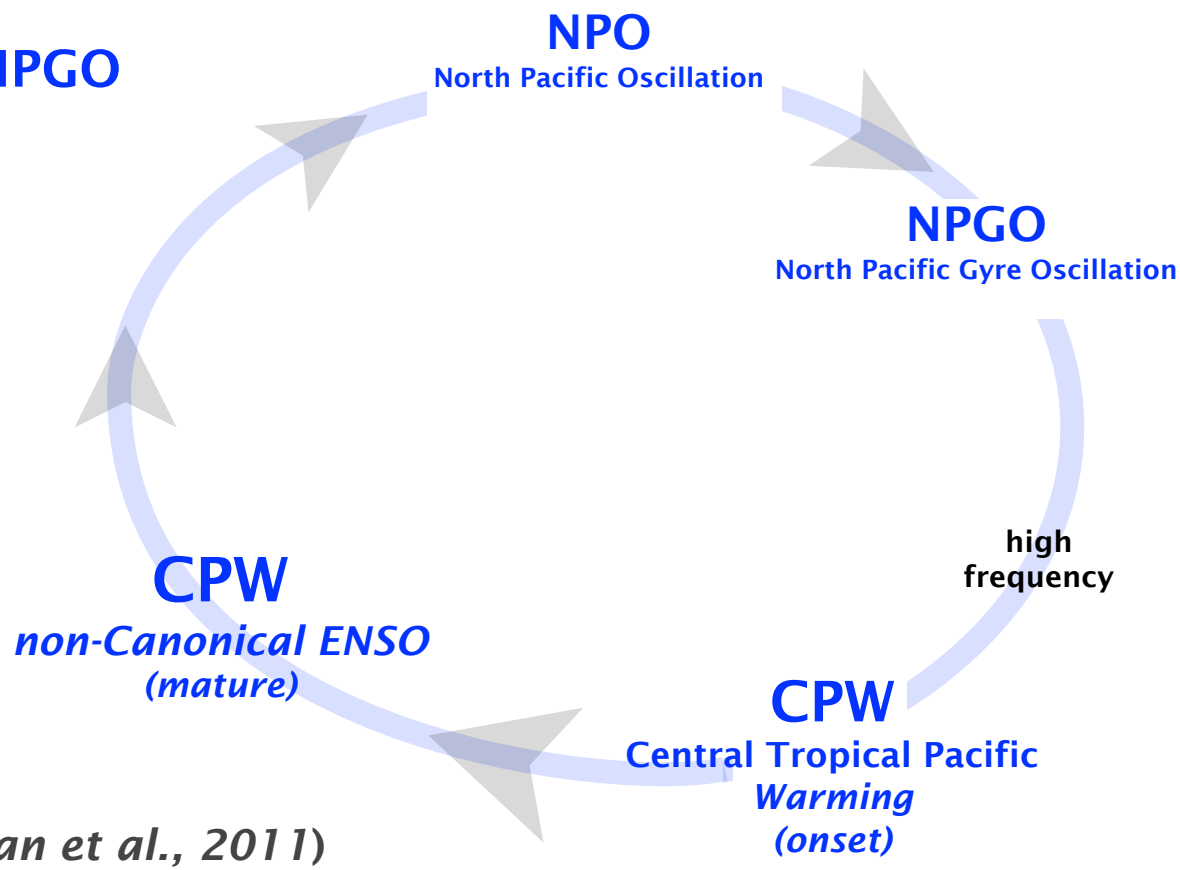


Combined Mode 2

QUESTION:

Is the variance of the CPW/NPO/NPGO increasing as a result of climate change?

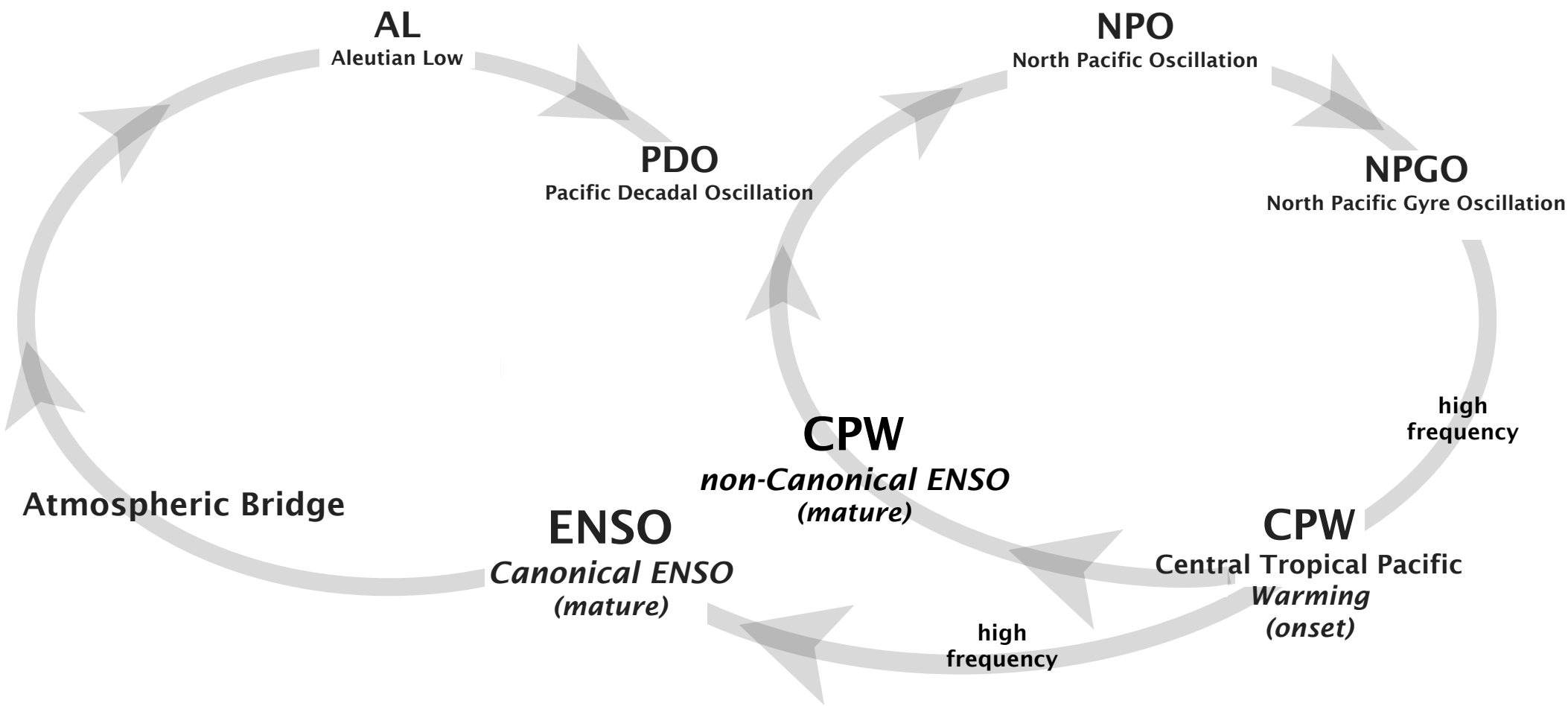


APPROACH:

- ❖ linear inverse modeling (*Newman et al., 2011*)
- ❖ paleo multi-proxy reconstruction of CPW (*Nurhati et al., 2011*)
- ❖ unforced climate of 2000 year climate model simulation

→ so far these findings suggest that changes in CPW/NPO/NPGO variance are not statistically significant

Test the AR4 models Pacific decadal dynamics 1800-2000



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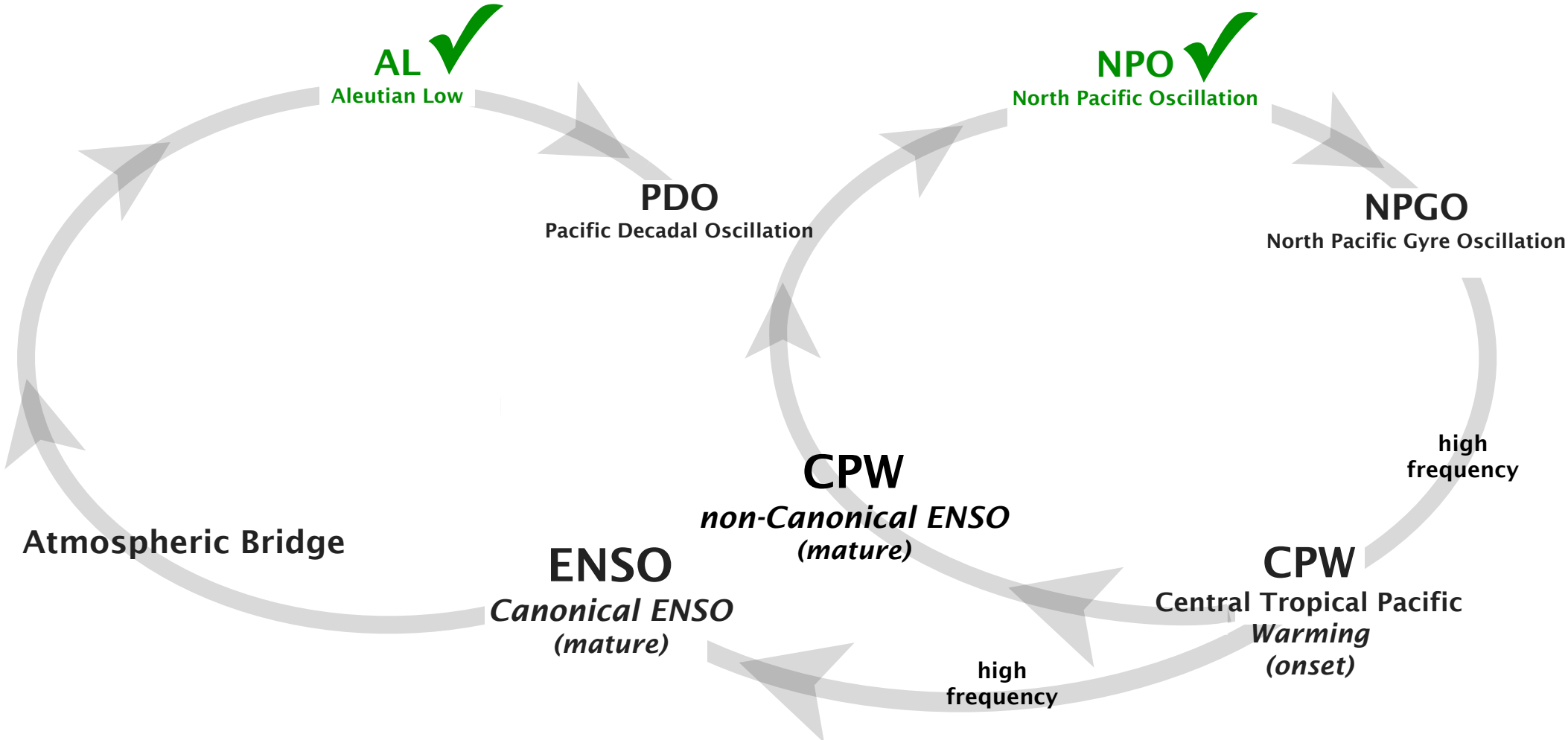

1. Capture the spatial expression of the atmospheric modes

Furtado et al., 2011

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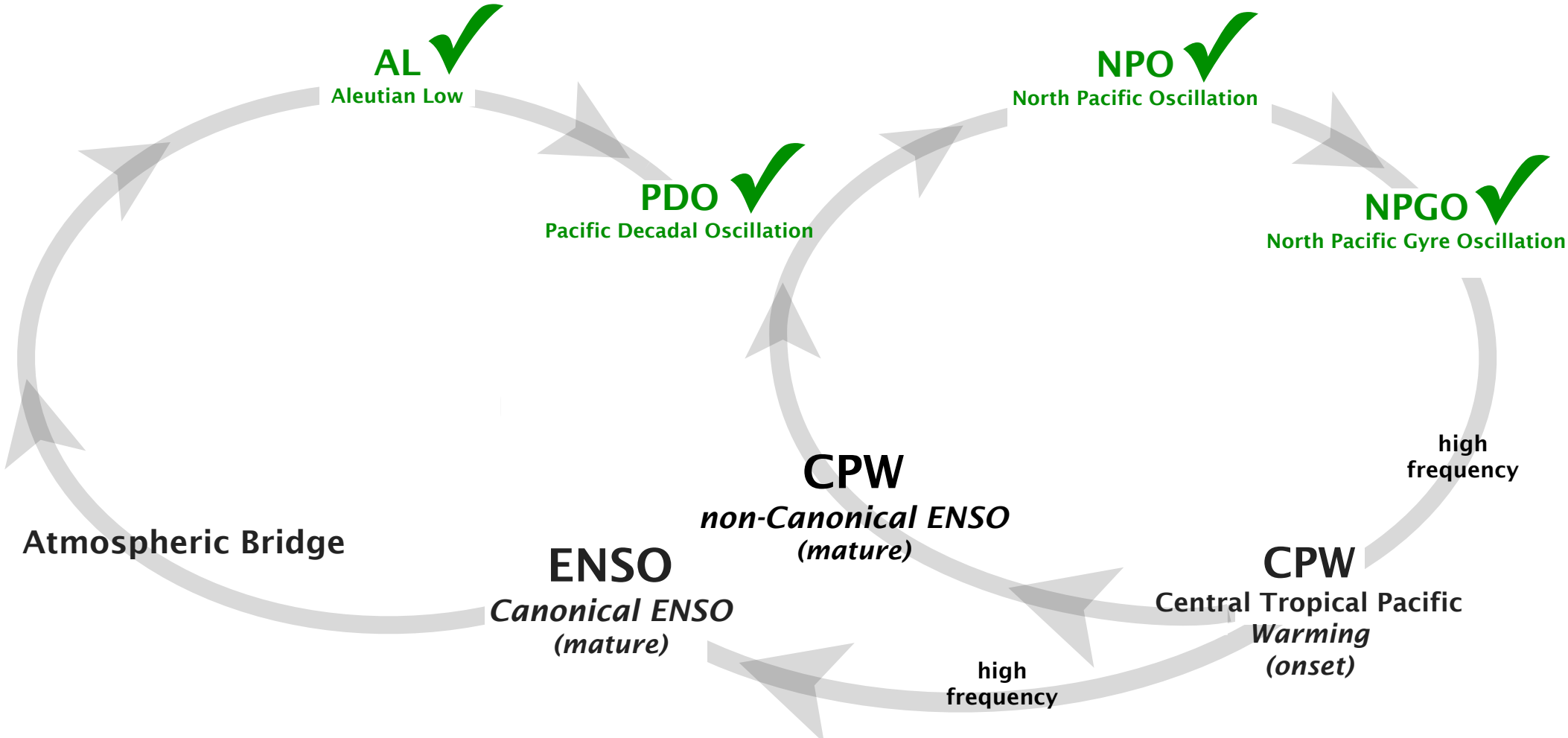

1. Capture the spatial expression of the atmospheric & oceanic modes

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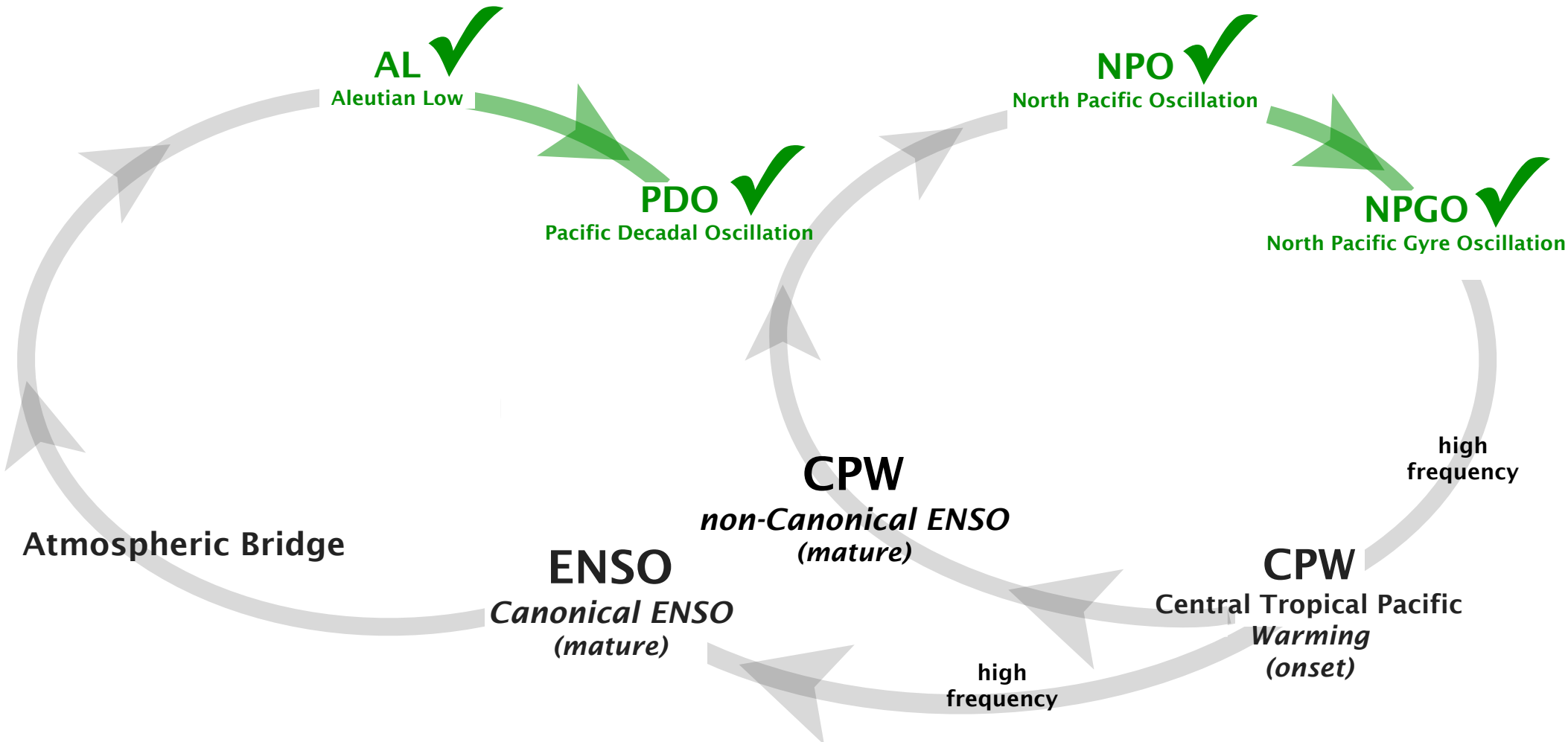

1. Capture the spatial expression of the atmospheric & oceanic modes
2. Capture the dynamics of the oceanic response to atmospheric forcing

Furtado et al., 2011

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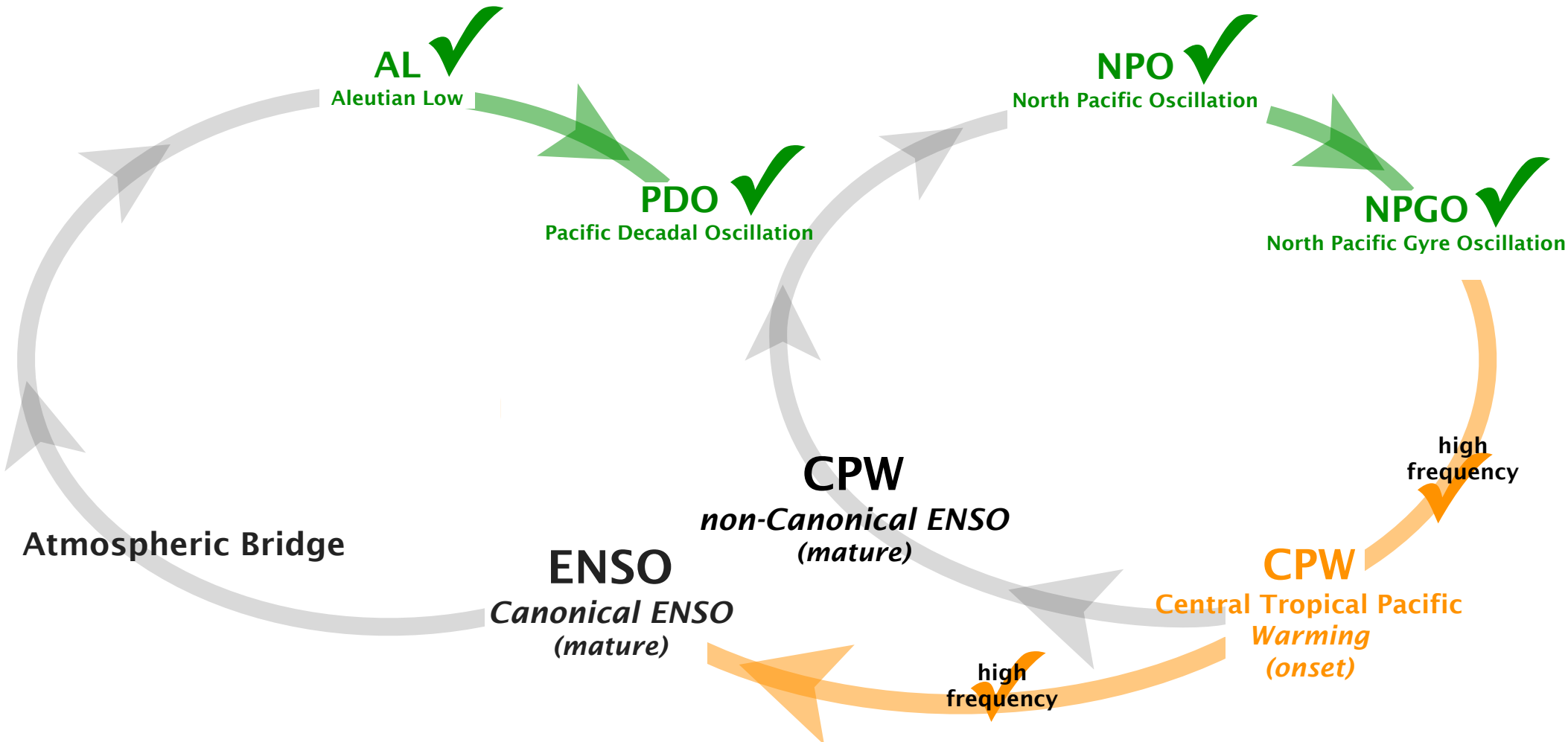
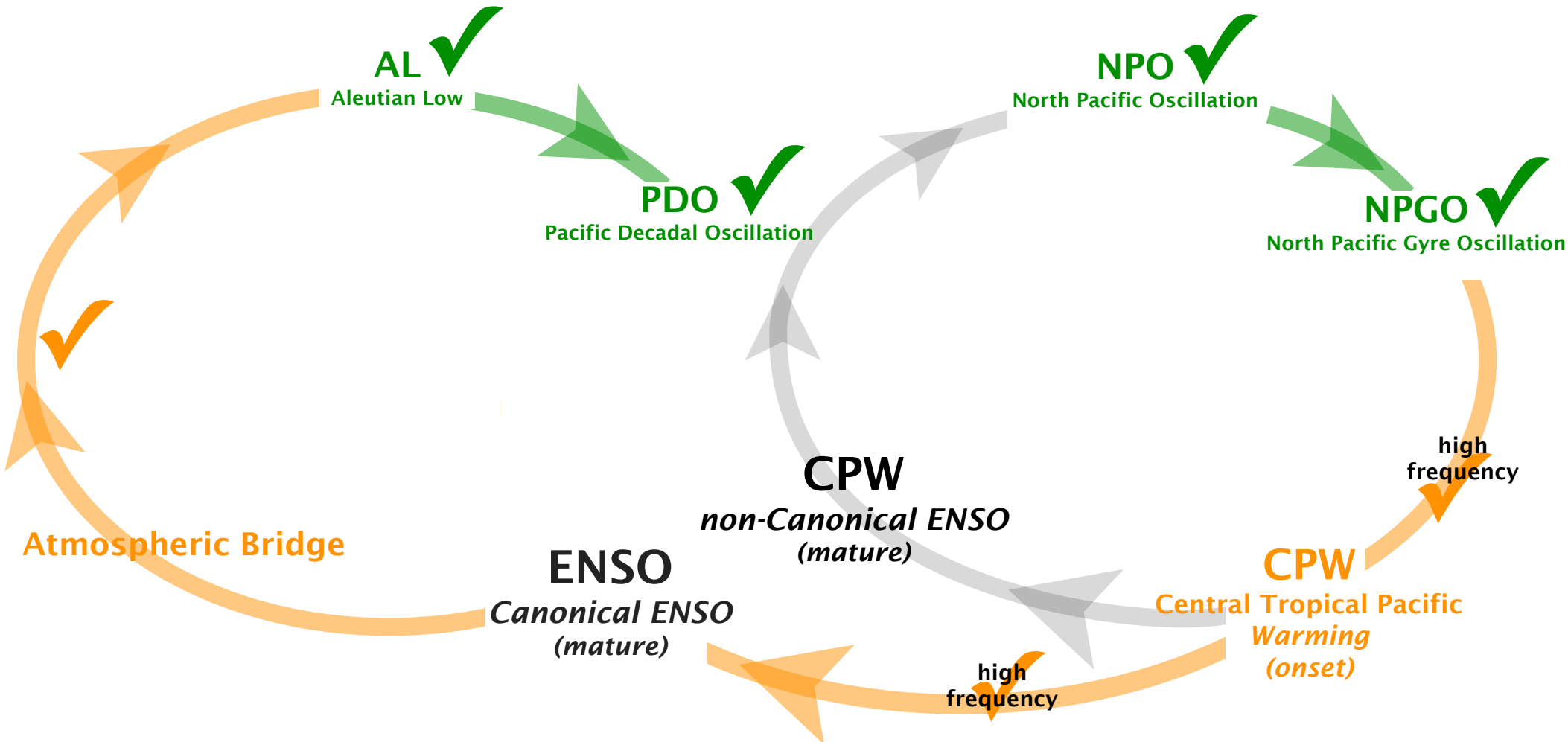


1. Capture the spatial expression of the atmospheric & oceanic modes
2. Capture the dynamics of the oceanic response to atmospheric forcing
3. Capture/Not Capture the extra-tropical forcing of ENSO

Furtado et al., 2011

Test the AR4 models Pacific decadal dynamics 1800-2000



1. Capture the spatial expression of the atmospheric & oceanic modes
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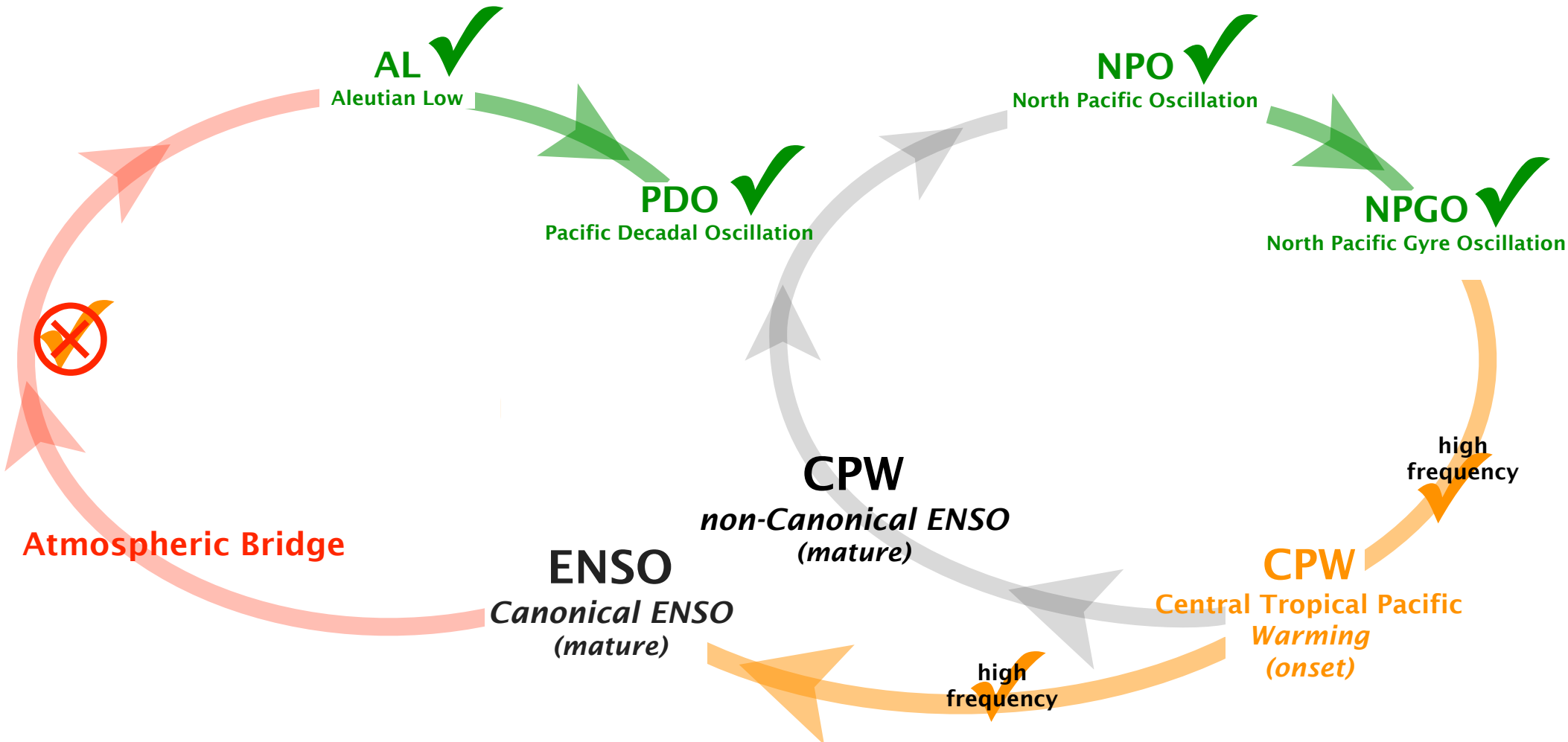

1. Capture the spatial expression of the atmospheric & oceanic modes
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3. Capture/Not Capture the extra-tropical forcing of ENSO
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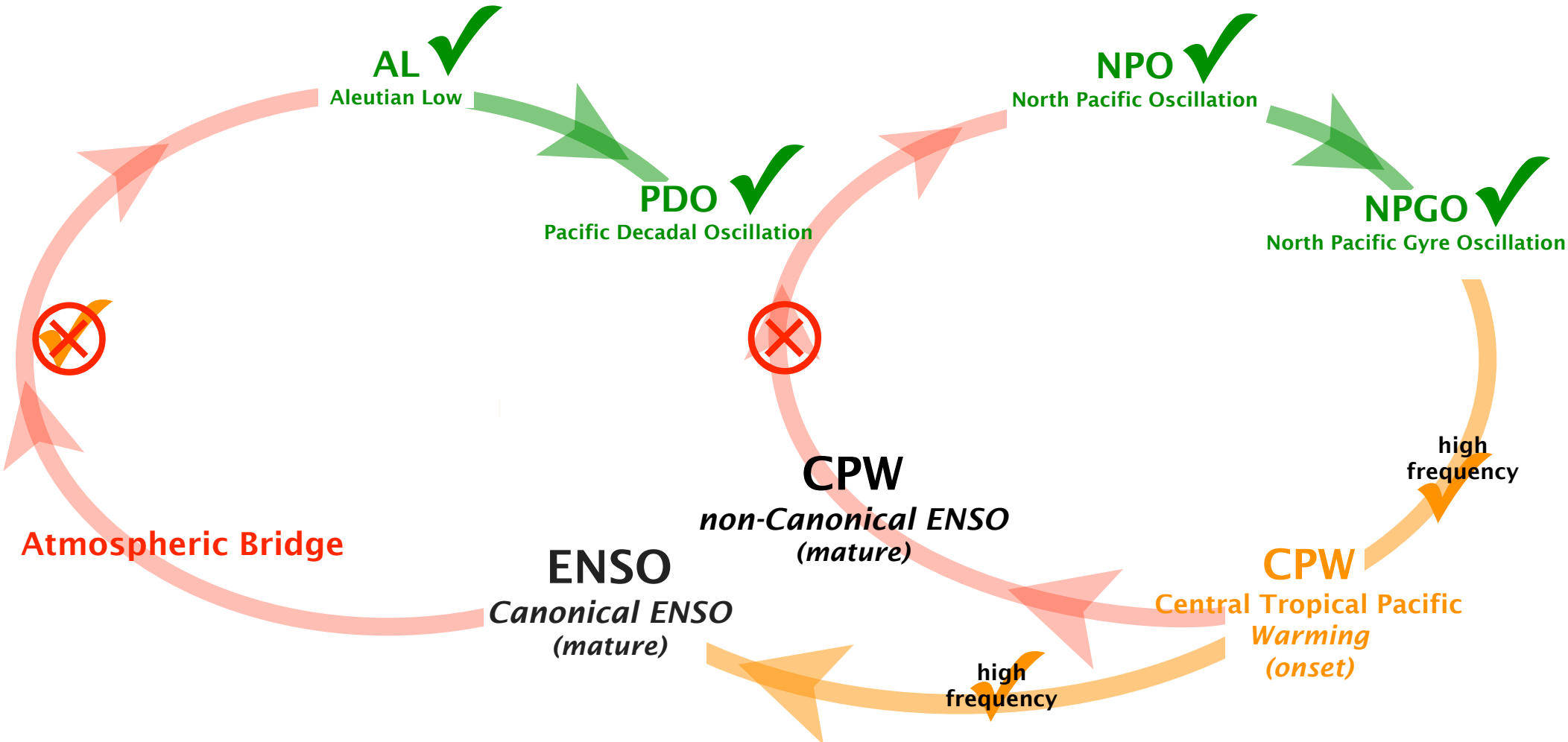
5. Not Capture the ENSO low-frequency forcing to the extra-tropics

Furtado et al., 2011

Test the AR4 models Pacific decadal dynamics 1800-2000



1. Capture the spatial expression of the atmospheric & oceanic modes
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3. Capture/Not Capture the extra-tropical forcing of ENSO
4. Capture/Not Capture the ENSO forcing to the extra-tropics
5. Not Capture the ENSO and CPW low-frequency forcing to the extra-tropics

Furtado et al., 2011

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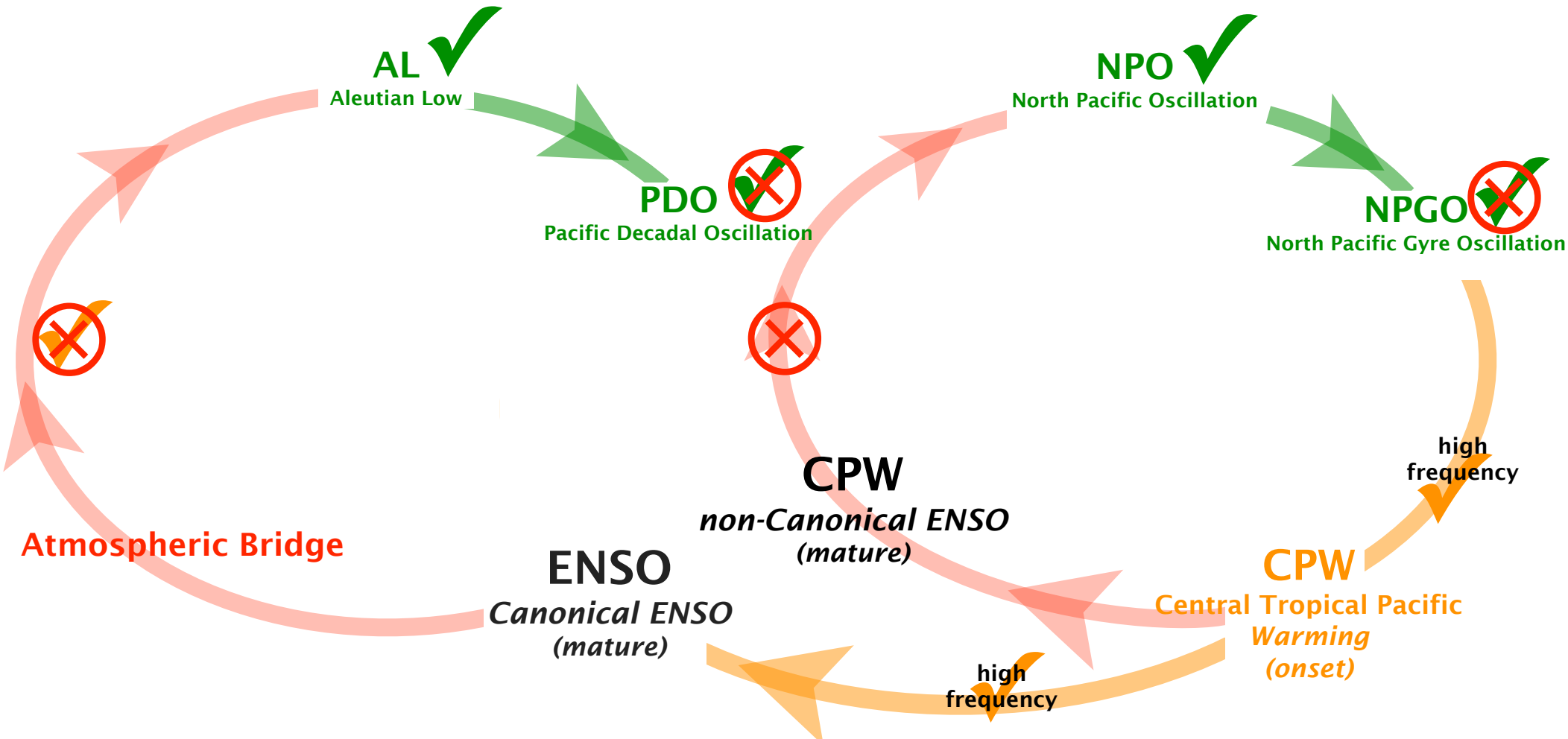

1. Capture the spatial expression of the atmospheric & oceanic modes
2. Capture the dynamics of the oceanic response to atmospheric forcing
3. Capture/Not Capture the extra-tropical forcing of ENSO
4. Capture/Not Capture the ENSO forcing to the extra-tropics
5. Not Capture the ENSO and CPW low-frequency forcing to the extra-tropics
6. Not Capture the frequency content of the oceanic modes

Furtado et al., 2011

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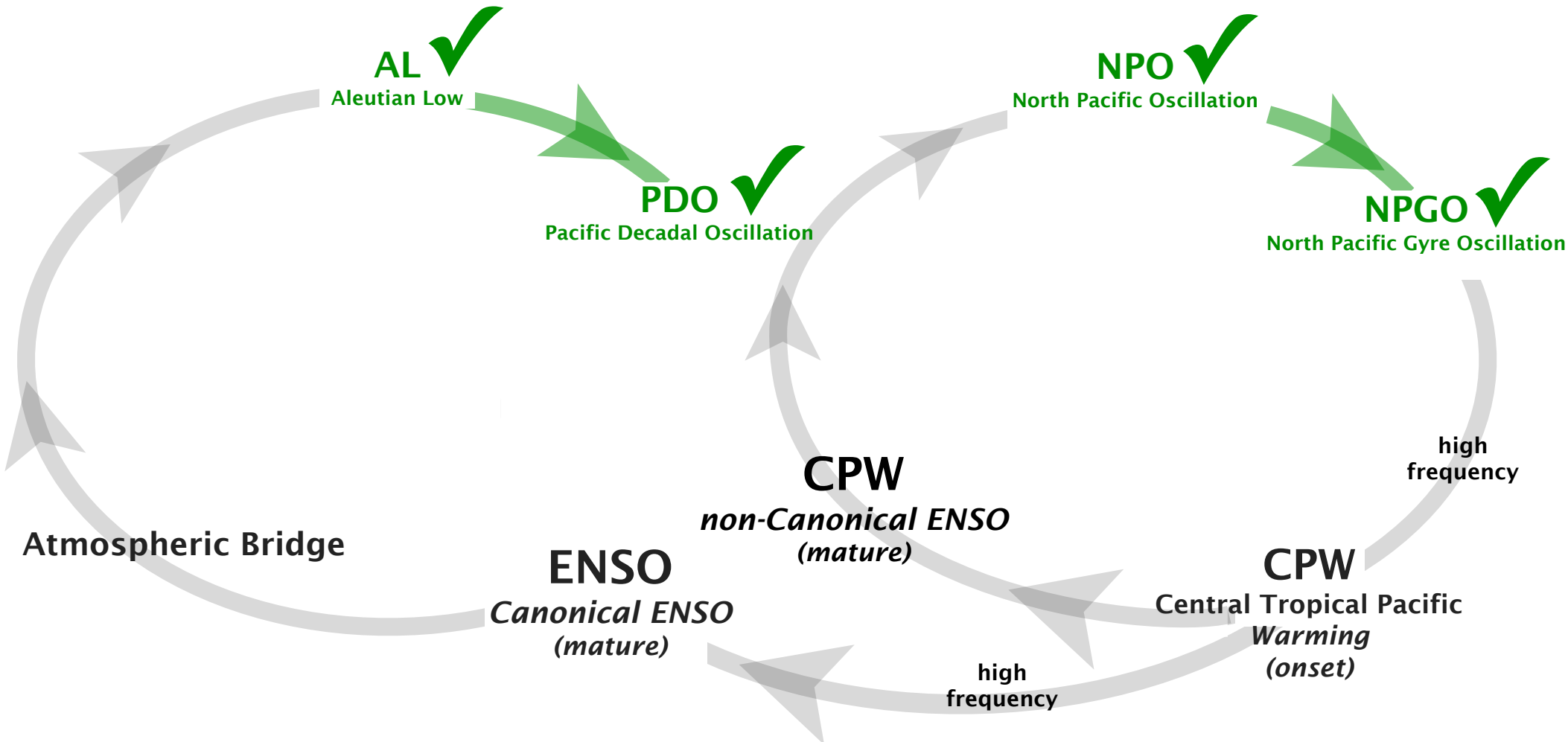

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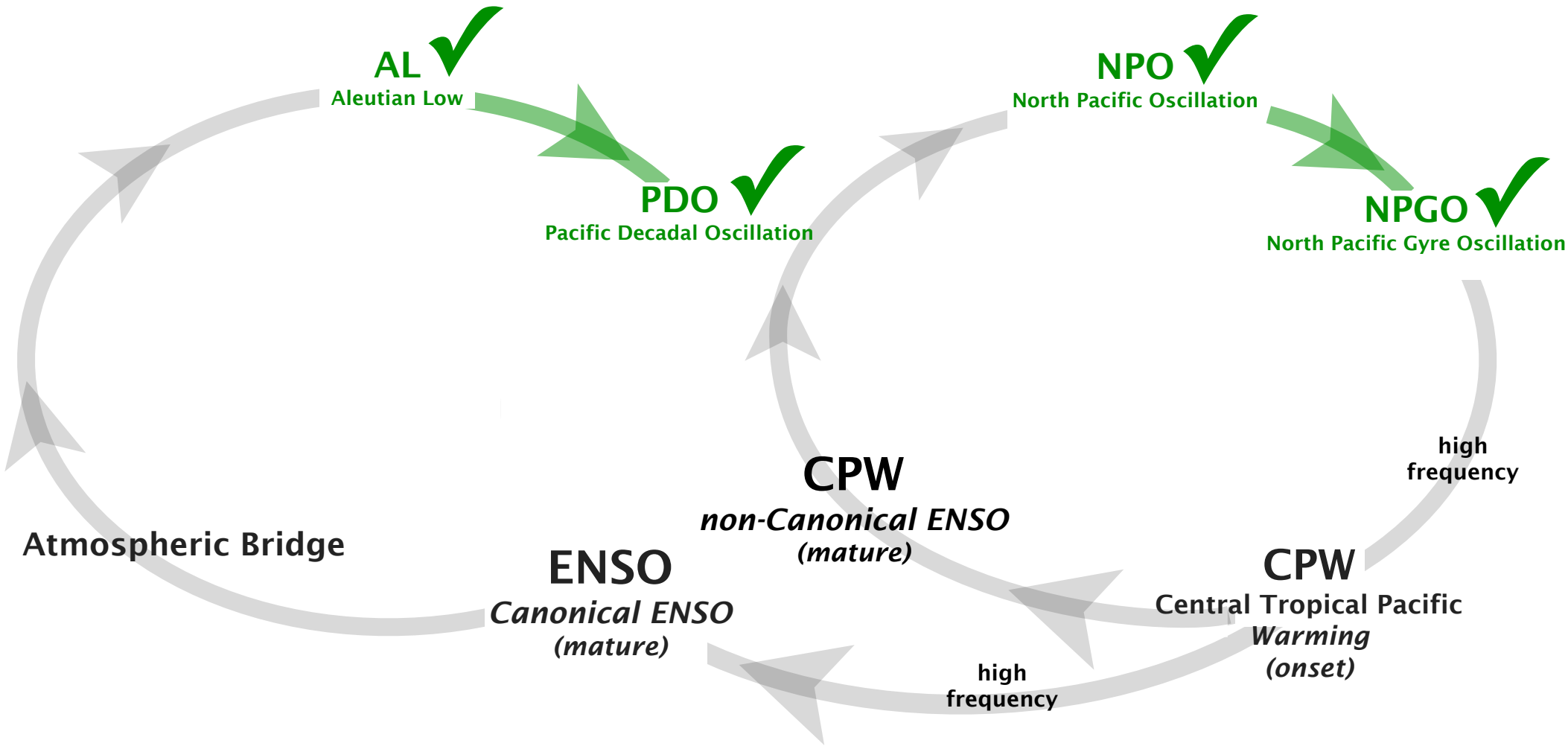

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Furtado et al., 2011

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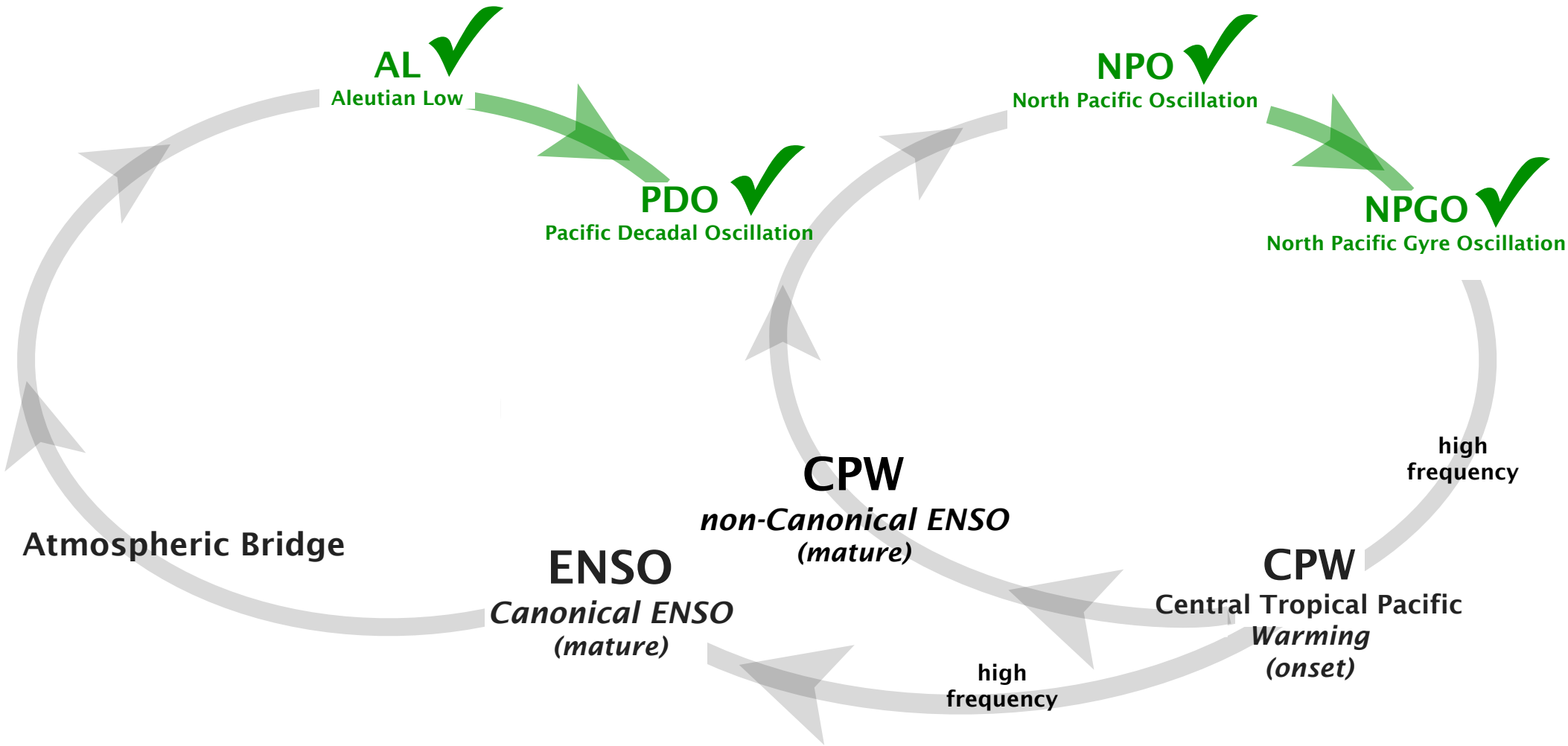

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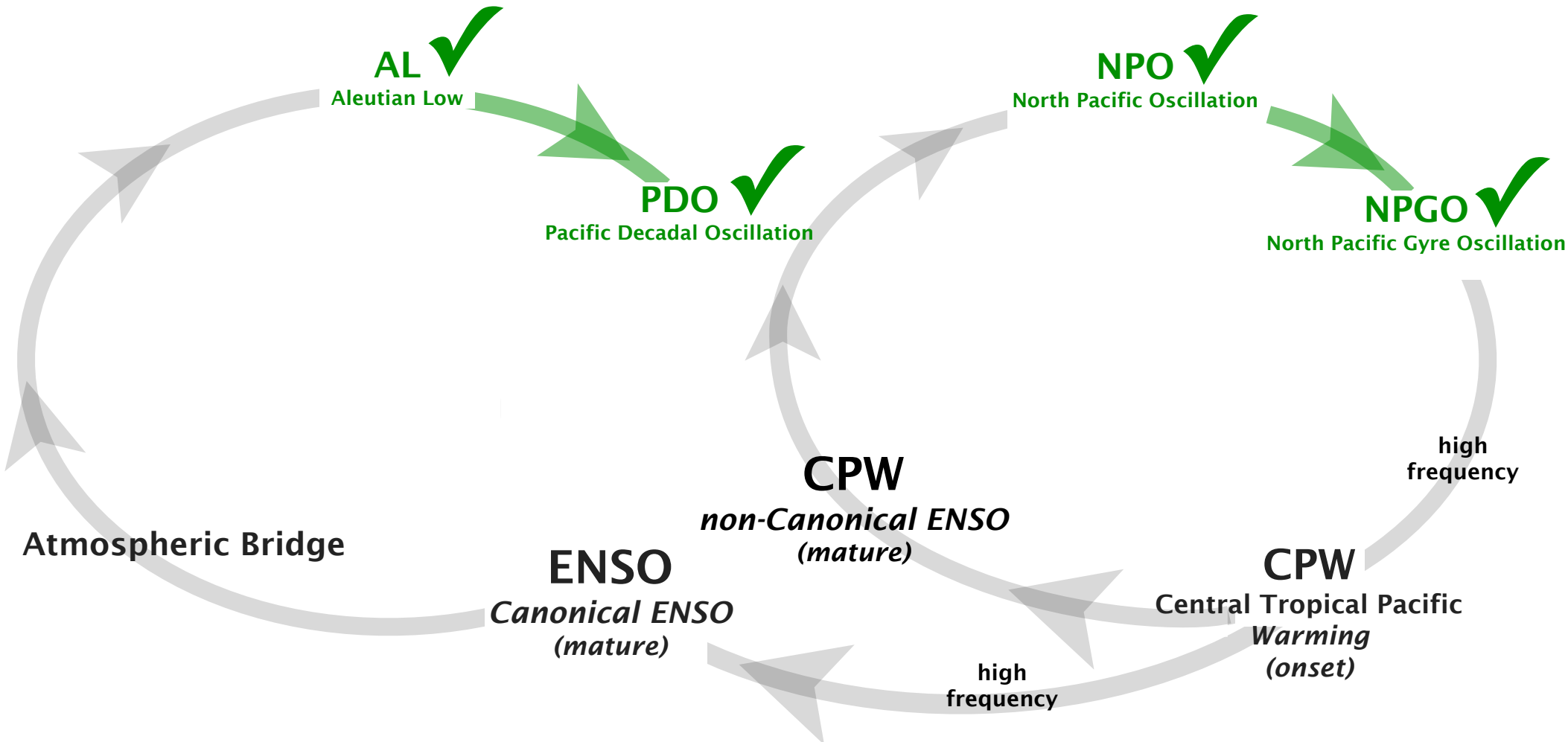
Furtado et al., 2011

Test the AR4 models Pacific decadal dynamics 1800-2000



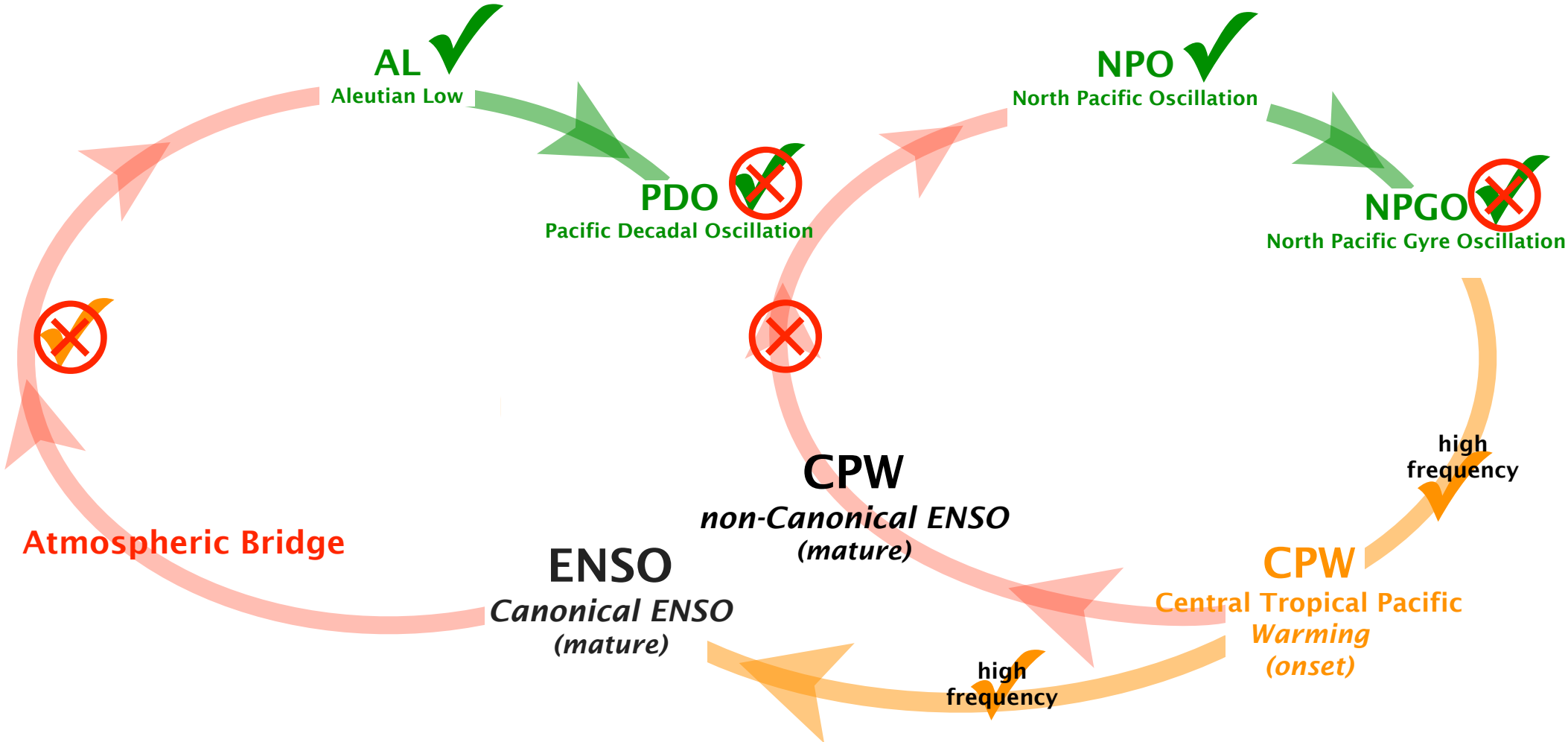
QUESTION:

What changes do the AR4 models predict in the future?

models are inconsistent in predicting changes in the decadal modes spatial structure and frequency

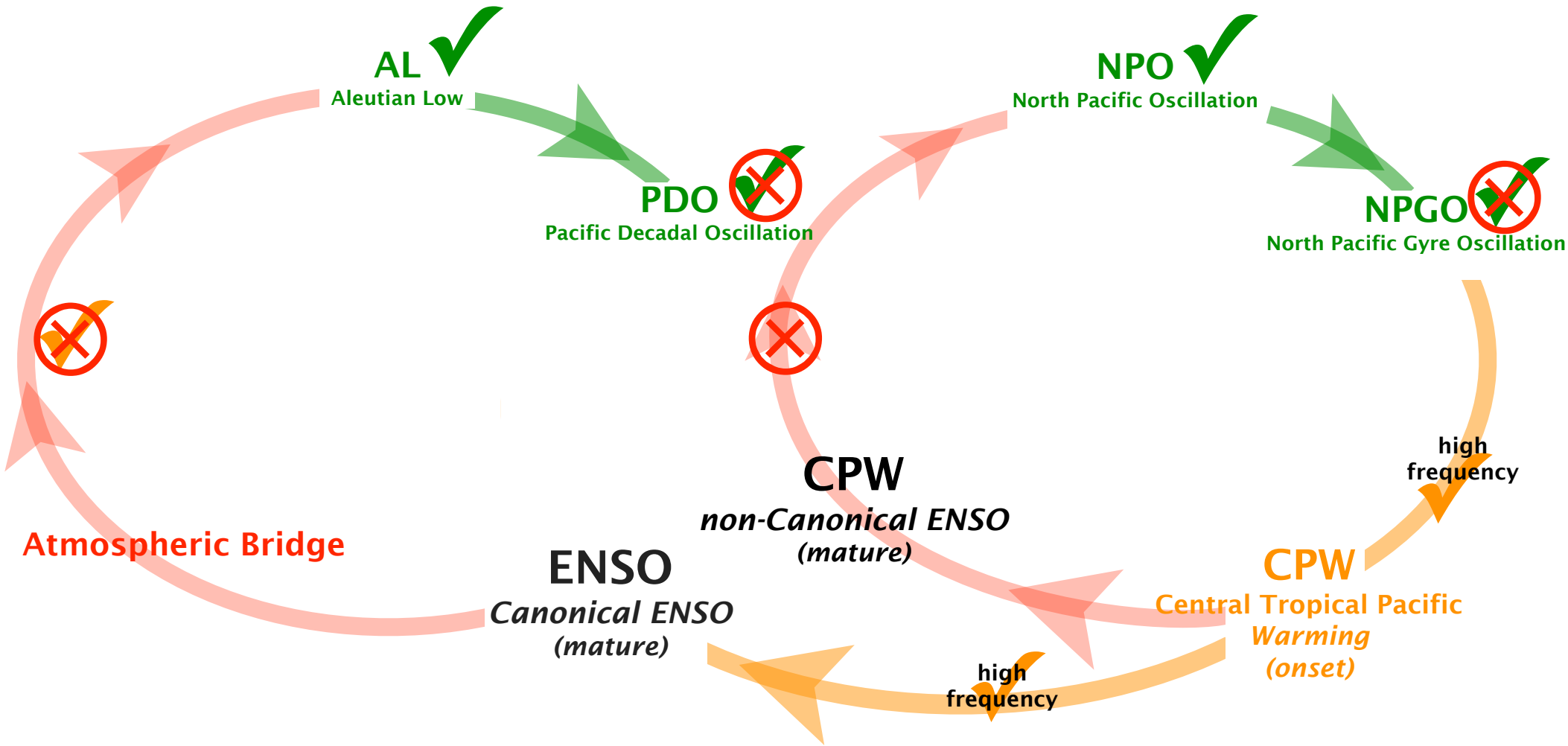
Furtado et al., 2011

Test the AR4 models Pacific decadal dynamics 1800-2000



Furtado et al., 2011

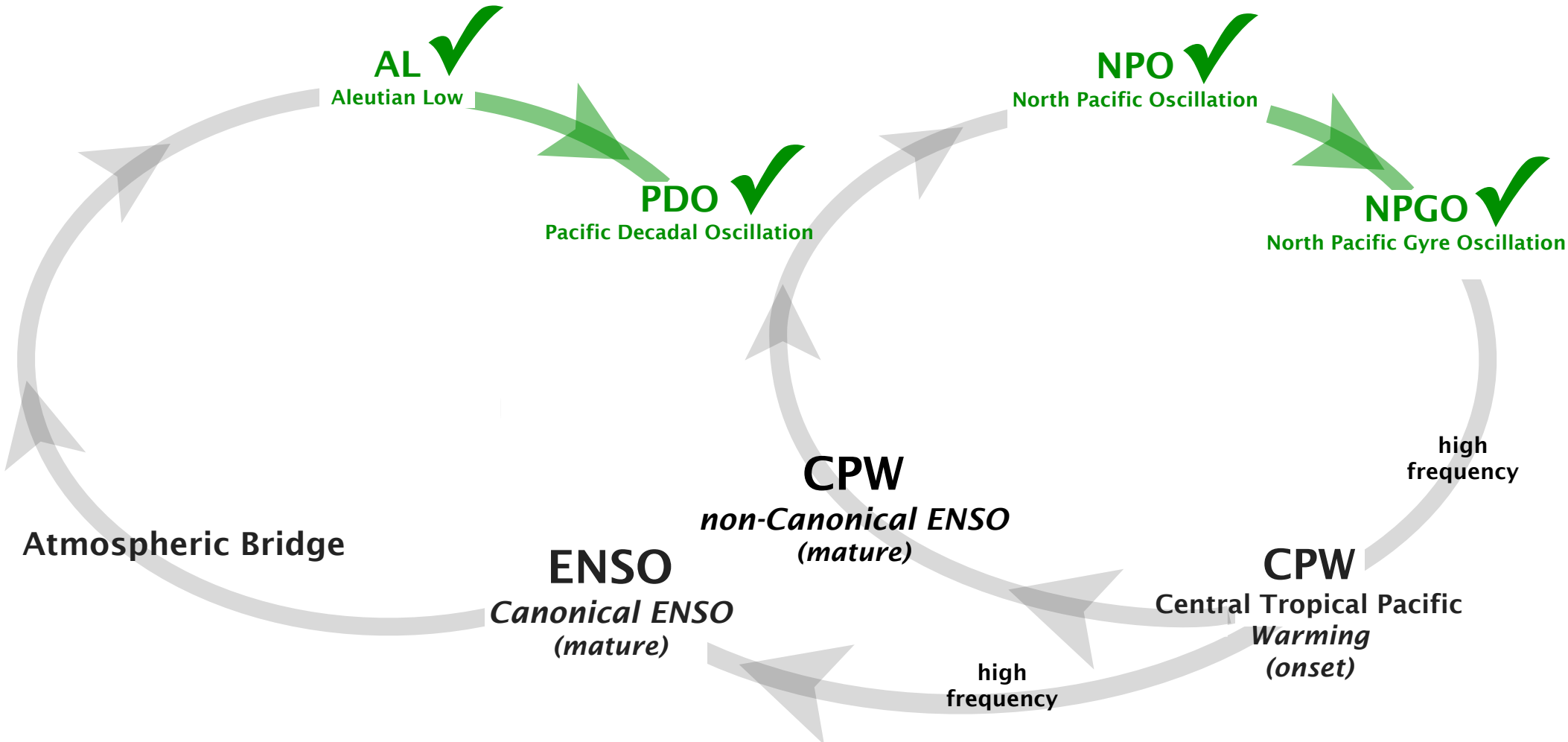
Test the AR4 models Pacific decadal dynamics 1800-2000



... however it is unclear if these predictions are meaningful given the model's bad representation of Pacific dynamics

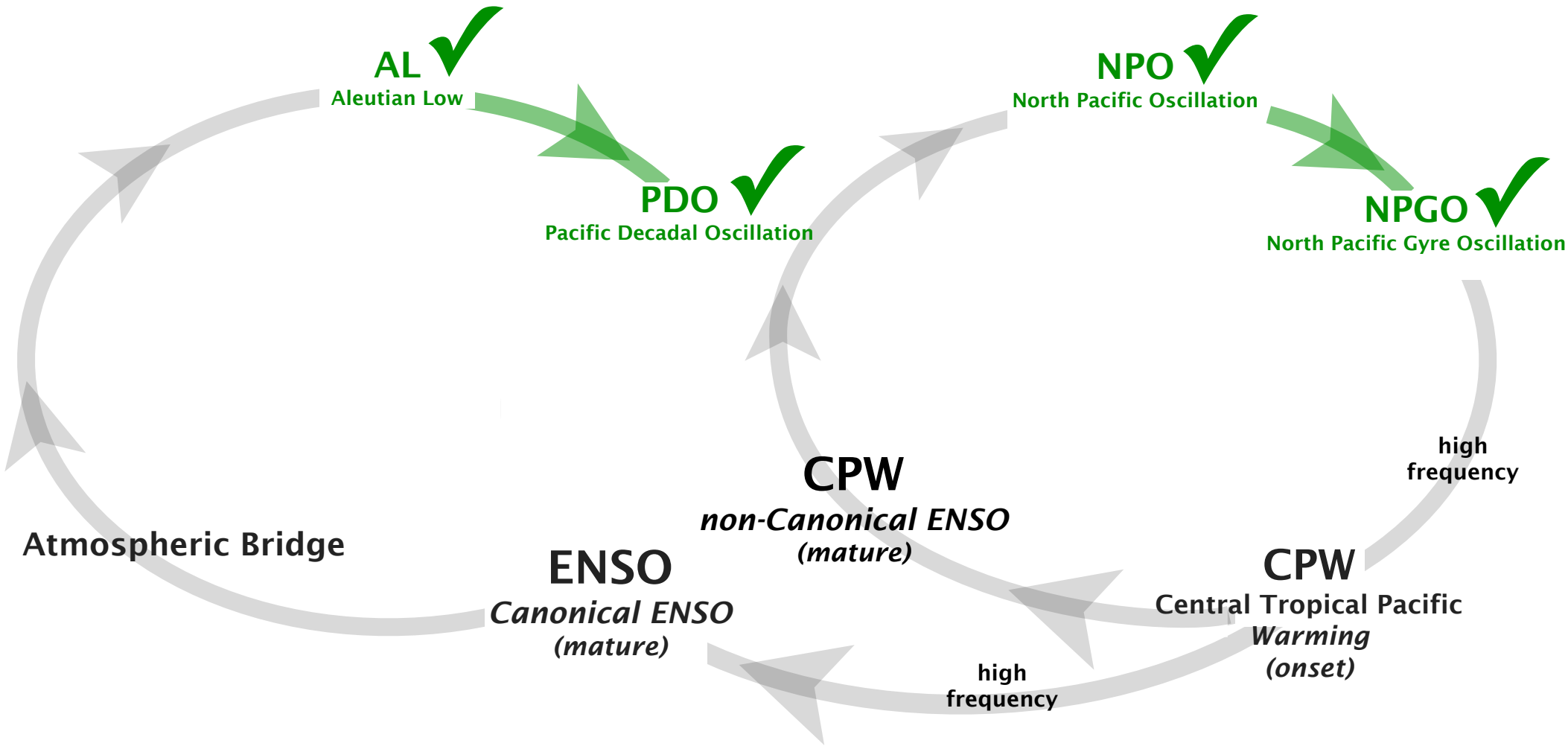
Furtado et al., 2011

Test the AR4 models Pacific decadal dynamics 1800-2000



Furtado et al., 2011

Test the AR4 models Pacific decadal dynamics 1800-2000



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Furtado et al., 2011

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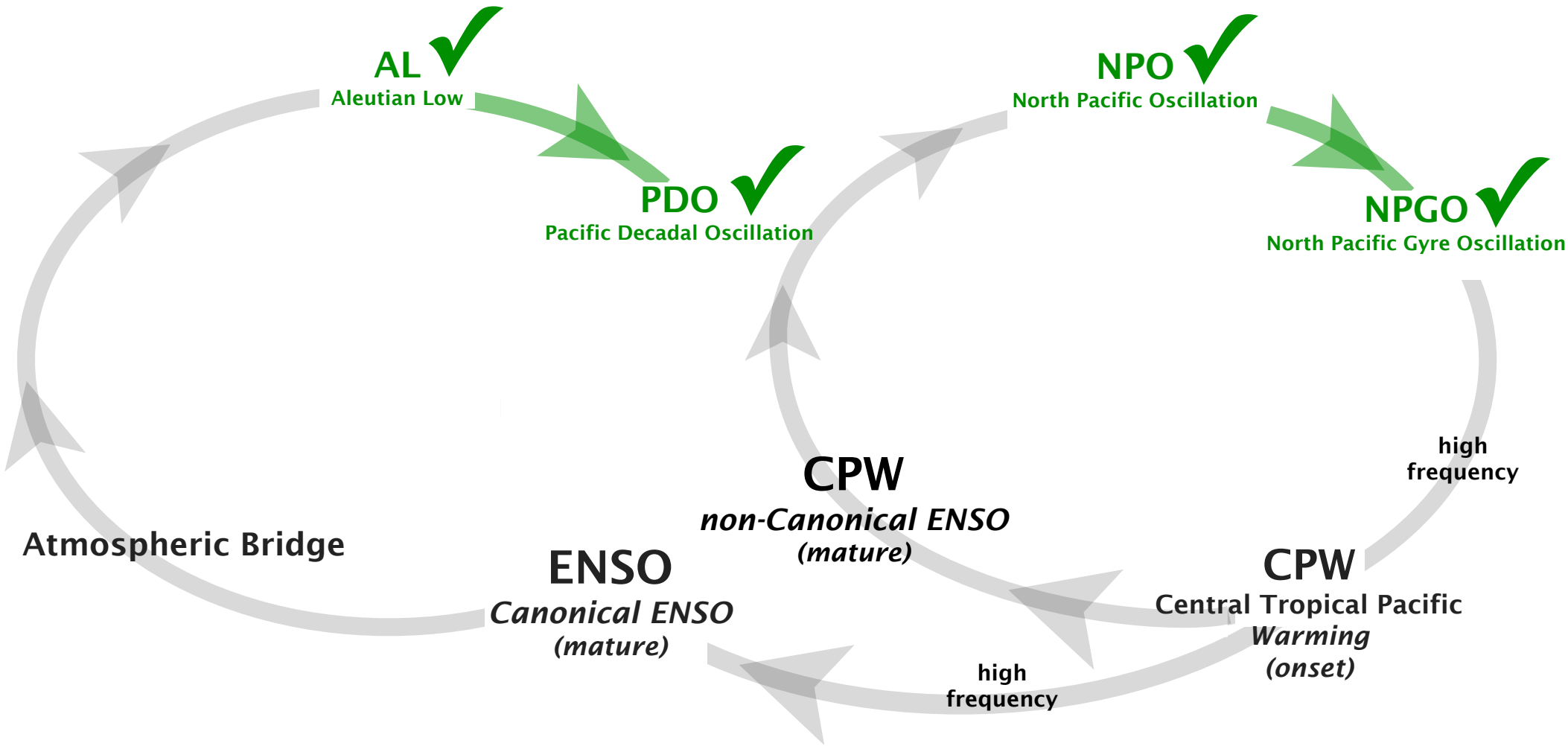

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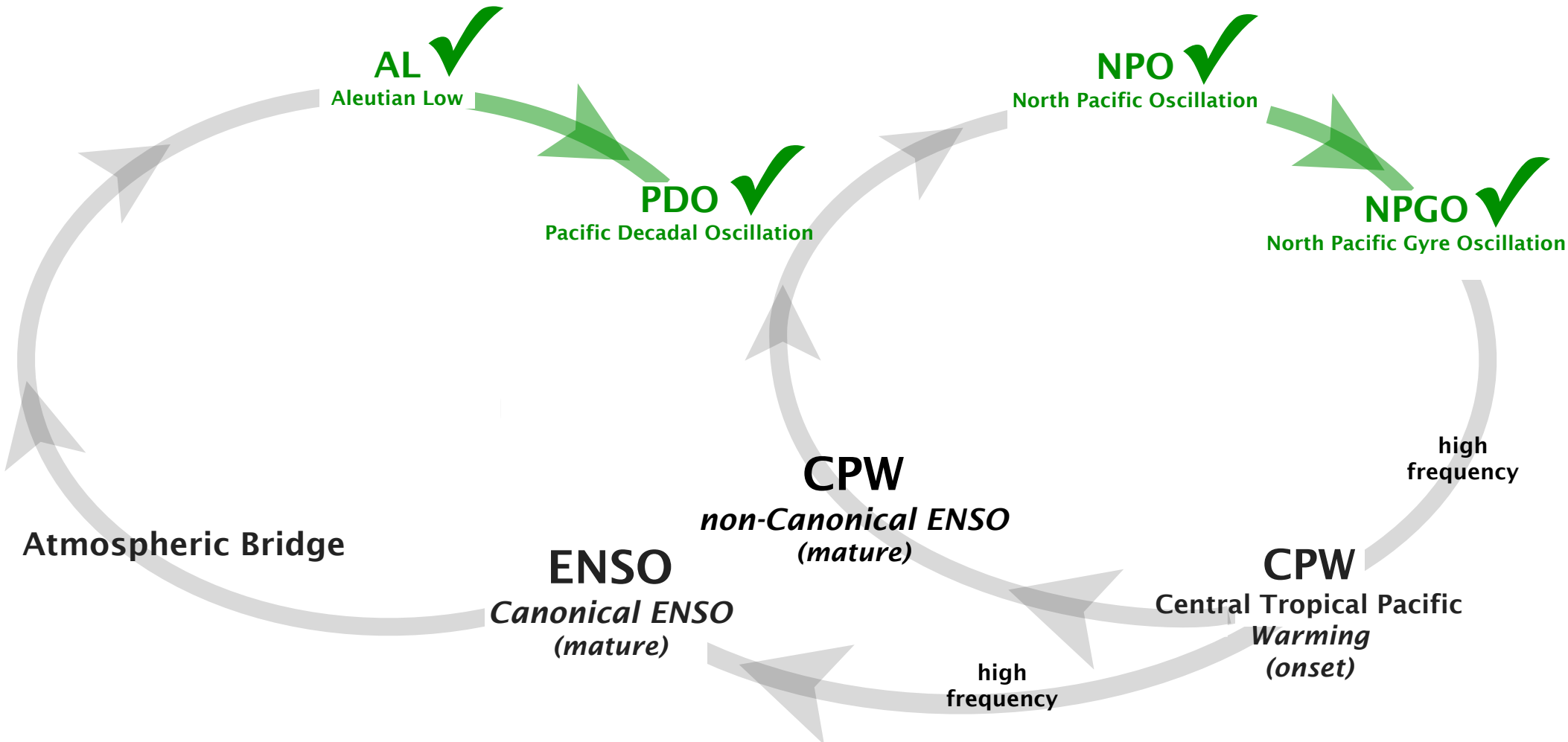

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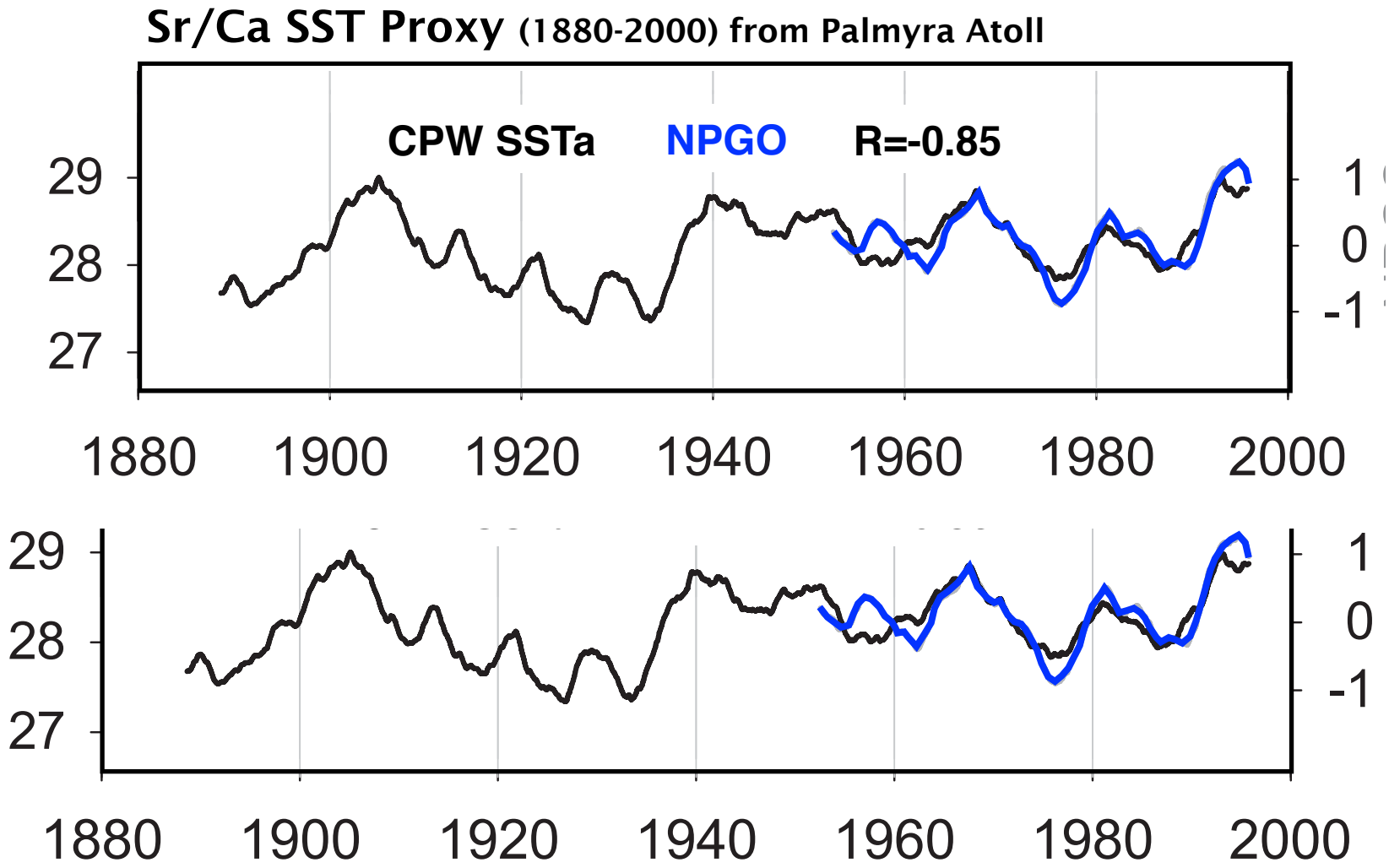
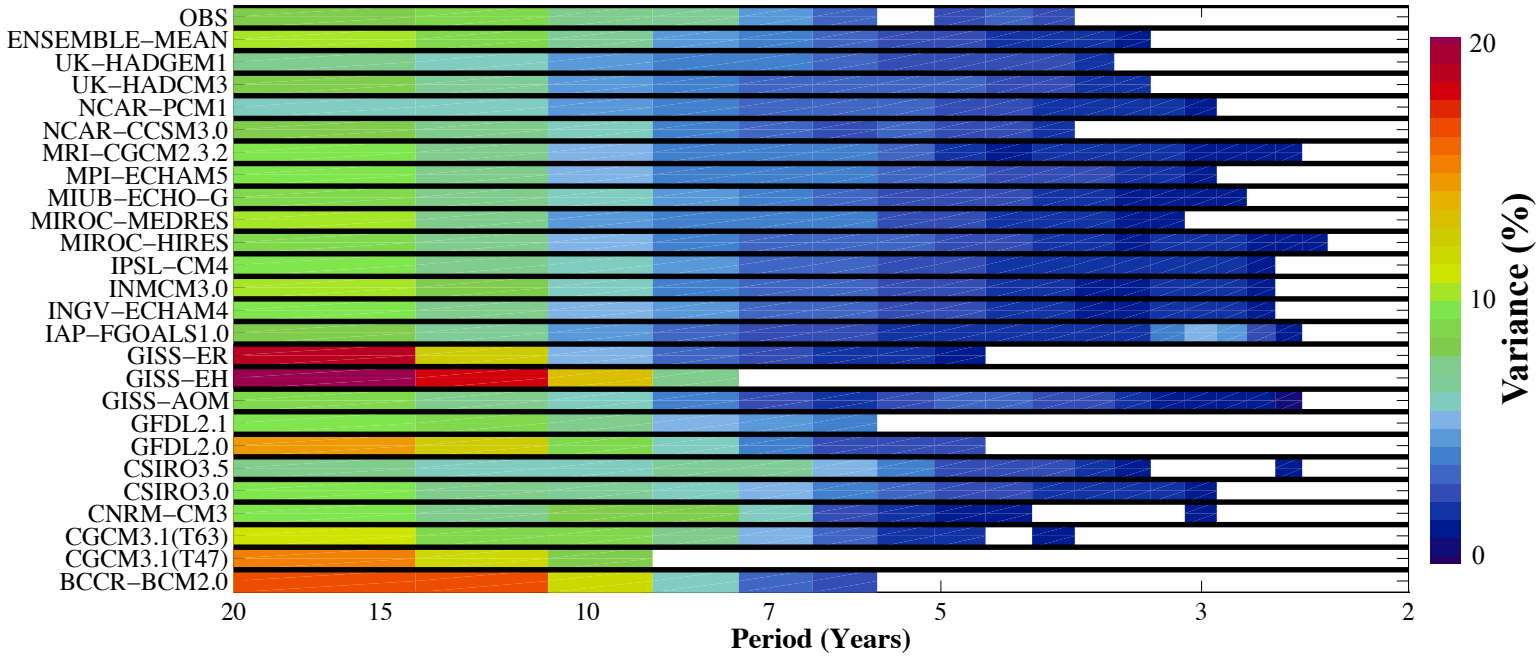
models are inconsistent in predicting changes in the decadal modes spatial structure and frequency

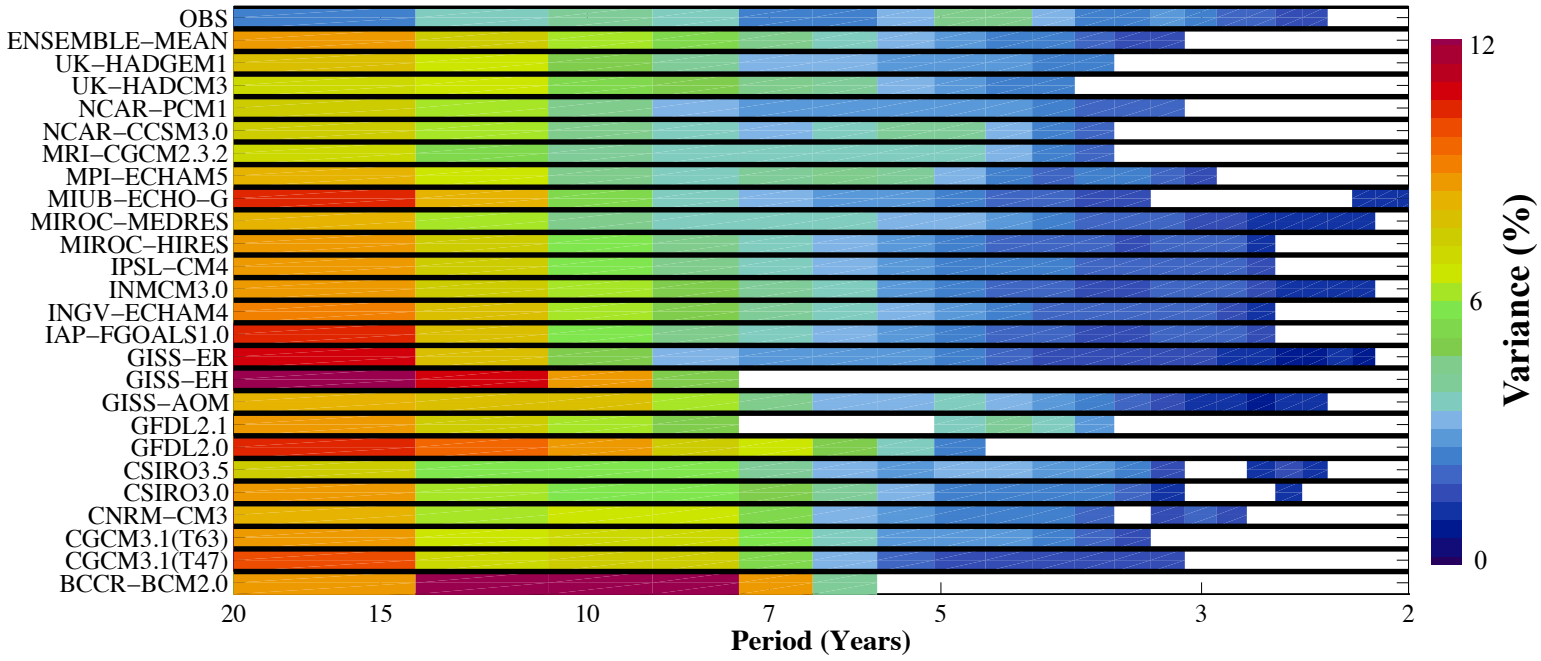
Furtado et al., 2011


Sr/Ca SST Proxy (1880-2000) from Palmyra Atoll
CPW SSTa
NPGO
R=-0.85
29
28
27
1
0
-1
1880
1900
1920
1940
1960
1980
2000

PDO mode SPECTRA



NPGO mode SPECTRA



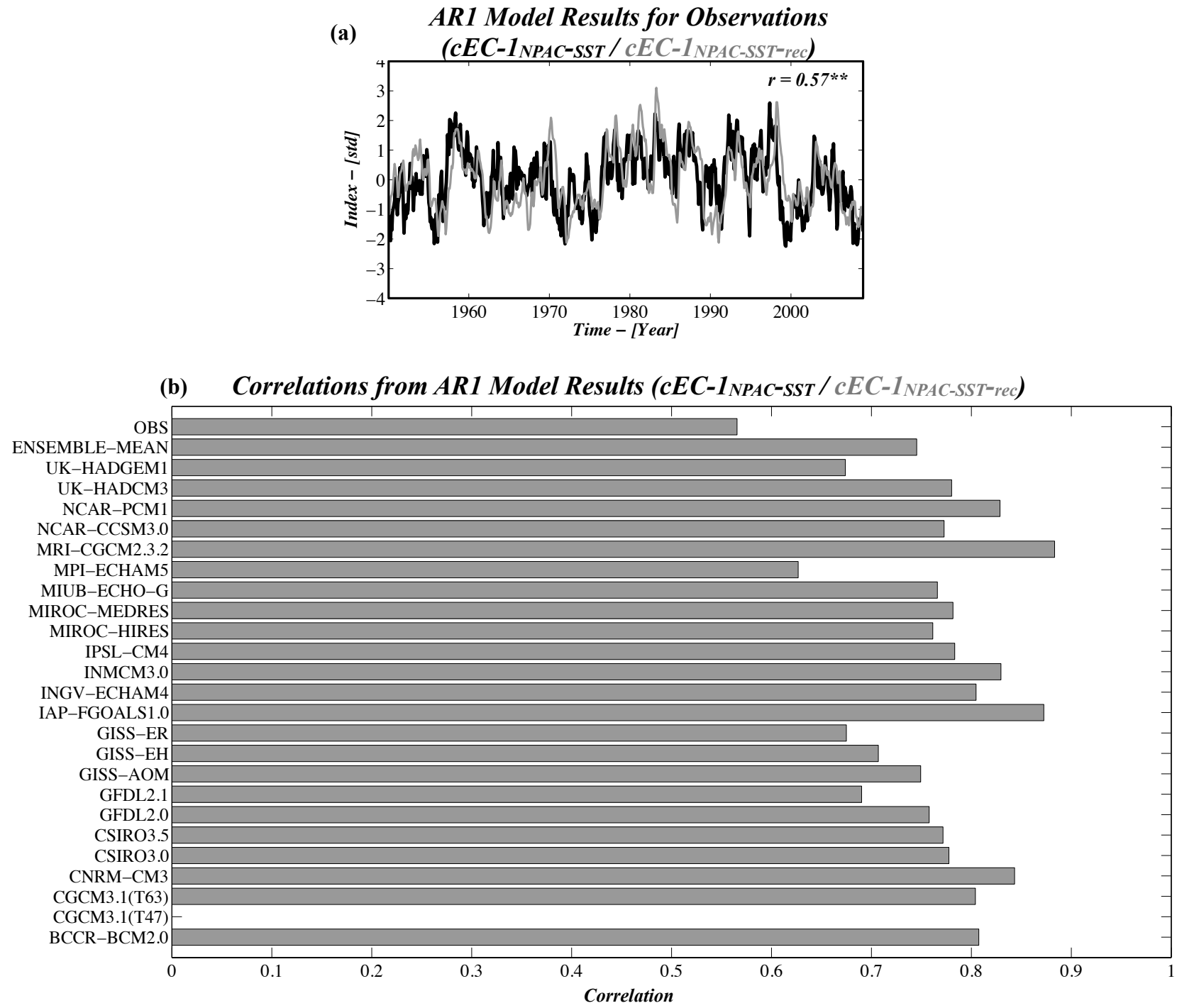


FIG. 6. (a) The observed cEC-$1_{\text{NPAC-SST}}$ index and the cEC-$1_{\text{NPAC-SST-rec}}$ index (gray line) from the AR-1 model (see text). Correlation between cEC-$1_{\text{NPAC-SST}}$ and cEC-$1_{\text{NPAC-SST-rec}}$ is shown and is significant at the 99% significance level (double asterisk). (b) Correlations between the cEC-$1_{\text{NPAC-SST}}$ index and cEC-$1_{\text{NPAC-SST-rec}}$ for the observations, the ensemble-mean, and all 24 models for their 20C3M runs. Only correlations exceeding the 95% significance level are plotted.

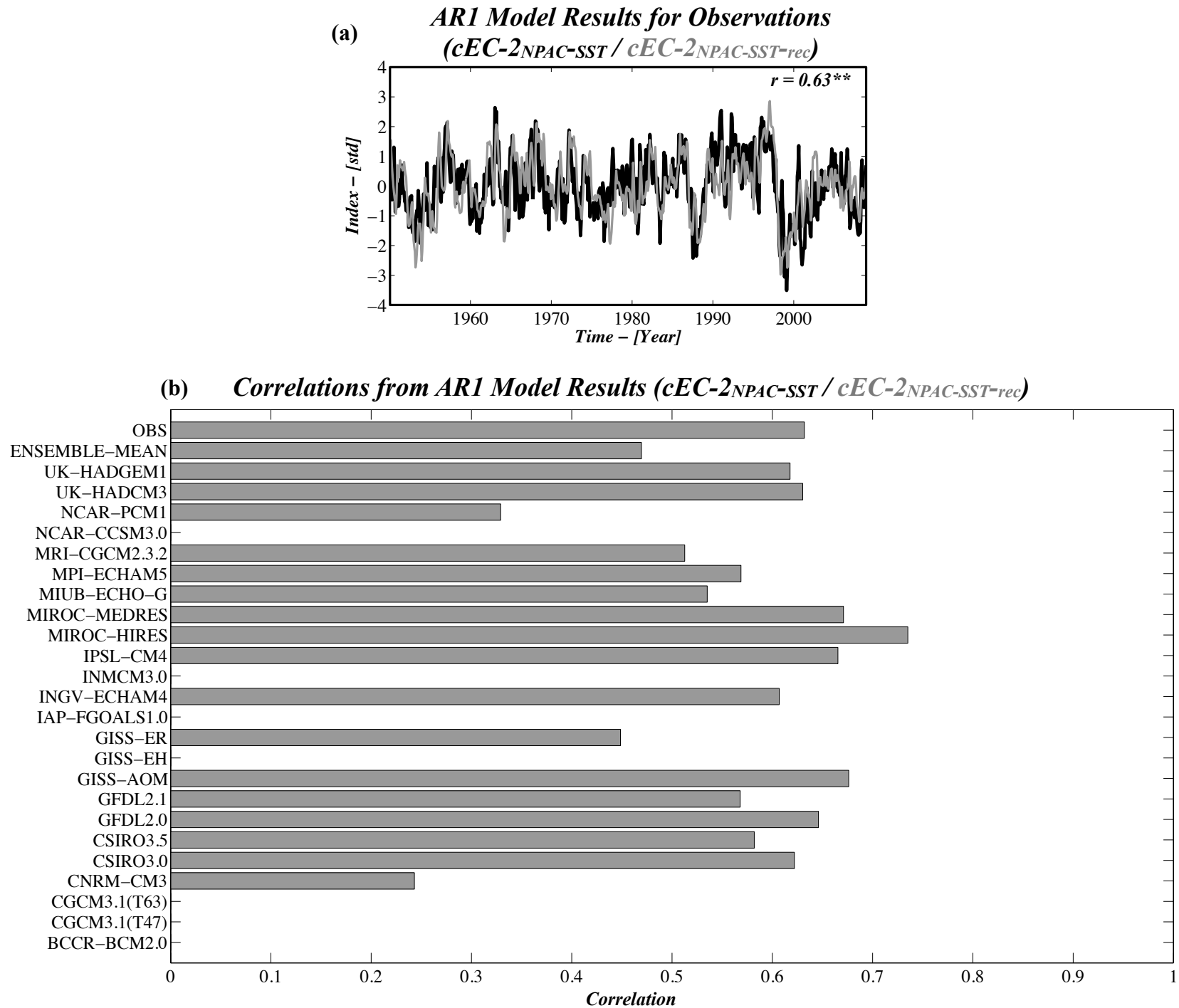


FIG. 7. (a) The observed cEC-$2_{\text{NPAC-SST}}$ index and the cEC-$2_{\text{NPAC-SST-rec}}$ index (gray line) from the AR-1 model (see text). Correlation between cEC-$2_{\text{NPAC-SST}}$ and cEC-$2_{\text{NPAC-SST-rec}}$ is shown and is significant at the 99% significance level (double asterisk). (b) Correlations between the cEC-$2_{\text{NPAC-SST}}$ index and cEC-$2_{\text{NPAC-SST-rec}}$ for the observations, the ensemble-mean, and all 24 models for their 20C3M runs. Only correlations exceeding the 95% significance level are plotted.

Furtado et al. 2011: Low-frequency dynamics of the North Pacific Oscillation. Climate Dynamics, submi

Vimont and Battisti, 2011: Influence of the meridional mode on the zonal mode (ENSO) of variability in

Di Lorenzo et al. 2011: ENSO and the North Pacific Gyre Oscillation: an integrated view of Pacific decad

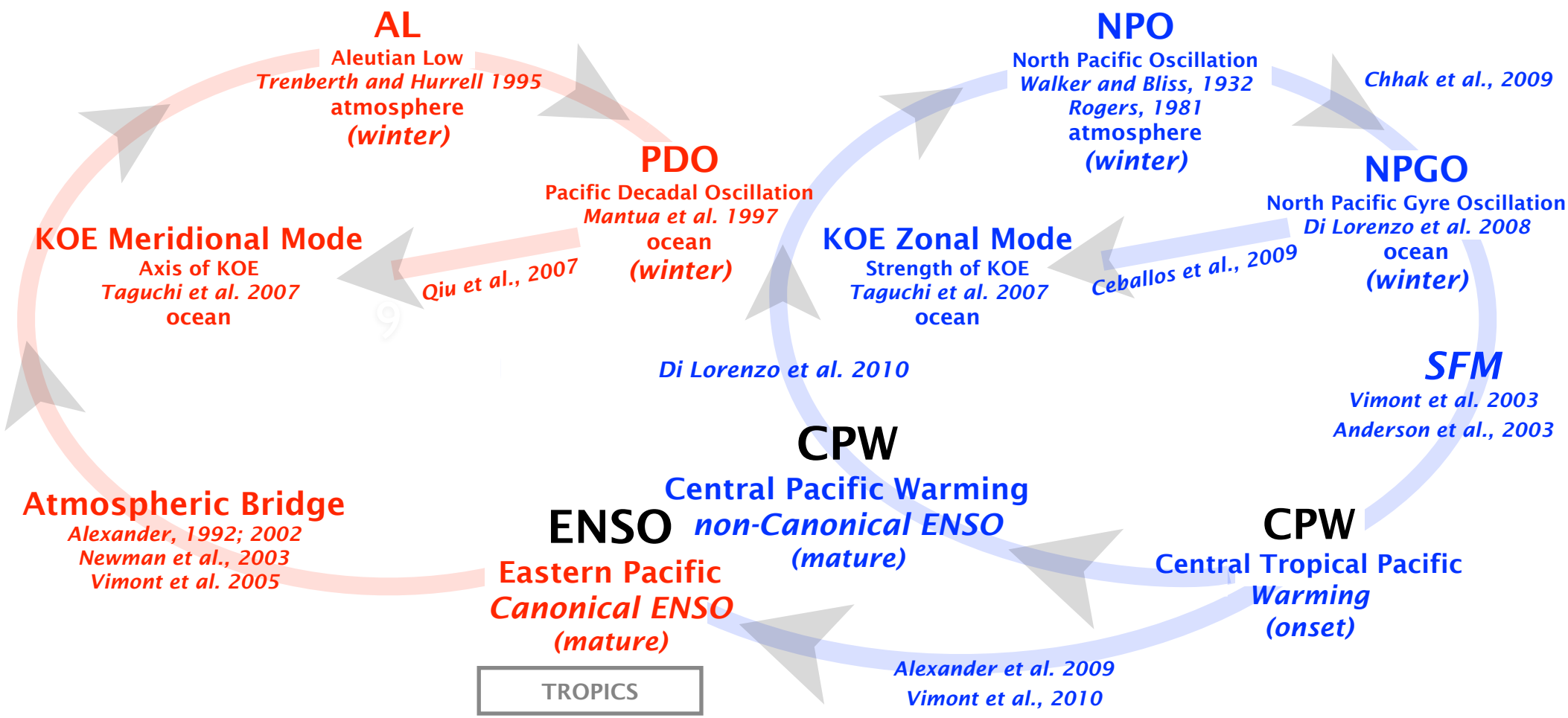
Di Lorenzo et al. 2010: **Central Pacific Warming El Nino and decadal climate change in the North Pacific**. *Nature Geoscience*, DOI: 10.1038/NGEO984.

Vimont, 2010: **Transient growth of thermodynamically coupled disturbances in the tropics under an equatorially symmetric mean state**. *Journal of Climate* , vol. 23 (21) pp. 5771-5789.

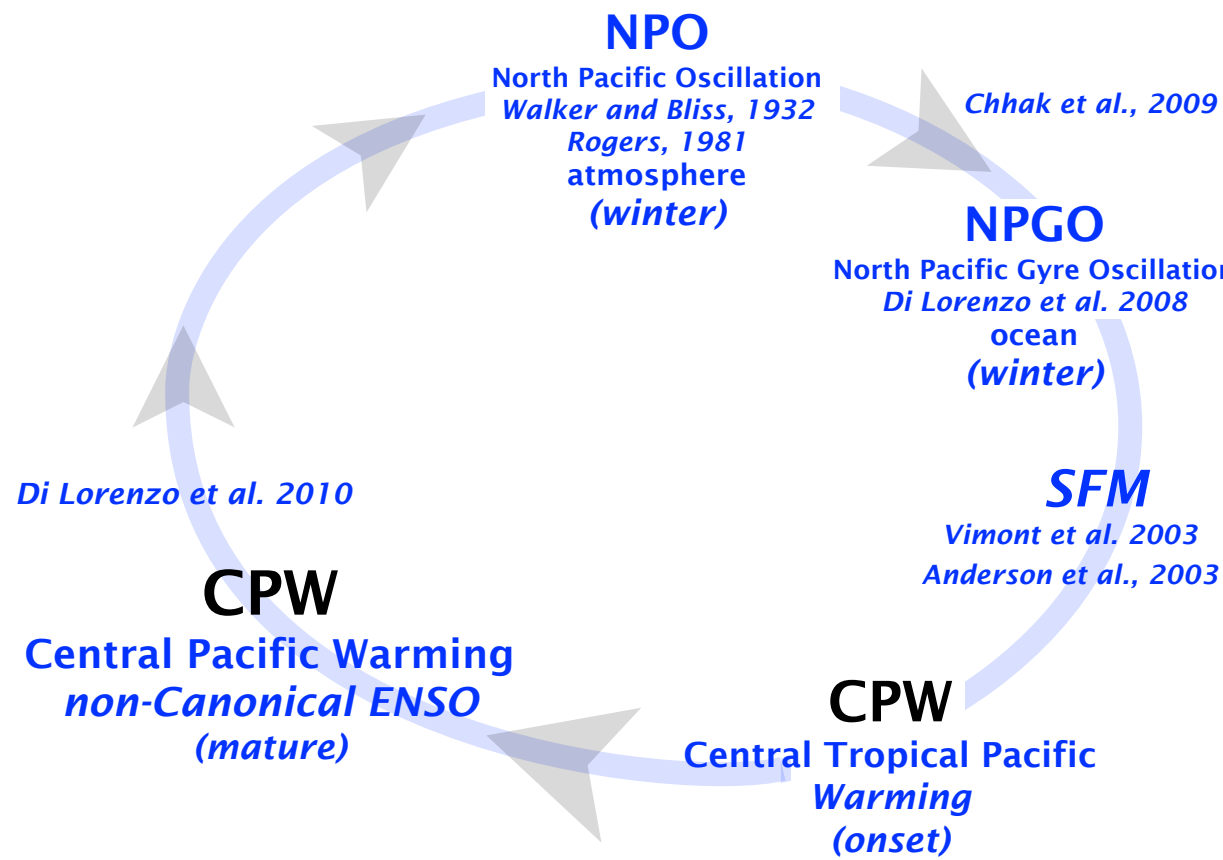
Furtado et al. 2011: **North Pacific Decadal Variability and Climate Change in the IPCC AR4 Models**. *Journal of Climate*, doi: 10.1175/2010JCLI3584.1.

Nurhati et al. 2011: **Decadal-scale SST and salinity variations in the central tropical Pacific: Signatures of natural and anthropogenic climate change**. *Journal of Climate*, vol. 24 (13) pp. 3294-3308.

Newman et al., 2011: **Natural variation in ENSO flavors**. *Geophysical Research Letters* , DOI: 10.1029/2011GL047658.



What do observations tell us about the impact of climate change on the decadal modes?



QUESTION:

How do AR4 models capture these Pacific decadal modes and their connections during past climate simulations 1800-2000 ?

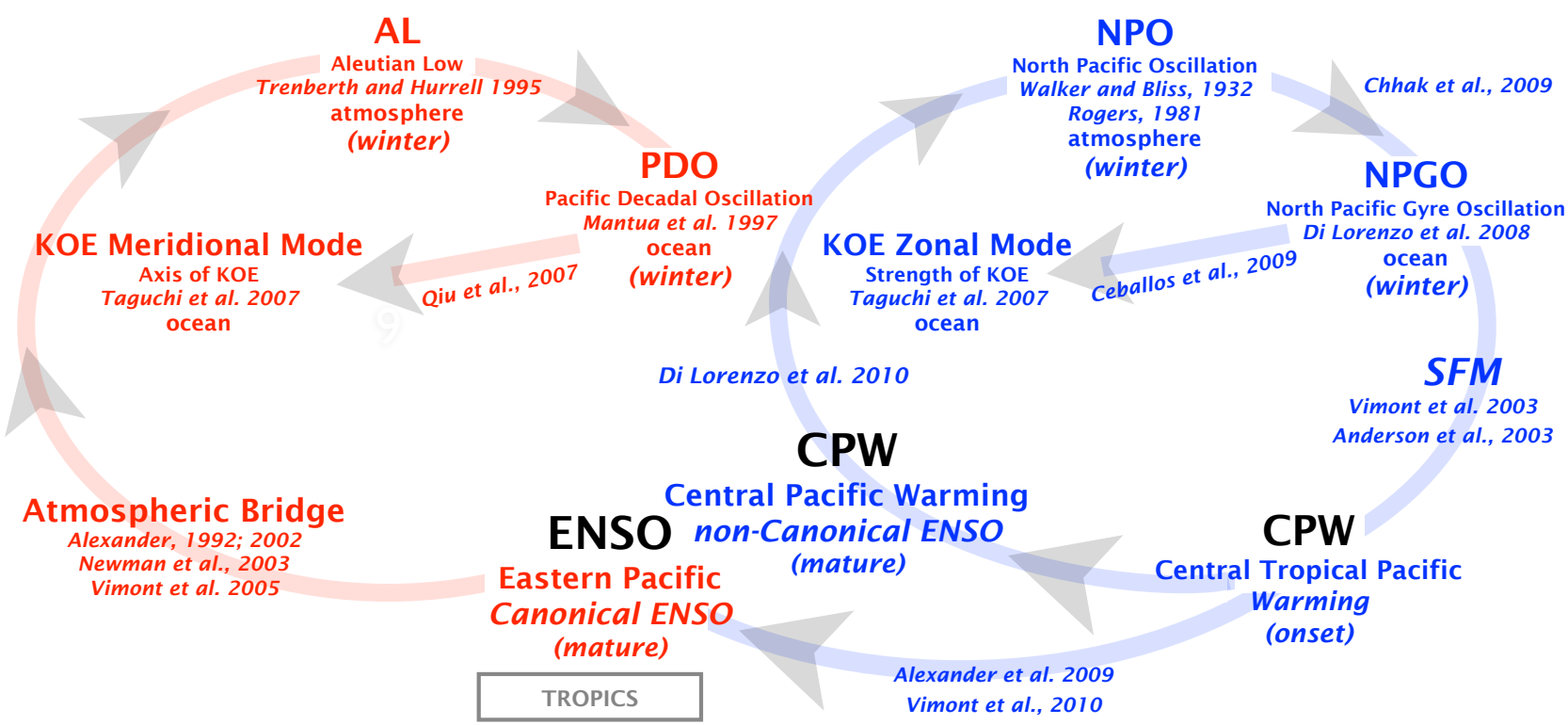
PODX – Pacific Ocean Decadal Variability & Climate Change Study – www.Pacific-Climate-Change.Org

file:///Users/manu/Neo/Neo.Webs/pax/pubs.html

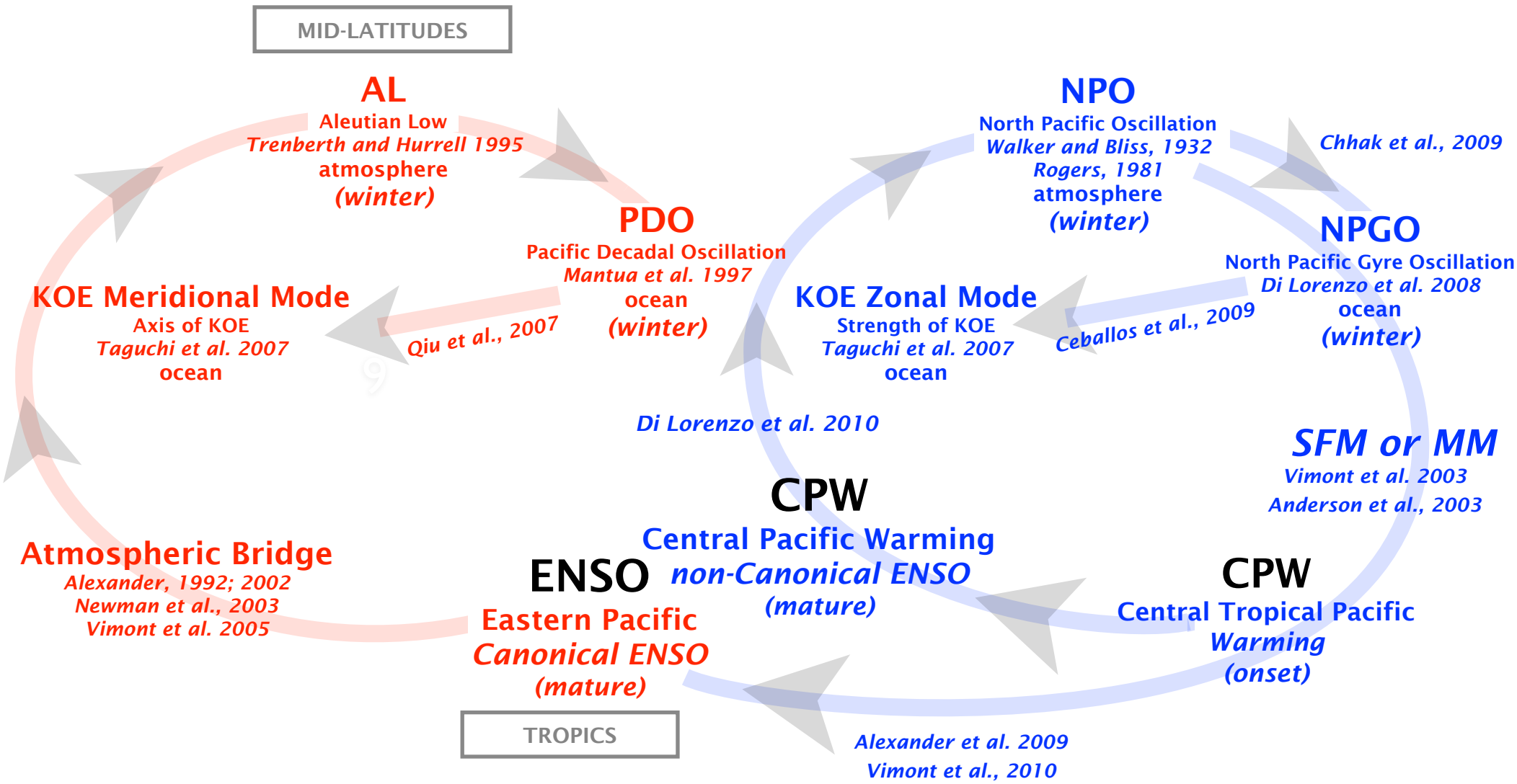
Google

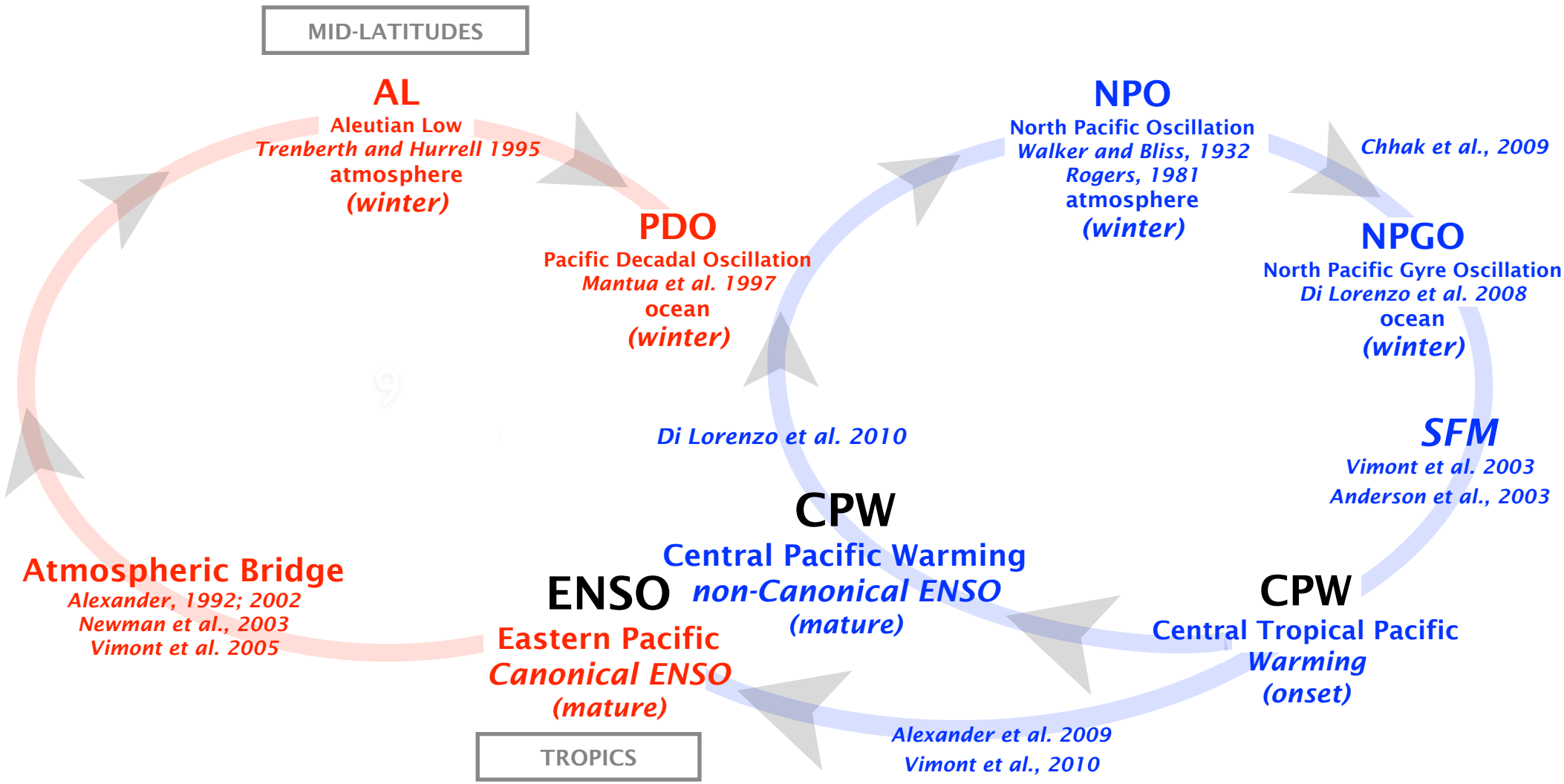
Atlanta | OS X | GaTech | Cucina | Cooking | Daycare | Soul | MATLAB | How to embe...k Overflow | PACE | PACE blog

Pacific Ocean Decadal Variability & Climate Change



Additional Slides


MID-LATITUDES
AL
Aleutian Low
Trenberth and Hurrell 1995
atmosphere
(winter)
PDO
Pacific Decadal Oscillation
Mantua et al. 1997
ocean
(winter)
KOE Meridional Mode
Axis of KOE
Taguchi et al. 2007
ocean
Qiu et al., 2007
NPO
North Pacific Oscillation
Walker and Bliss, 1932
Rogers, 1981
atmosphere
(winter)
Chhak et al., 2009
NPGO
North Pacific Gyre Oscillation
Di Lorenzo et al. 2008
ocean
(winter)
KOE Zonal Mode
Strength of KOE
Taguchi et al. 2007
ocean
Ceballos et al., 2009
Di Lorenzo et al. 2010
SFM or MM
Vimont et al. 2003
Anderson et al., 2003
CPW
Central Pacific Warming
non-Canonical ENSO
(mature)
ENSO
Eastern Pacific
Canonical ENSO
(mature)
Atmospheric Bridge
Alexander, 1992; 2002
Newman et al., 2003
Vimont et al. 2005
CPW
Central Tropical Pacific
Warming
(onset)
Alexander et al. 2009
Vimont et al., 2010
TROPICS


MID-LATITUDES
AL
Aleutian Low
Trenberth and Hurrell 1995
atmosphere
(winter)
PDO
Pacific Decadal Oscillation
Mantua et al. 1997
ocean
(winter)
NPO
North Pacific Oscillation
Walker and Bliss, 1932
Rogers, 1981
atmosphere
(winter)
Chhak et al., 2009
NPGO
North Pacific Gyre Oscillation
Di Lorenzo et al. 2008
ocean
(winter)
SFM
Vimont et al. 2003
Anderson et al., 2003
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CPW
Central Pacific Warming
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(mature)
ENSO
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Warming
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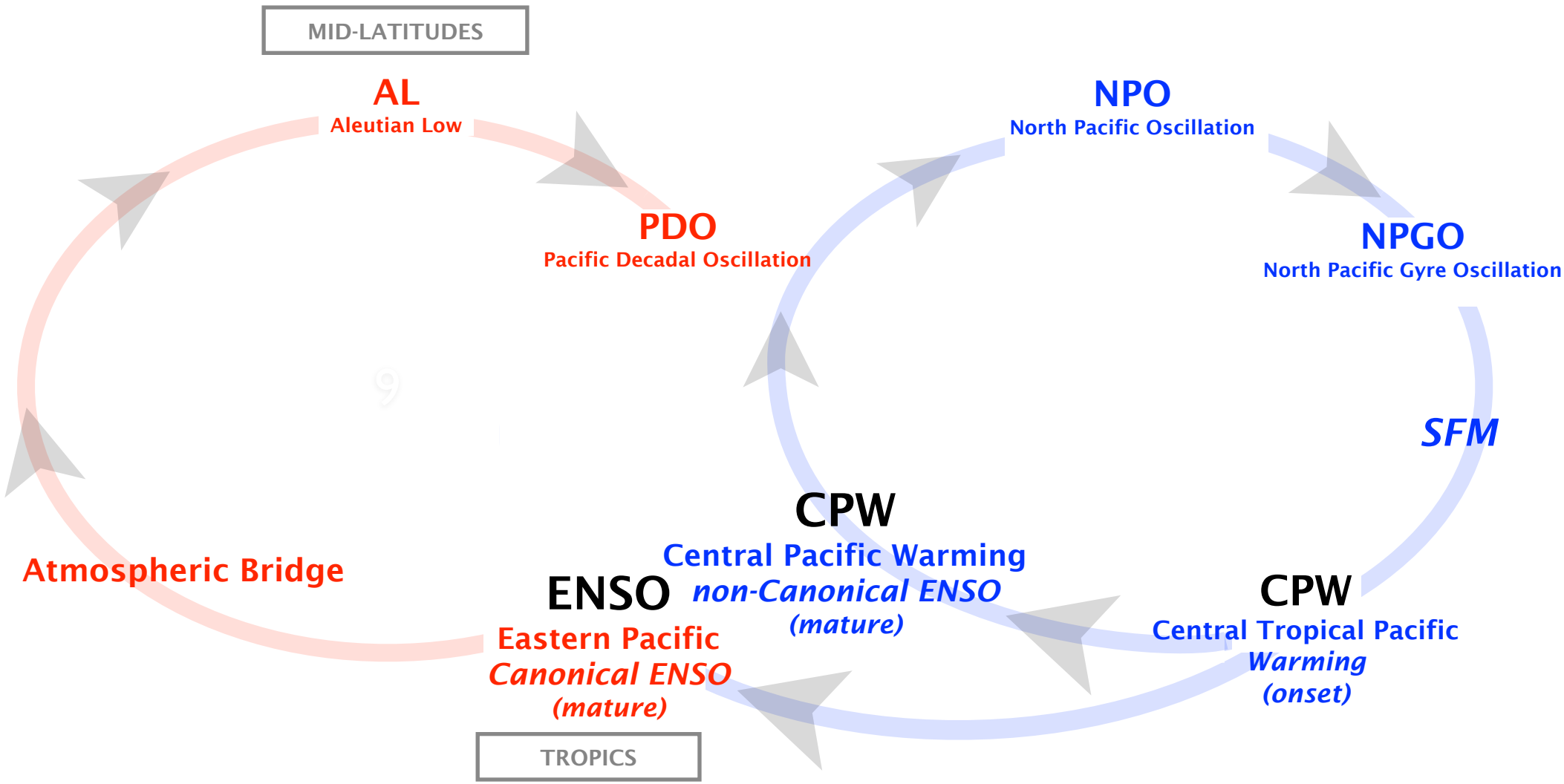
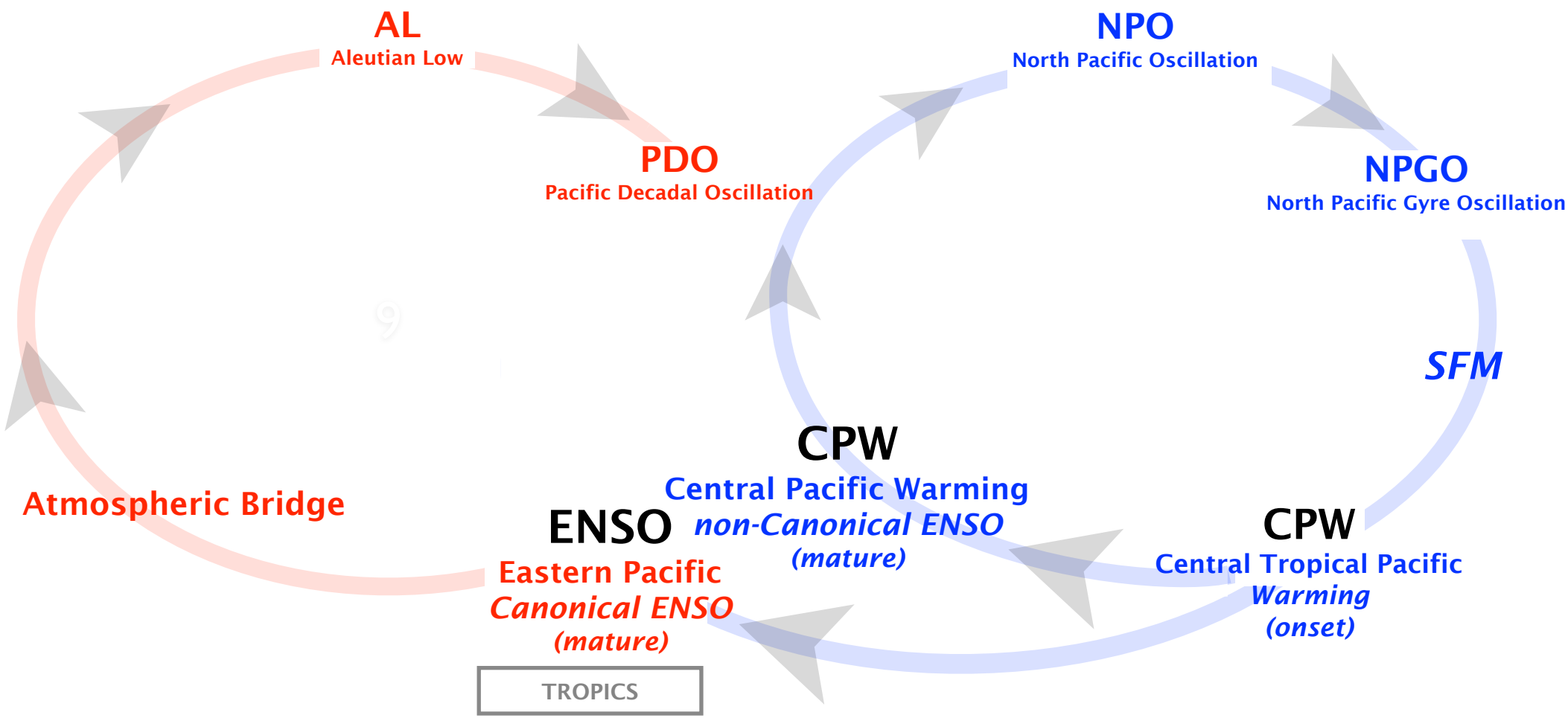
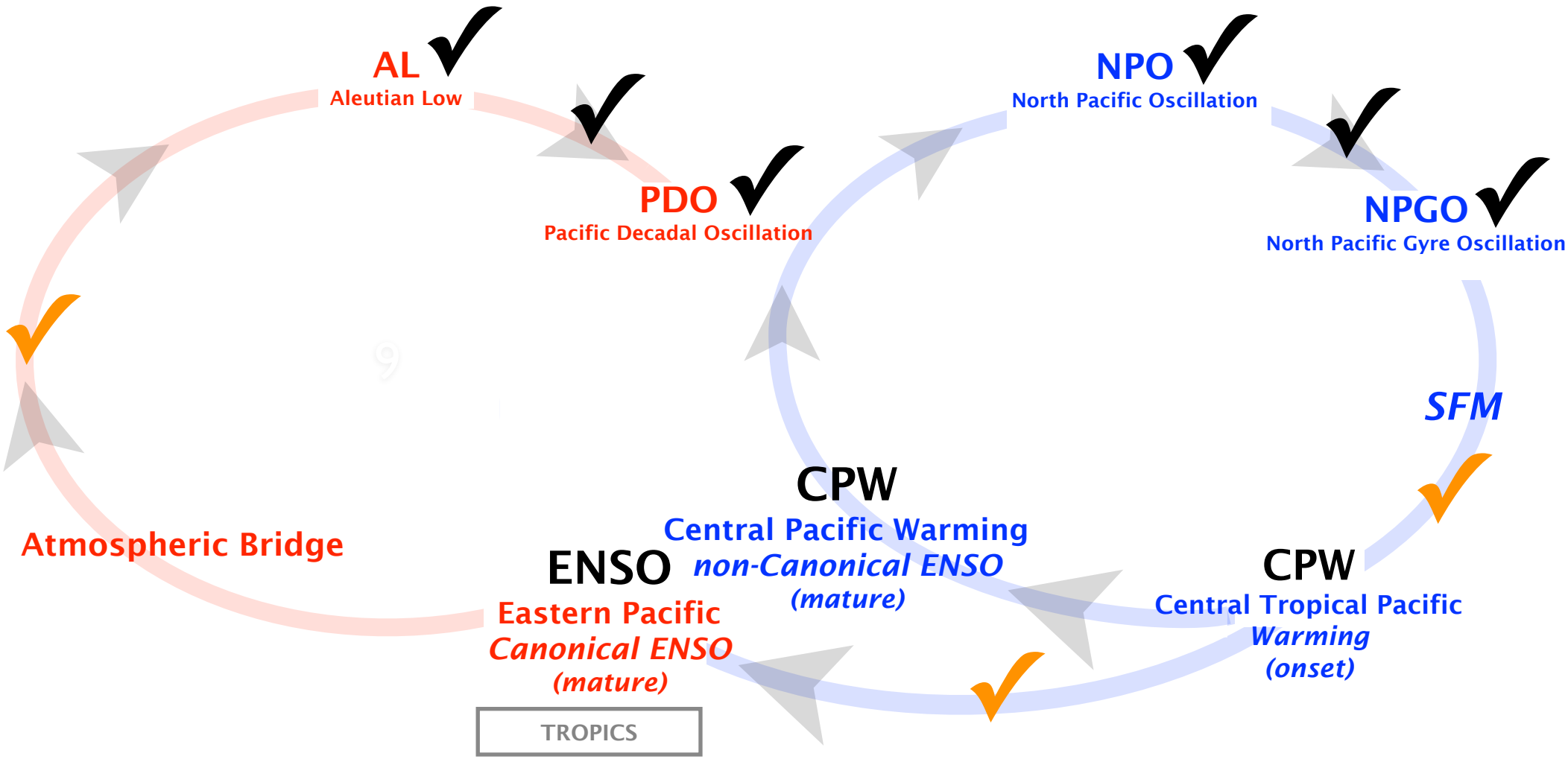
TROPICS


MID-LATITUDES
AL
Aleutian Low
PDO
Pacific Decadal Oscillation
NPO
North Pacific Oscillation
NPGO
North Pacific Gyre Oscillation
SFM
Atmospheric Bridge
CPW
Central Pacific Warming
non-Canonical ENSO
(mature)
ENSO
Eastern Pacific
Canonical ENSO
(mature)
CPW
Central Tropical Pacific
Warming
(onset)
TROPICS

Decadal climate dynamics of the AR4 Models (*1800-2000*)

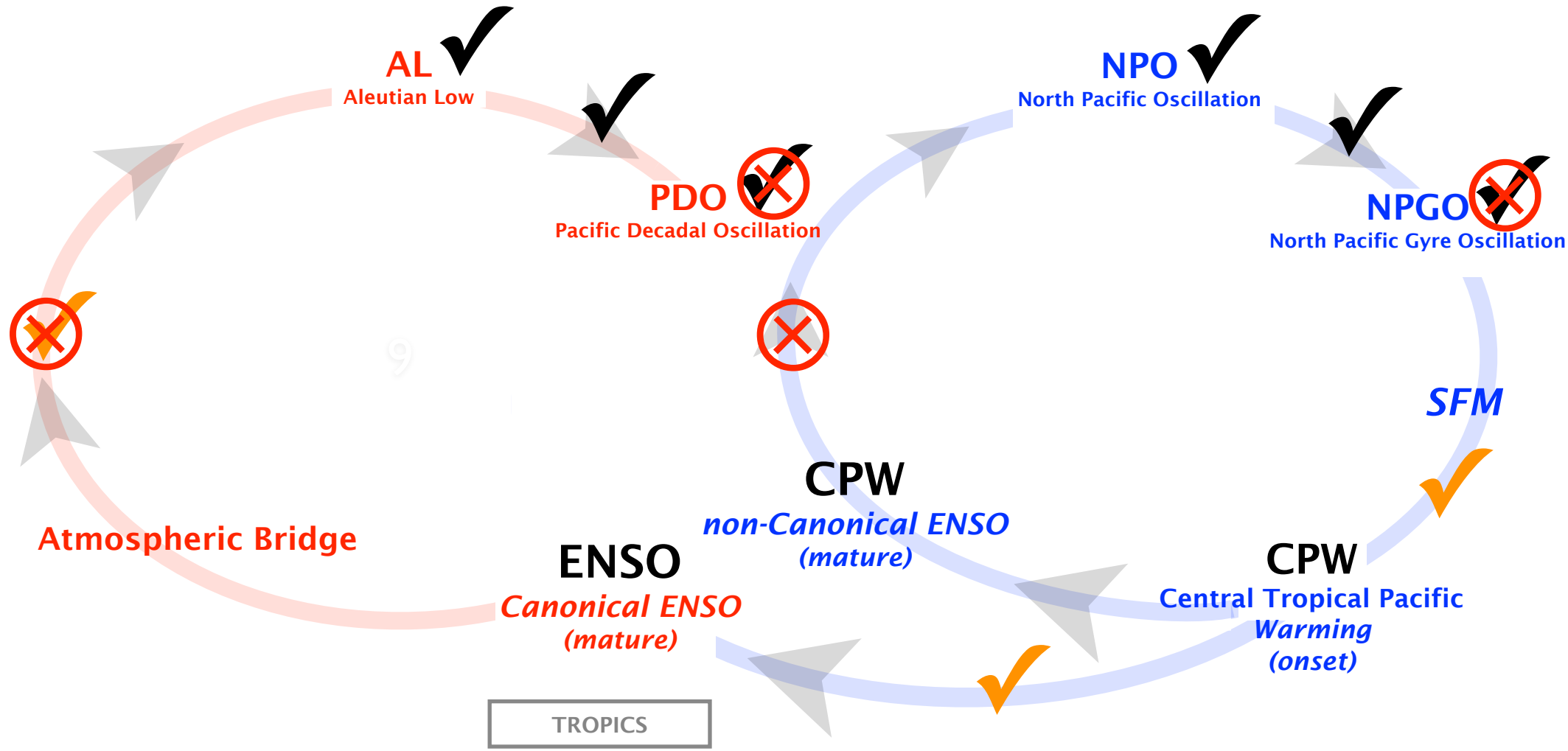


Decadal climate dynamics of the AR4 Models (*1800-2000*)



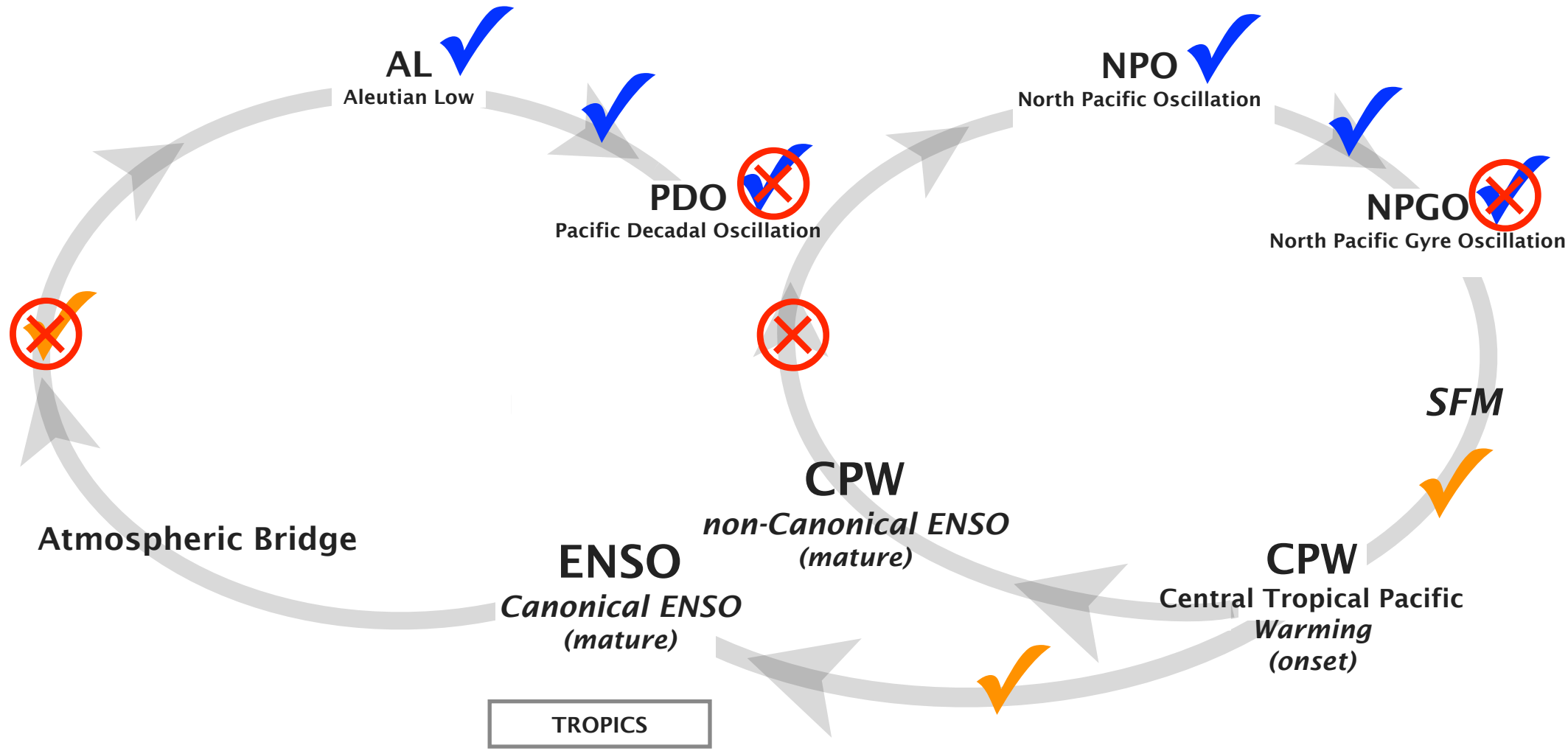
1. Capture the spatial expression of the modes
2. Capture the dynamics of the oceanic response to atmospheric forcing
3. Capture/Not Capture some of the ENSO extra-tropical teleconnections and forcing
4. Capture/Not Capture the ENSO forcing to the extra-tropics
5. Not Capture the frequency of the oceanic modes
6. Not Capture the ENSO & CPW low-frequency forcing to extra-tropics

Decadal climate dynamics of the AR4 Models (*1800-2000*)



1. Capture the spatial expression of the modes
2. Capture the dynamics of the oceanic response to atmospheric forcing
3. Capture/Not Capture some of the ENSO extra-tropical teleconnections and forcing
4. Capture/Not Capture the ENSO forcing to the extra-tropics
5. Not Capture the frequency of the oceanic modes
6. Not Capture the ENSO & CPW low-frequency forcing to extra-tropics

Decadal climate dynamics of the AR4 Models (*1800-2000*)



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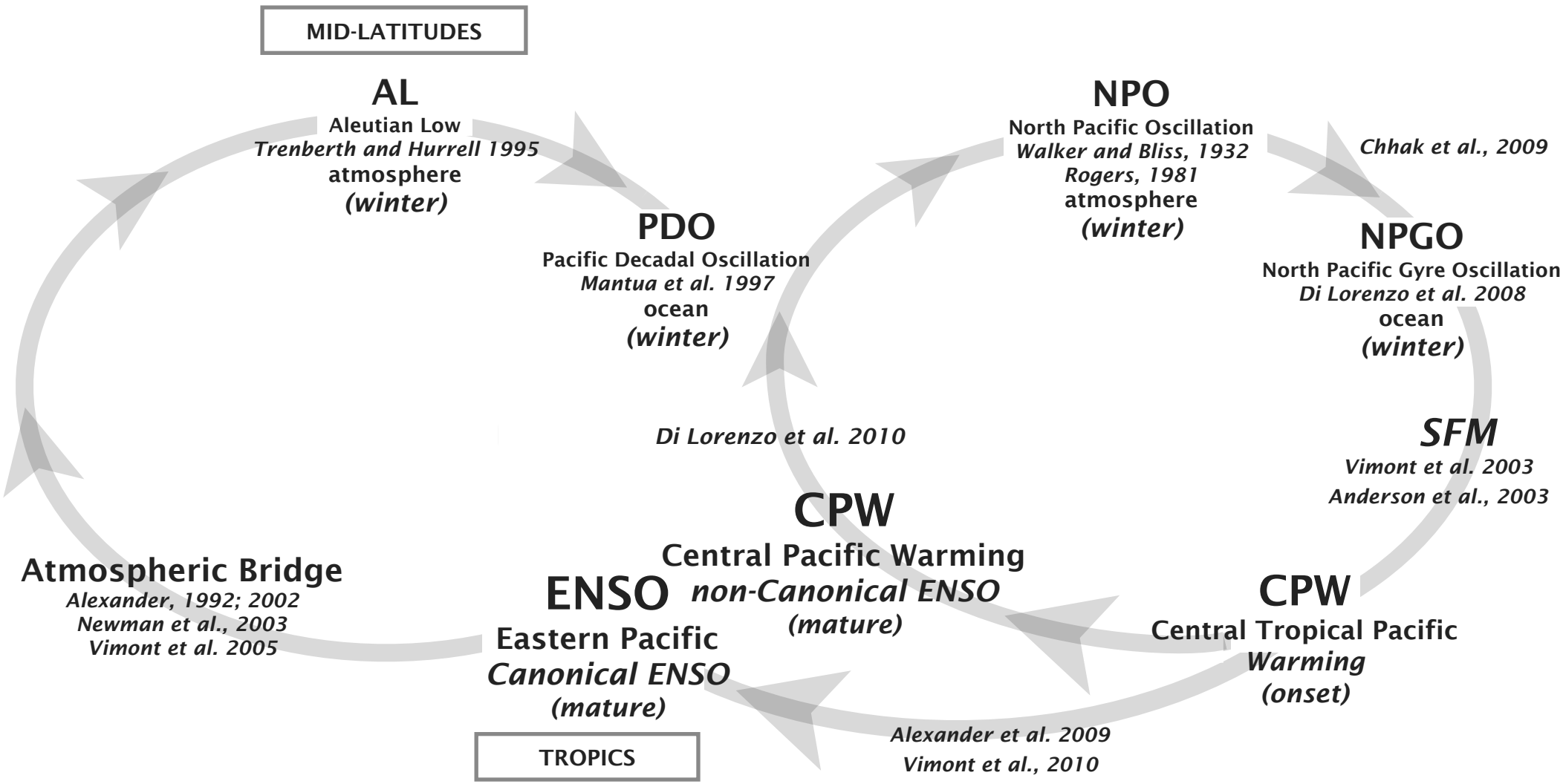
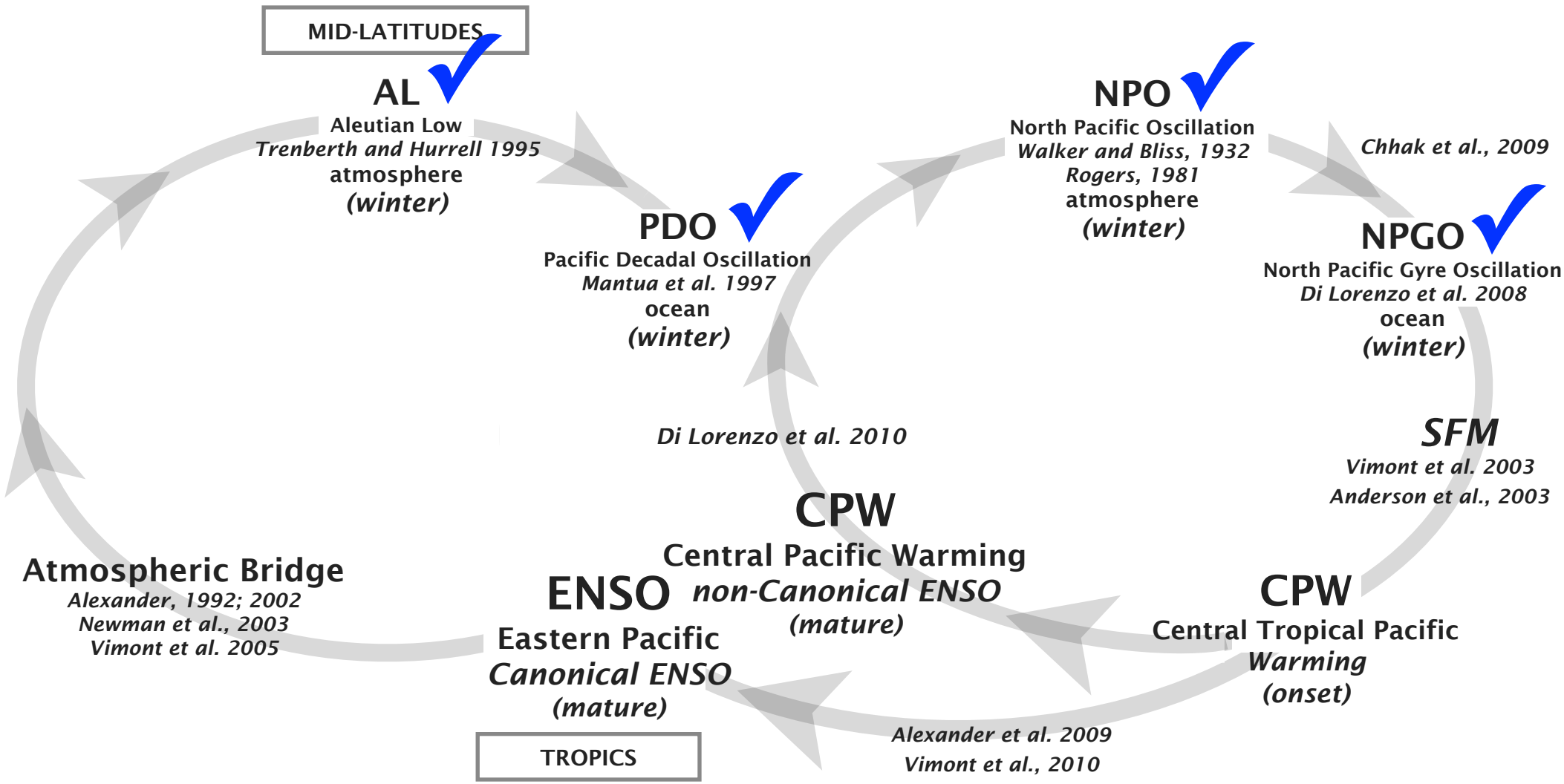

MID-LATITUDES
AL
Aleutian Low
Trenberth and Hurrell 1995
atmosphere
(winter)
PDO
Pacific Decadal Oscillation
Mantua et al. 1997
ocean
(winter)
NPO
North Pacific Oscillation
Walker and Bliss, 1932
Rogers, 1981
atmosphere
(winter)
Chhak et al., 2009
NPGO
North Pacific Gyre Oscillation
Di Lorenzo et al. 2008
ocean
(winter)
Di Lorenzo et al. 2010
SFM
Vimont et al. 2003
Anderson et al., 2003
CPW
Central Pacific Warming
non-Canonical ENSO
(mature)
Atmospheric Bridge
Alexander, 1992; 2002
Newman et al., 2003
Vimont et al. 2005
ENSO
Eastern Pacific
Canonical ENSO
(mature)
CPW
Central Tropical Pacific
Warming
(onset)
Alexander et al. 2009
Vimont et al., 2010
TROPICS


MID-LATITUDES
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Aleutian Low
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(winter)
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Mantua et al. 1997
ocean
(winter)
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ENSO
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Canonical ENSO
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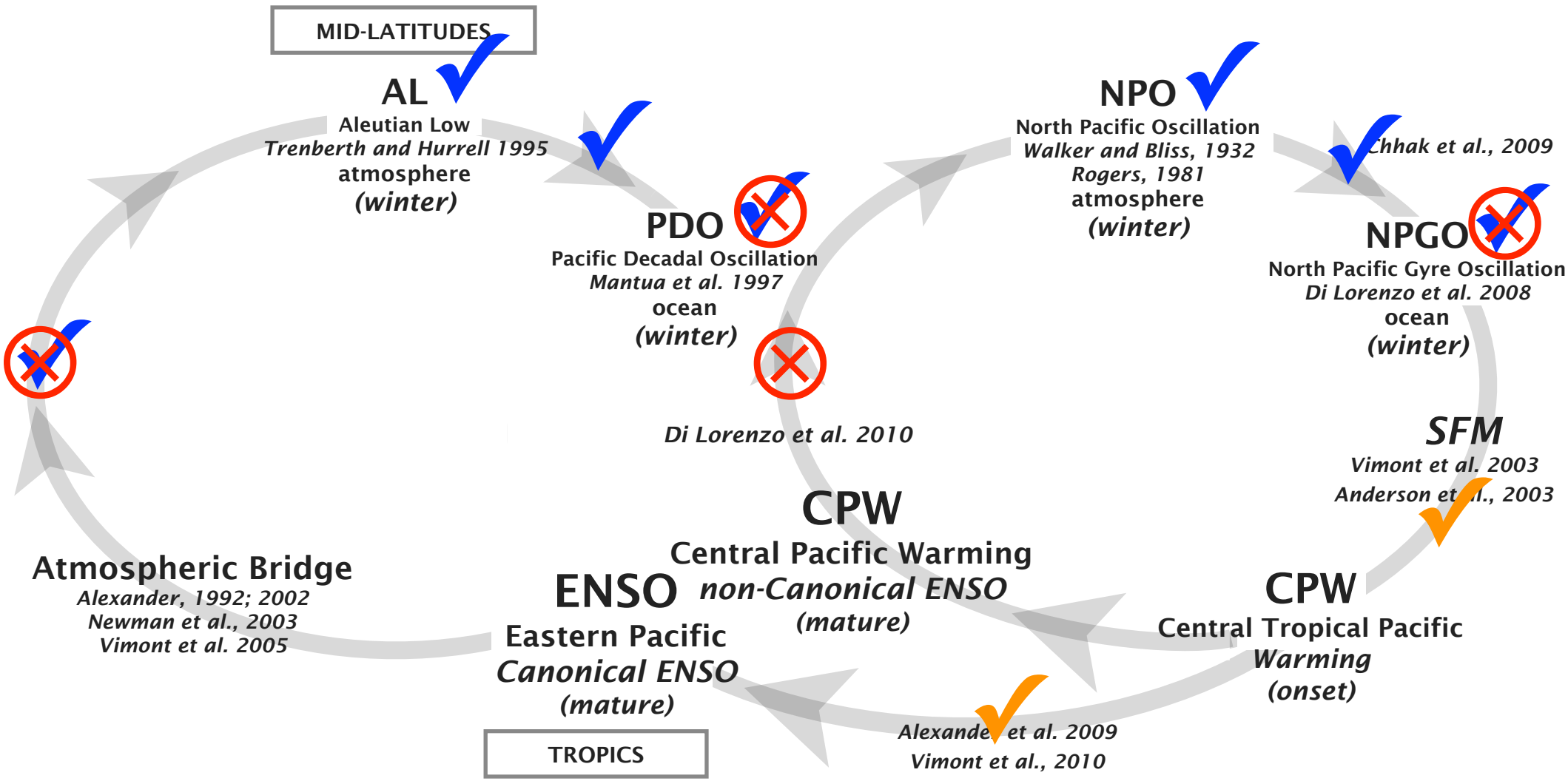
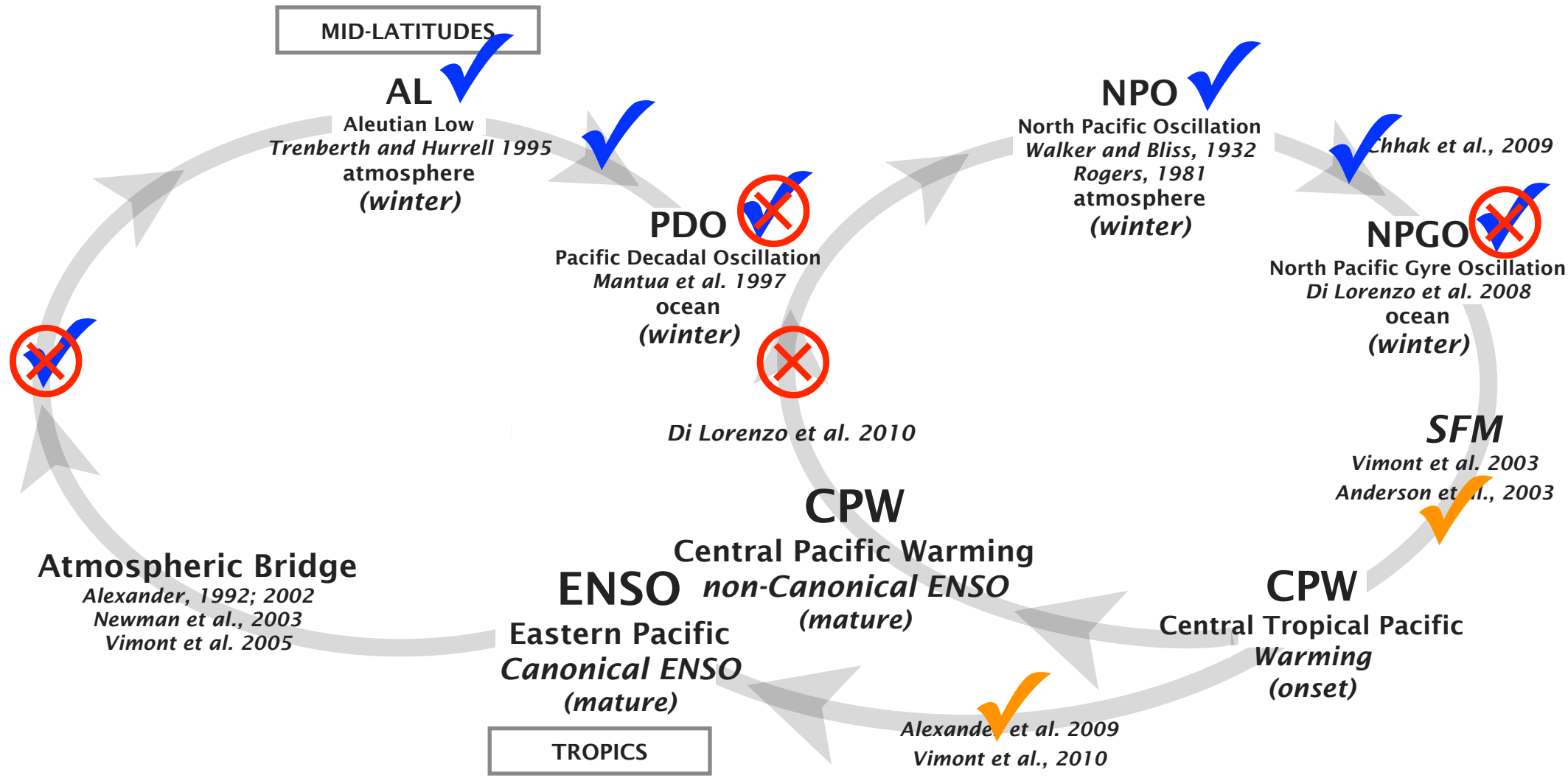
CPW
Central Tropical Pacific
Warming
(onset)
Alexander et al. 2009
Vimont et al., 2010
TROPICS

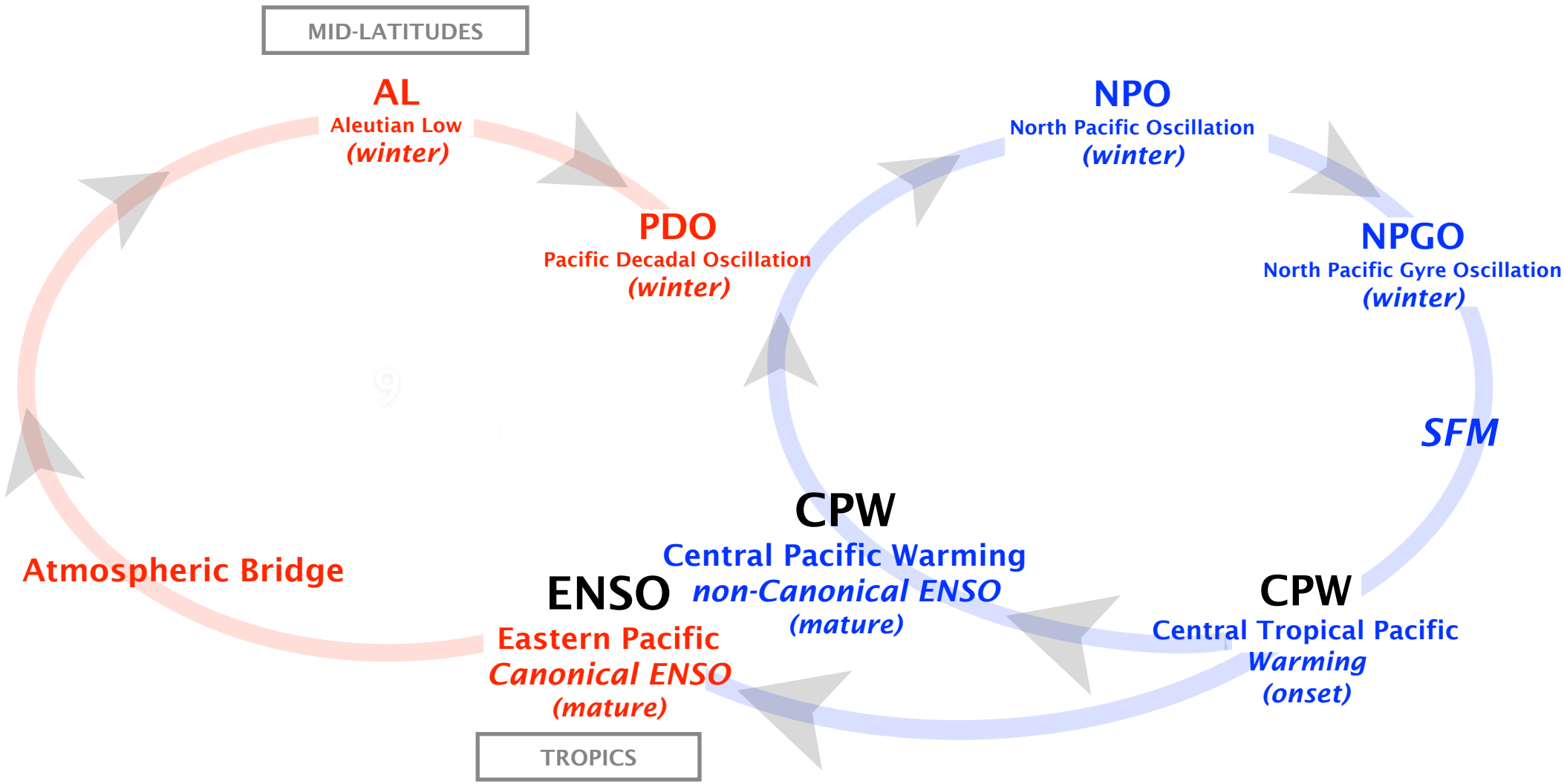
Testing the decadal climate dynamics of the AR4 Models (1800-2000)



1. Capture the spatial expression of the modes
2. Capture the dynamics of the oceanic response to atmospheric forcing
3. Capture/Not Capture some of the ENSO extra-tropical teleconnections and forcing
4. Capture/Not Capture the ENSO forcing to the extra-tropics
5. Not Capture the frequency of the oceanic modes
6. Not Capture the ENSO & CPW low-frequency forcing to extra-tropics



1. Capture the spatial expression of the modes
2. Capture the dynamics of the oceanic response to atmospheric forcing
3. Capture/Not Capture some of the ENSO extra-tropical teleconnections and forcing
3. Capture/Not Capture the ENSO forcing to the extra-tropics
4. Not Capture the frequency of the oceanic modes
5. Not Capture the ENSO & CPW low-frequency forcing to extra-tropics


MID-LATITUDES
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Pacific Decadal Oscillation
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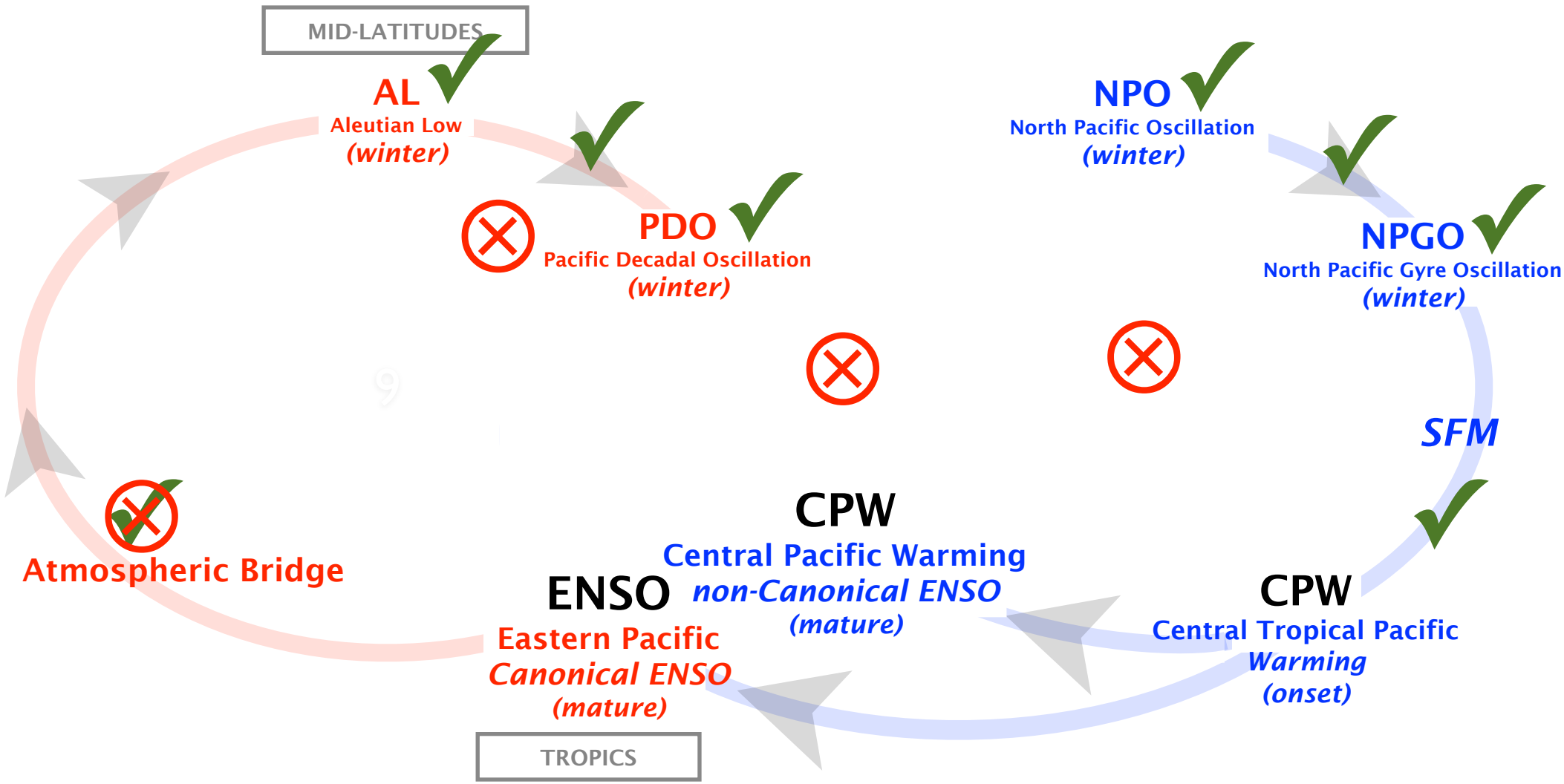
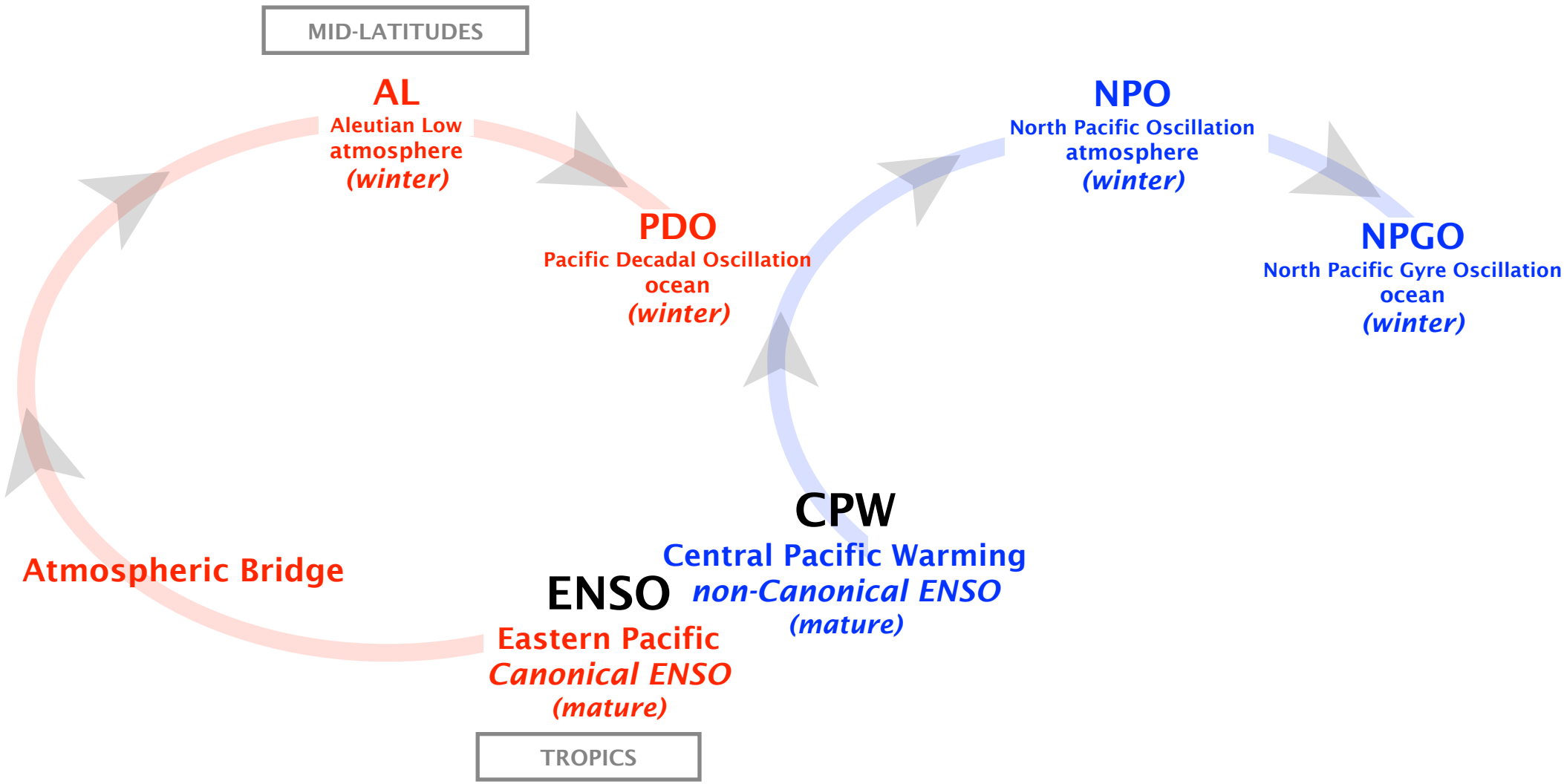
Warming
(onset)
Atmospheric Bridge
ENSO
Eastern Pacific
Canonical ENSO
(mature)
TROPICS



1. **Capture** the spatial expression of the modes
2. **Capture** the atmospheric forcing and oceanic response dynamics
3. **Capture/Not Capture** some of the ENSO extra-tropical teleconnections and forcing
3. **Capture/Not Capture** the extra-tropical forcing of ENSO
4. **Not Capture** the frequency of the oceanic modes
5. **Not Capture** the CPW extra-tropical teleconnection and forcing


MID-LATITUDES
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Aleutian Low
atmosphere
(winter)
PDO
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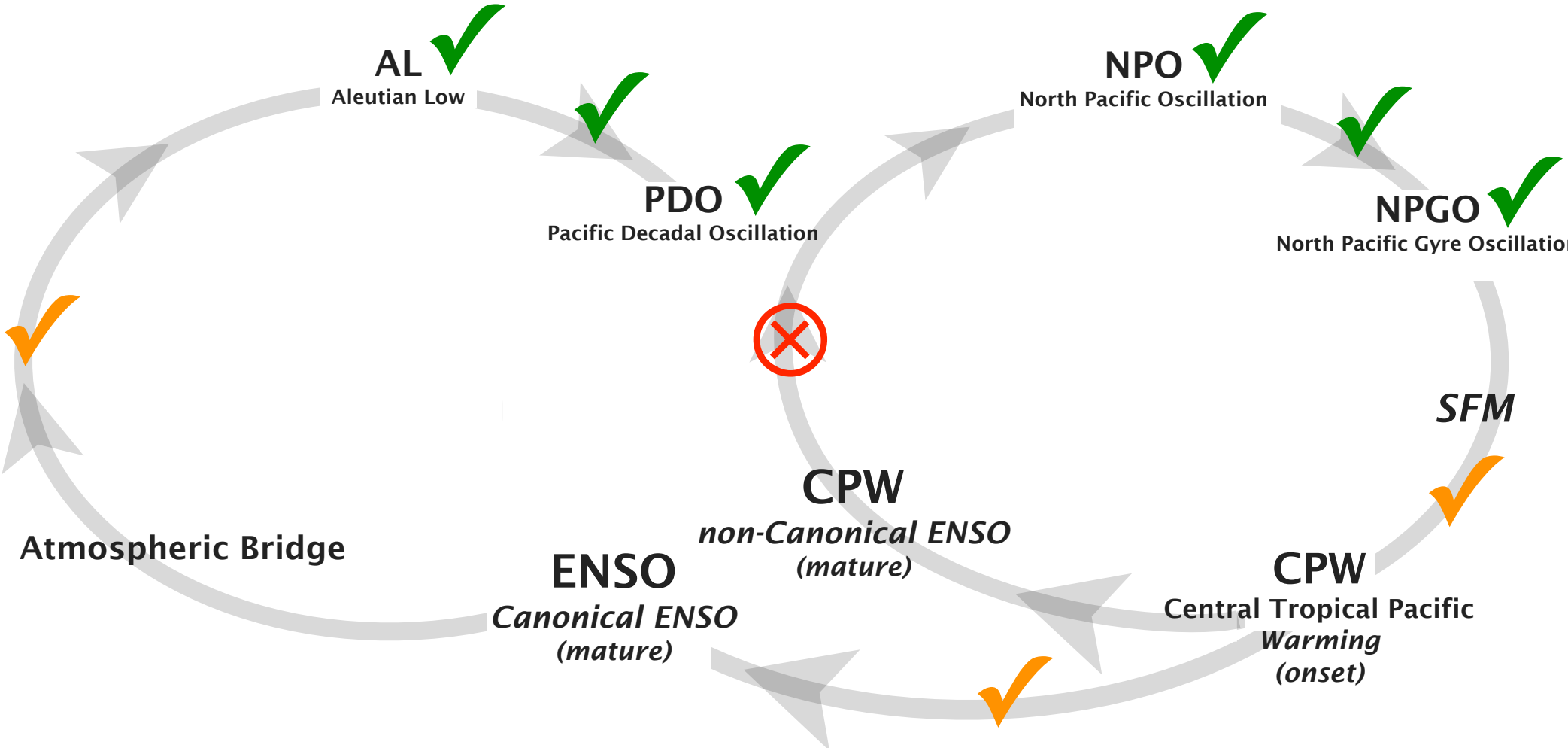
ocean
(winter)
NPO
North Pacific Oscillation
atmosphere
(winter)
NPGO
North Pacific Gyre Oscillation
ocean
(winter)
CPW
Central Pacific Warming
non-Canonical ENSO
(mature)
ENSO
Eastern Pacific
Canonical ENSO
(mature)
Atmospheric Bridge
TROPICS

How do AR4 models capture Pacific decadal dynamics in the past climate ?

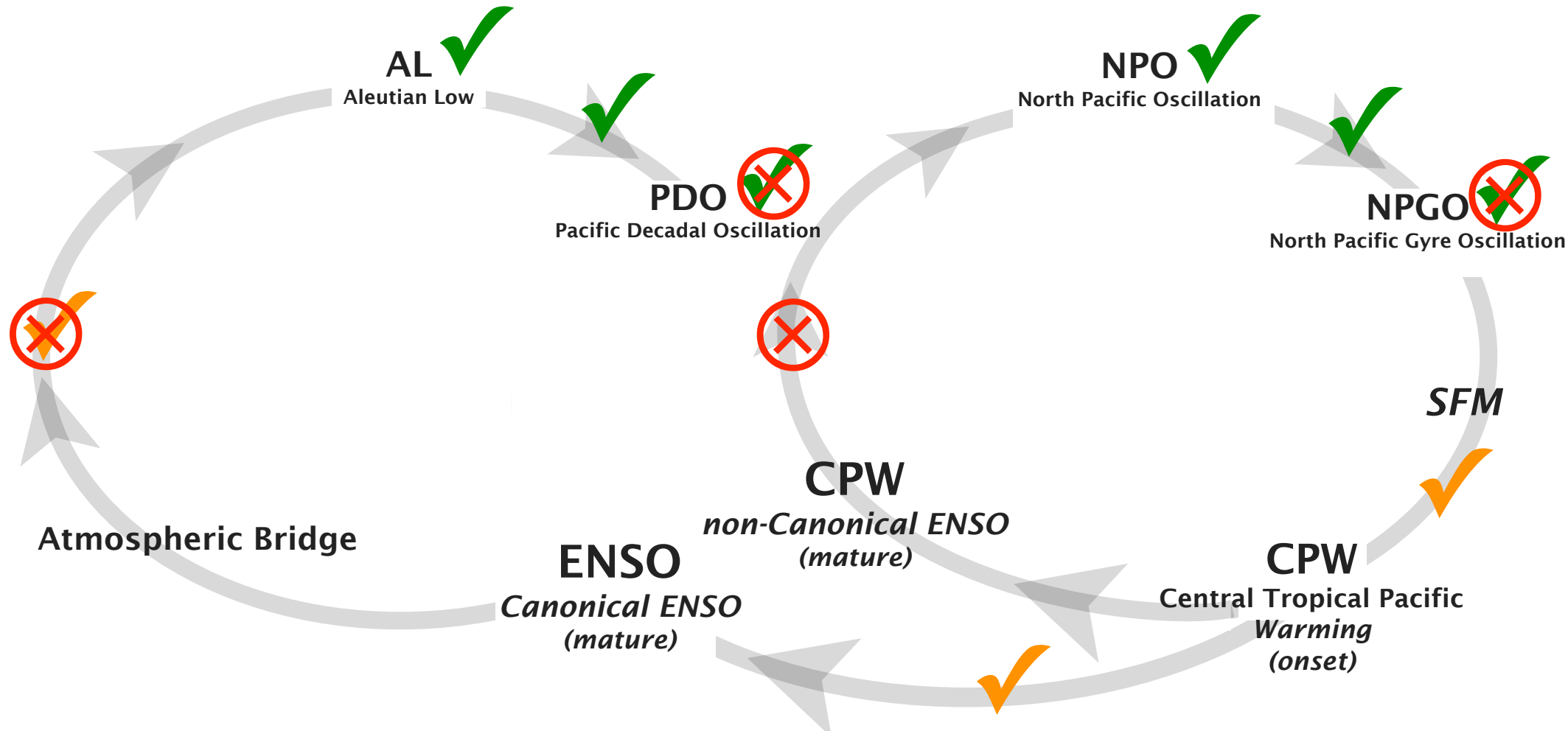


1. Capture the spatial expression of the modes
2. Capture the dynamics of the oceanic response to atmospheric forcing
3. Capture/Not Capture the extra-tropical forcing of ENSO
4. Capture/Not Capture the ENSO forcing to the extra-tropics
5. Not Capture the frequency of the oceanic modes
6. Not Capture the ENSO & CPW low-frequency forcing to extra-tropics

Furtado, Di Lorenzo, Schneider and Bond
Journal of Climate, 2011

Furtado, Di Lorenzo, Anderson and Schneider
Dynamics, in revision

How do AR4 models capture Pacific decadal dynamics in the past climate ?



1. Capture the spatial expression of the modes
2. Capture the dynamics of the oceanic response to atmospheric forcing
3. Capture/Not Capture meridional mode or SFM dynamics
4. Capture/Not Capture the ENSO forcing to the extra-tropics
5. Not Capture the frequency of the oceanic modes
6. Not Capture the ENSO & CPW low-frequency forcing to extra-tropics

Furtado, Di Lorenzo, Schneider and Bond
Journal of Climate, 2011

Furtado, Di Lorenzo, Anderson and Schneider
Climate Dynamics, in revision