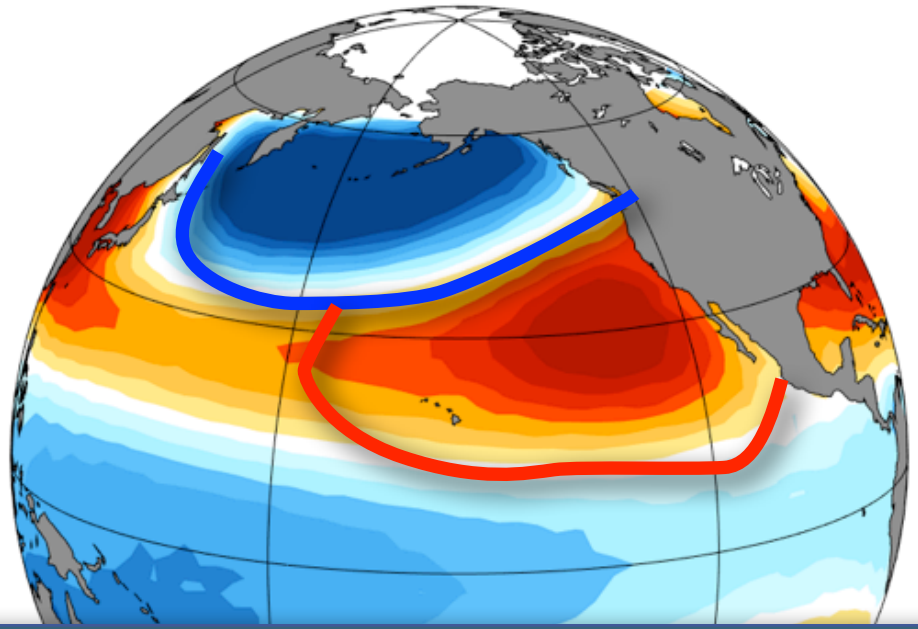
INCREASING VARIANCE AND SYNCHRONY IN NORTH PACIFIC CLIMATE AND ECOSYSTEMS

by **Emanuele Di Lorenzo**, Bryan Black,
Giovanni Liguori and Younji Joh

A brief Primer on

North Pacific Climate Variability

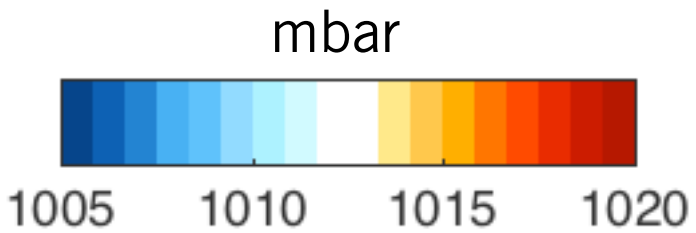


Mean Winter Atmospheric Circulation

Sea Level Pressure (SLP)

A brief Primer on

North Pacific Climate Variability



Mean Winter Atmospheric Circulation

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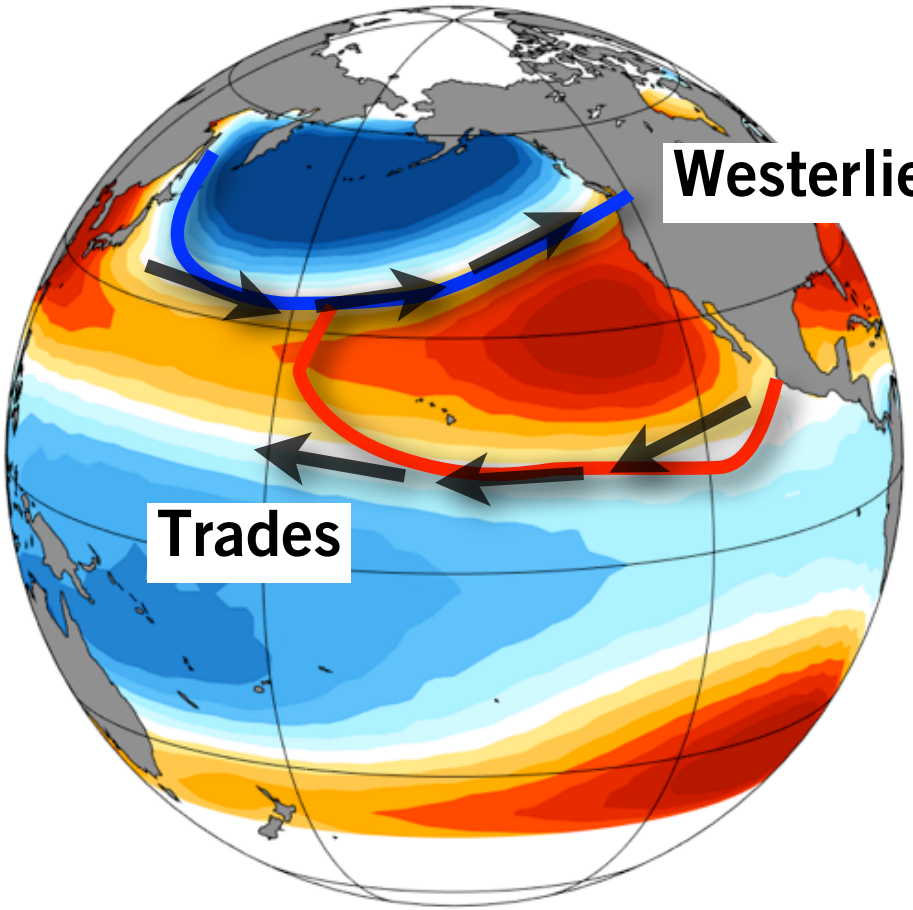
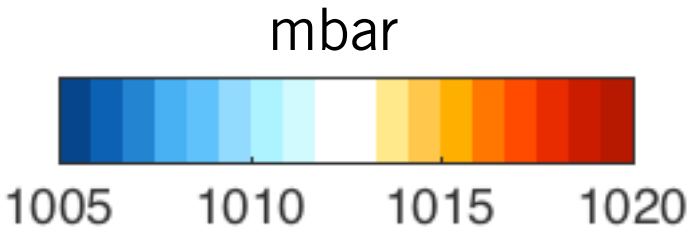
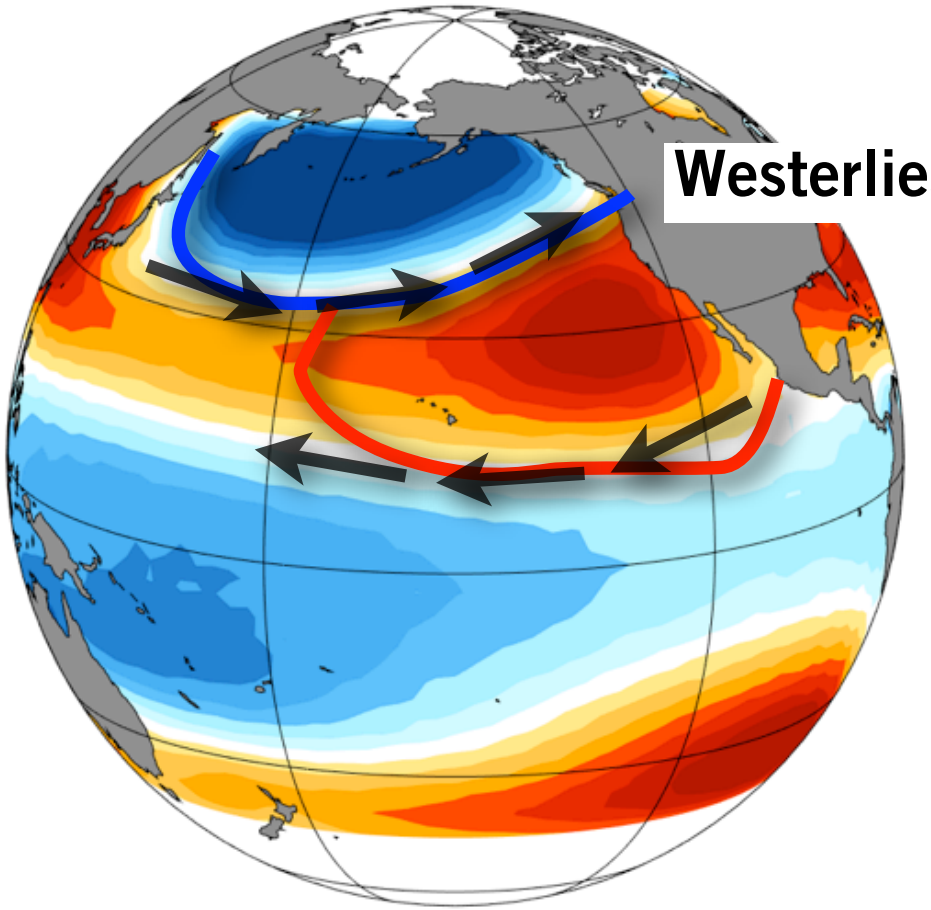


wind vectors

Mean Winter





Mean Winter

mbar

1005 1010 1015 1020

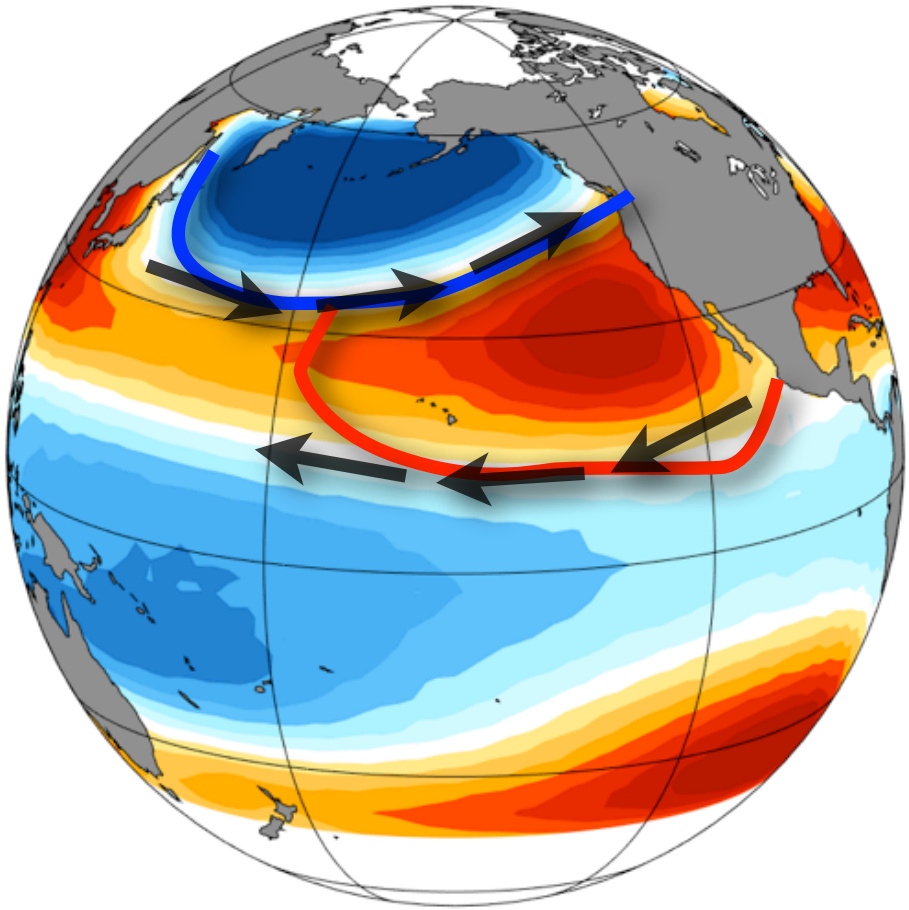
Anomalies in Westerlies

Change in Location

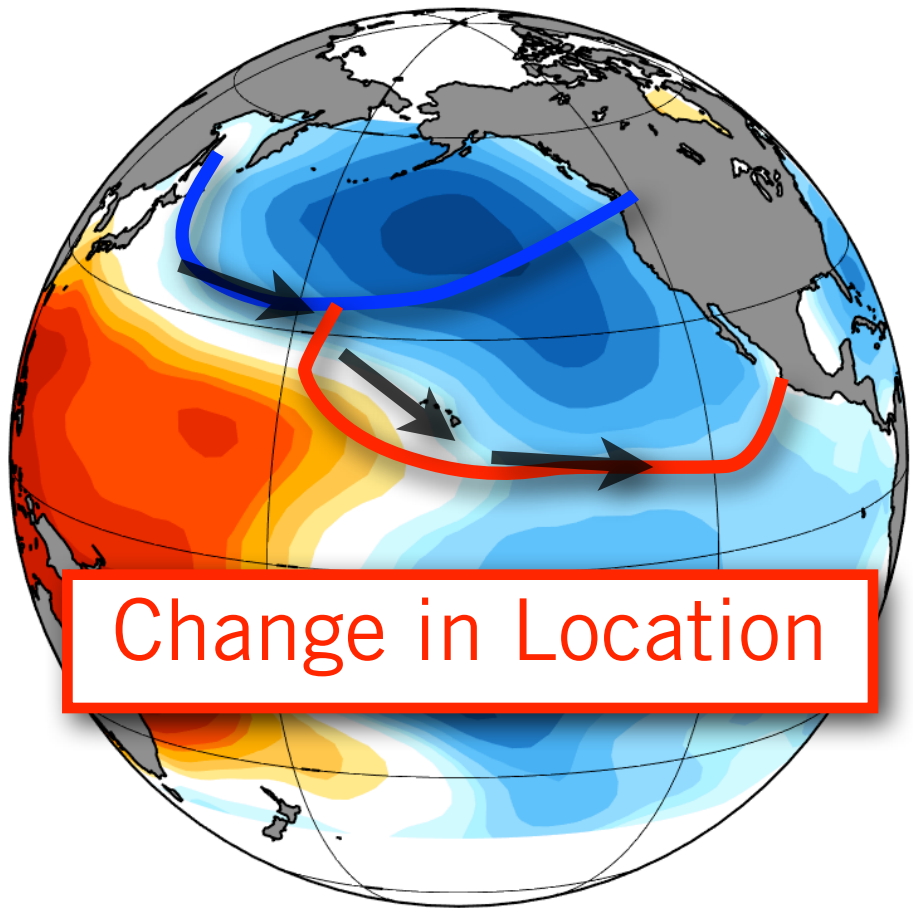
Change in Strength

Winter

SLPa



Mean Winter



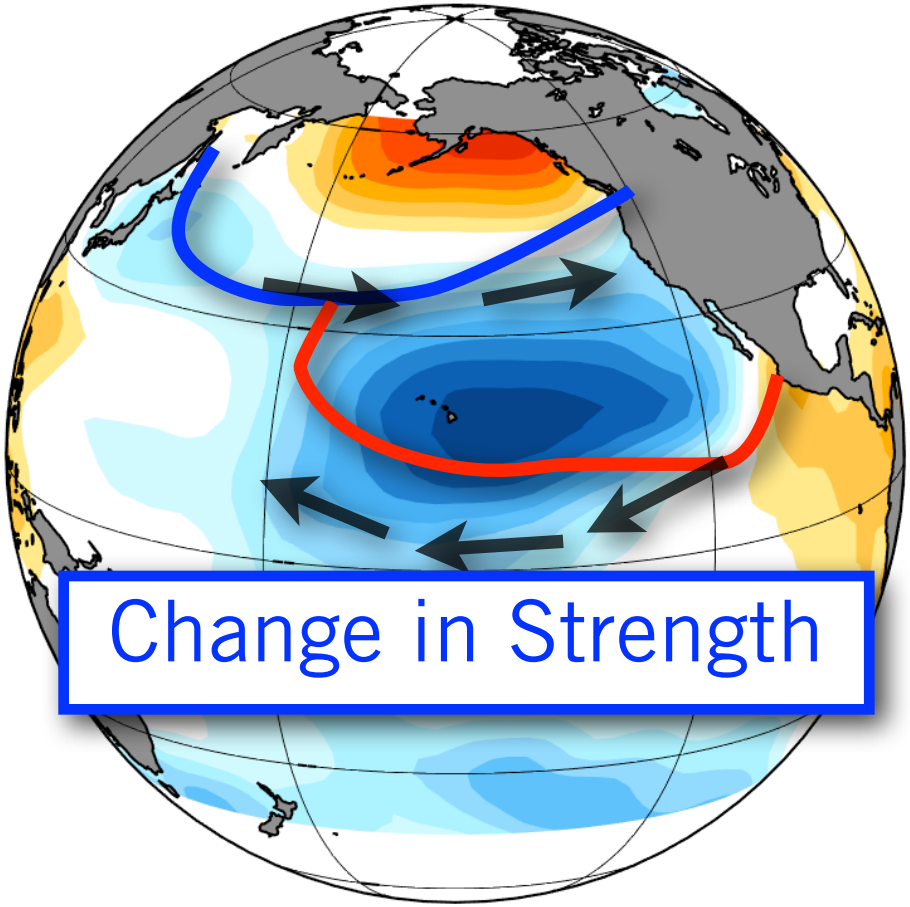
Anomalies

Extension of Aleutian Low

Southward Shift in the storm tracks

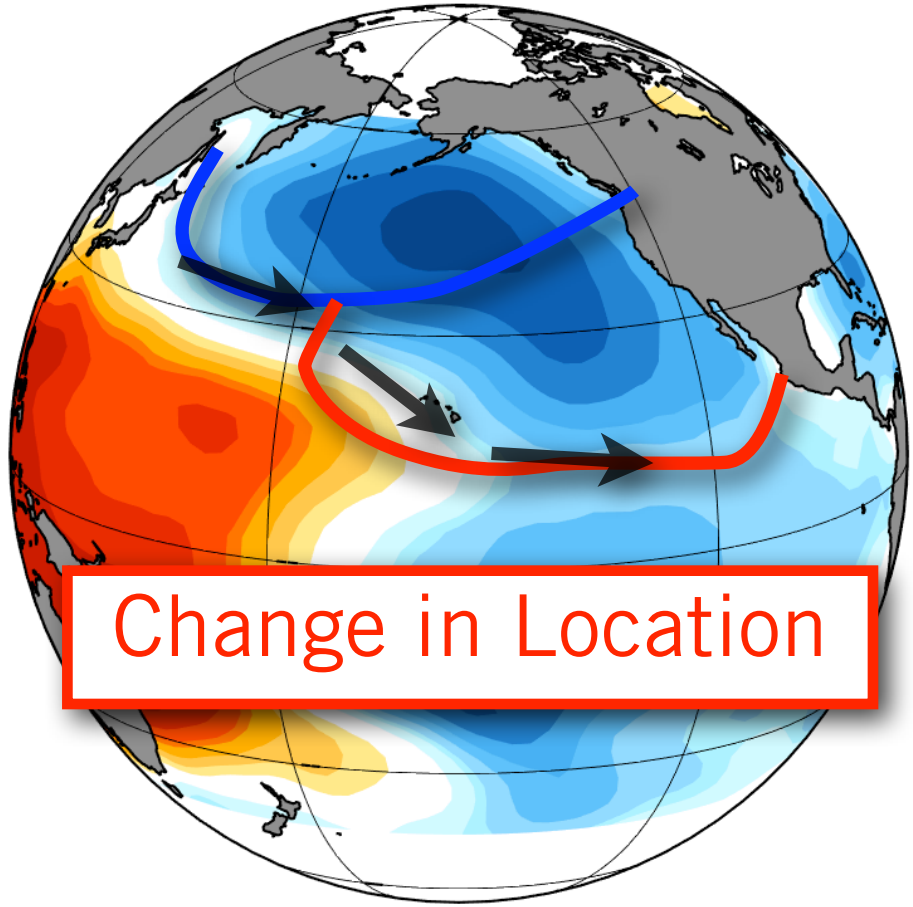
Winter

SLPa



Anomalies

Intensification of storm tracks



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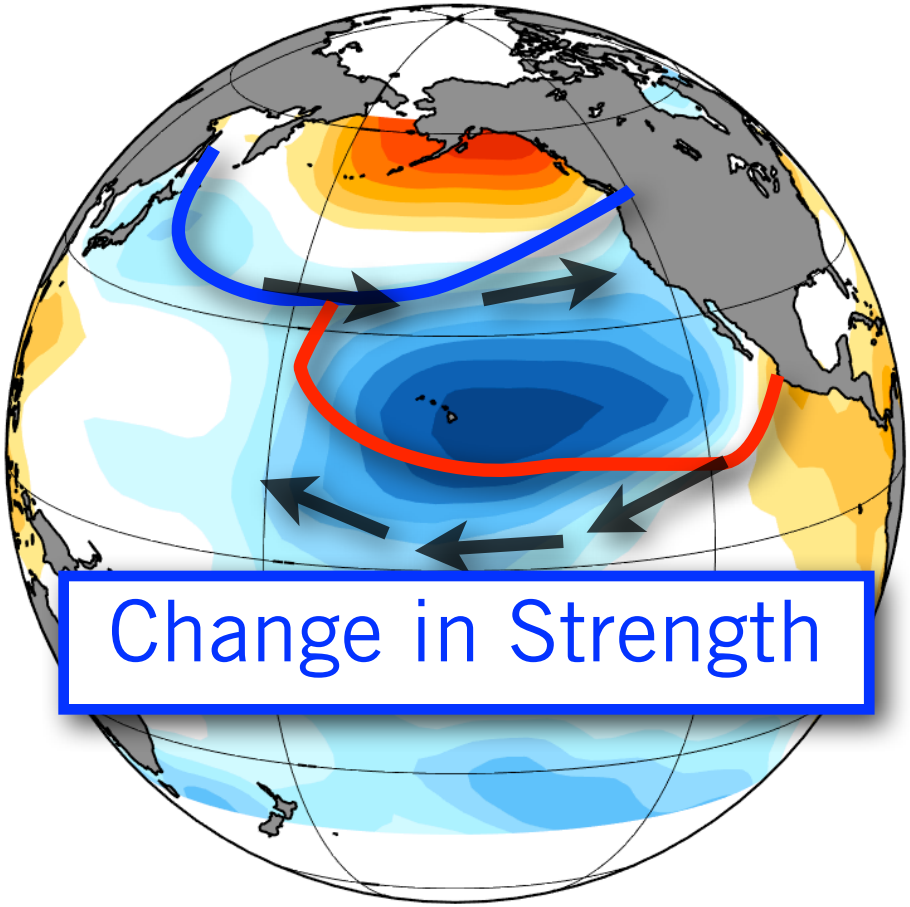
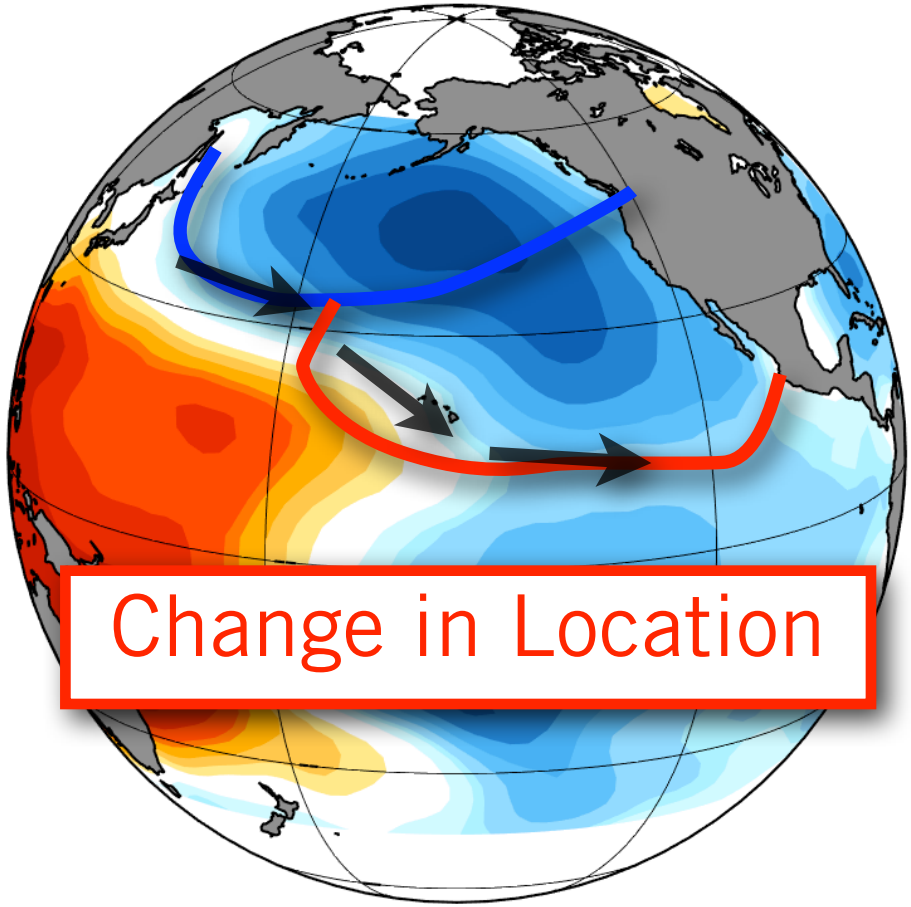
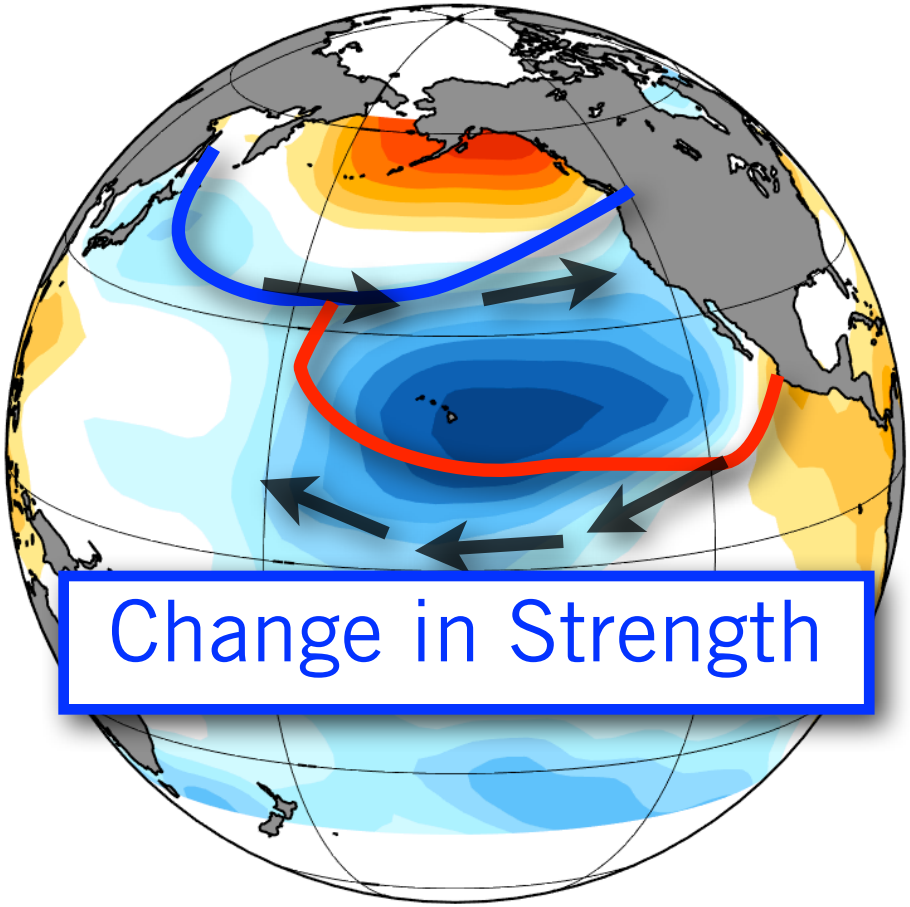
SLPa

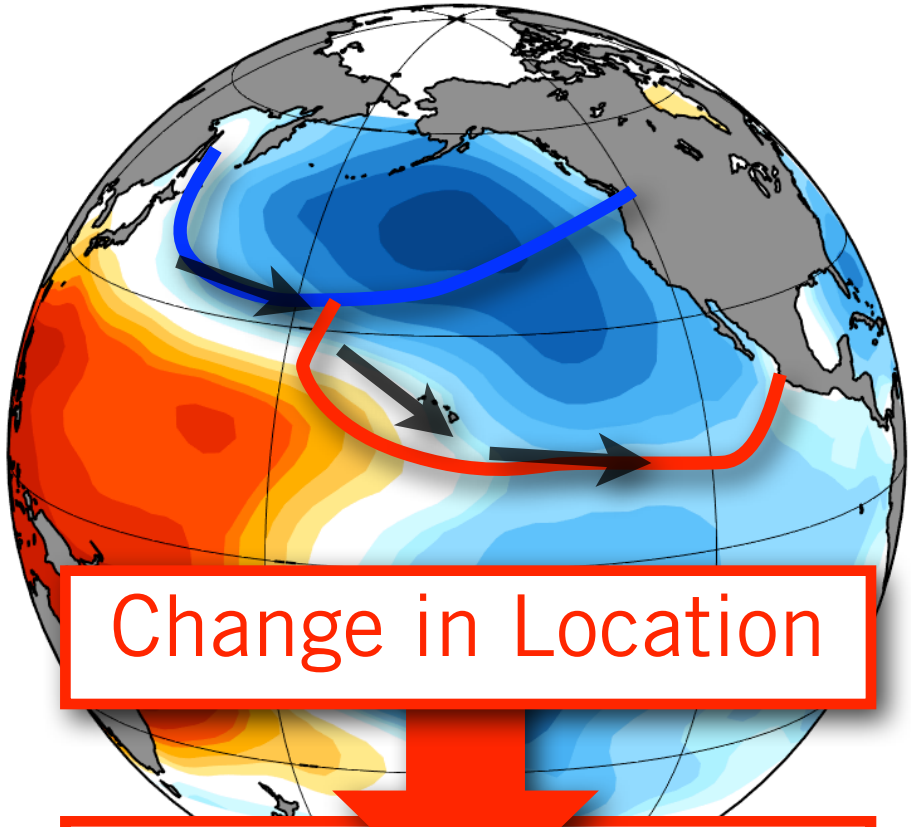




2 dominant types of changes



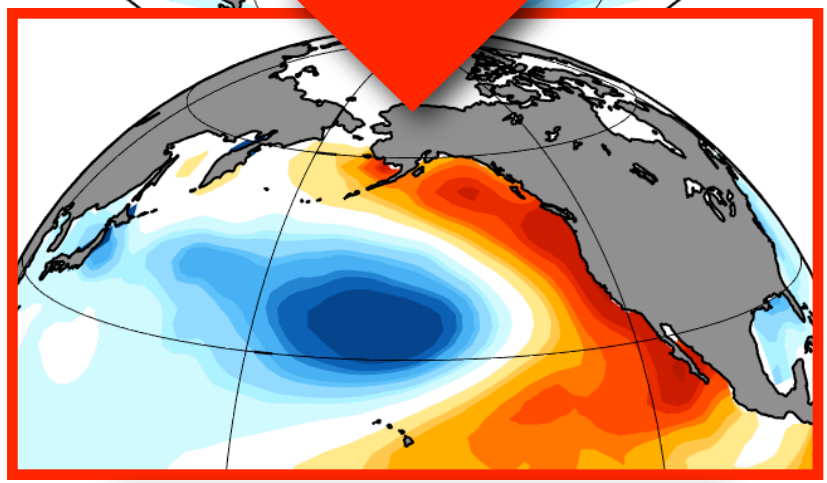
Winter
SLPa



Change in Strength

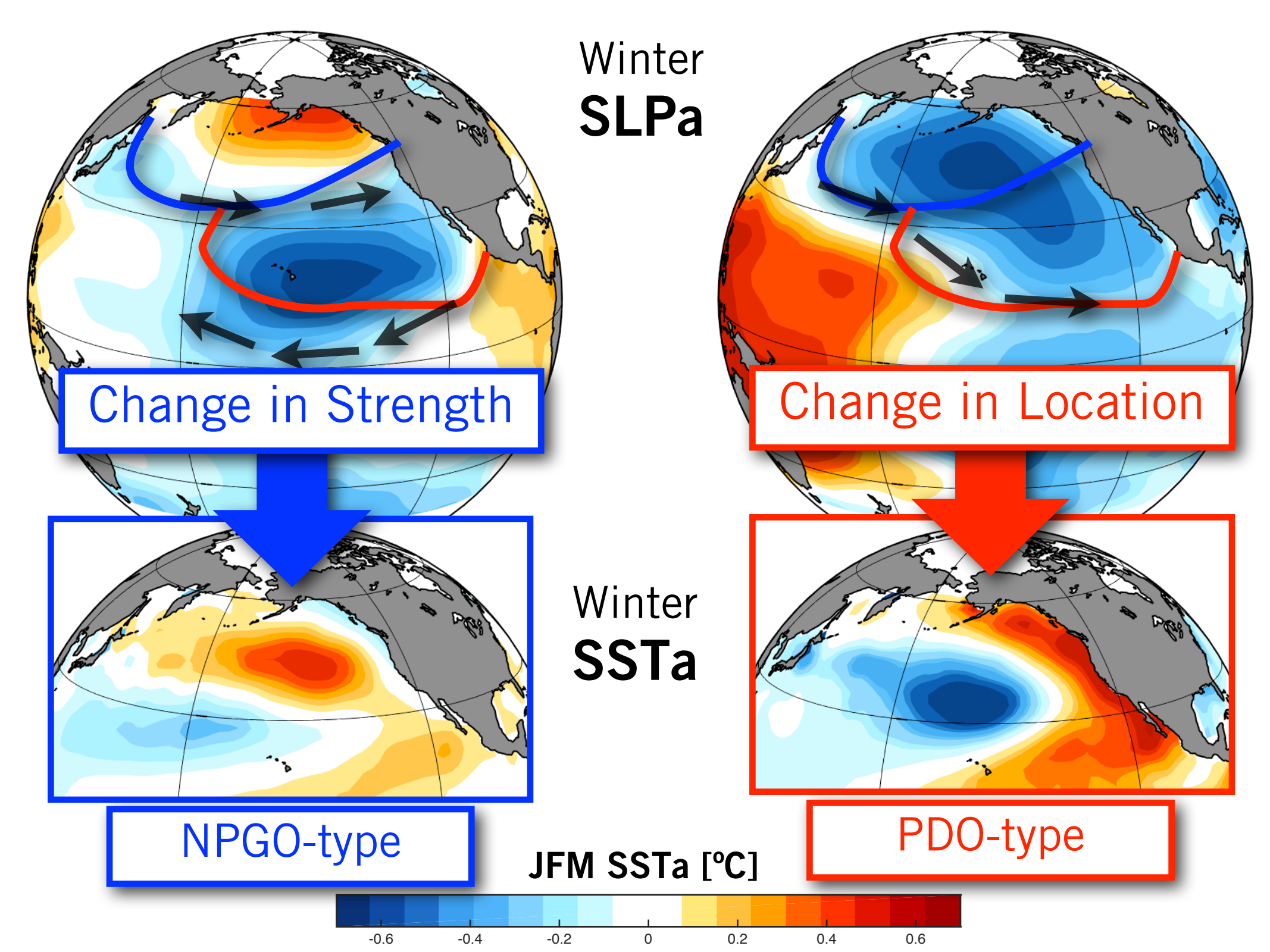
Change in Location

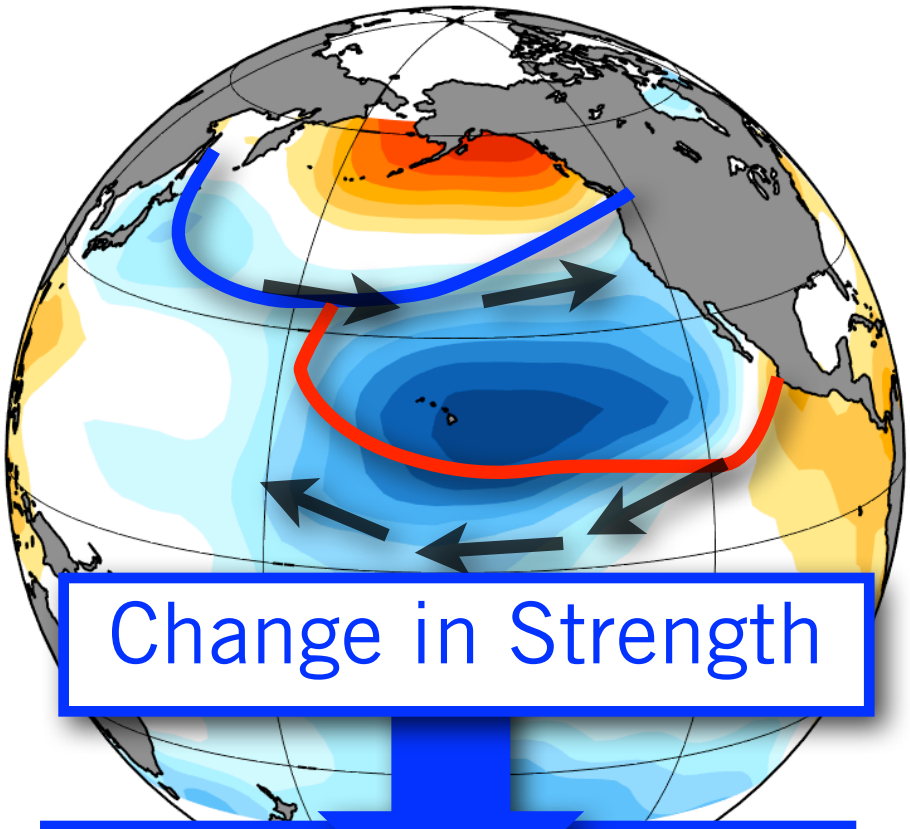
Winter
SSTa



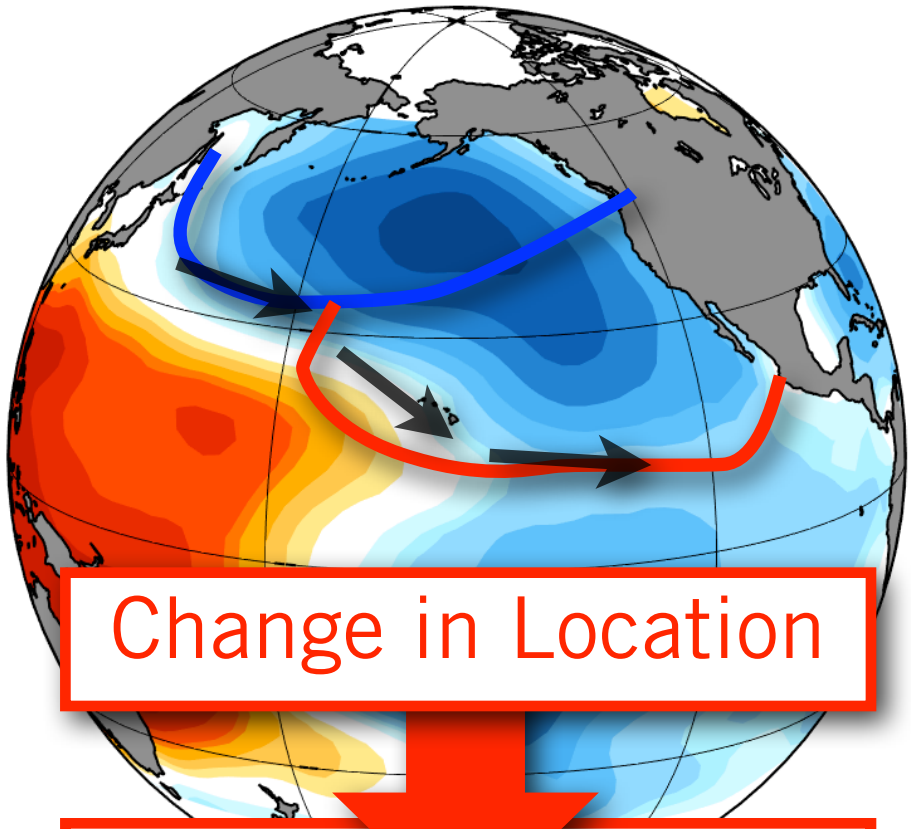
PDO-type

JFM SSTa [ºC]


Winter
SLPa
Change in Strength
Change in Location
Winter
SSTa
NPGO-type
PDO-type
JFM SSTa [ºC]
-0.6
-0.4
-0.2
0
0.2
0.4
0.6

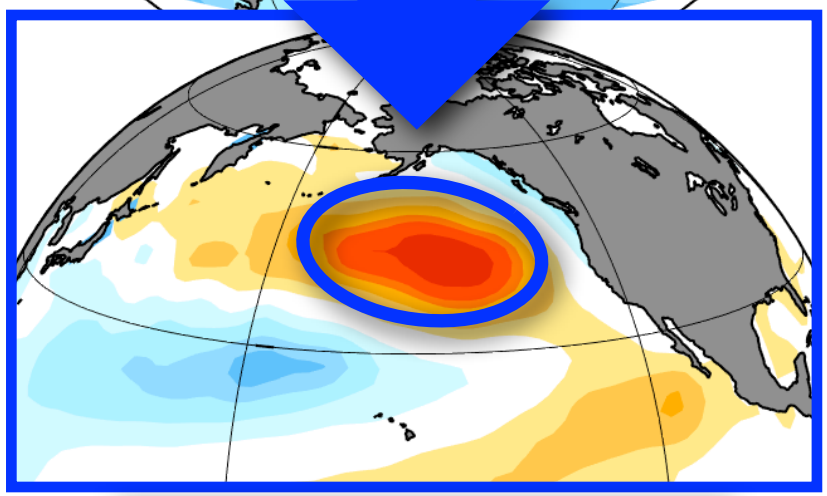


Winter
SLPa

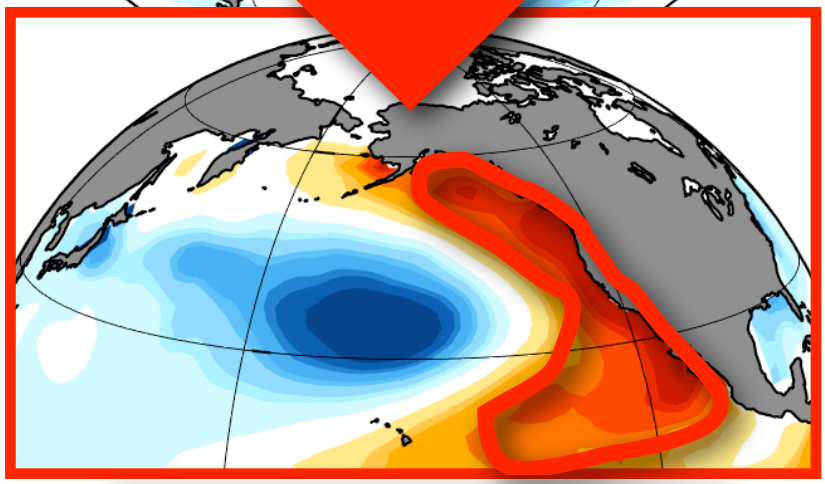


Change in Strength

Change in Location



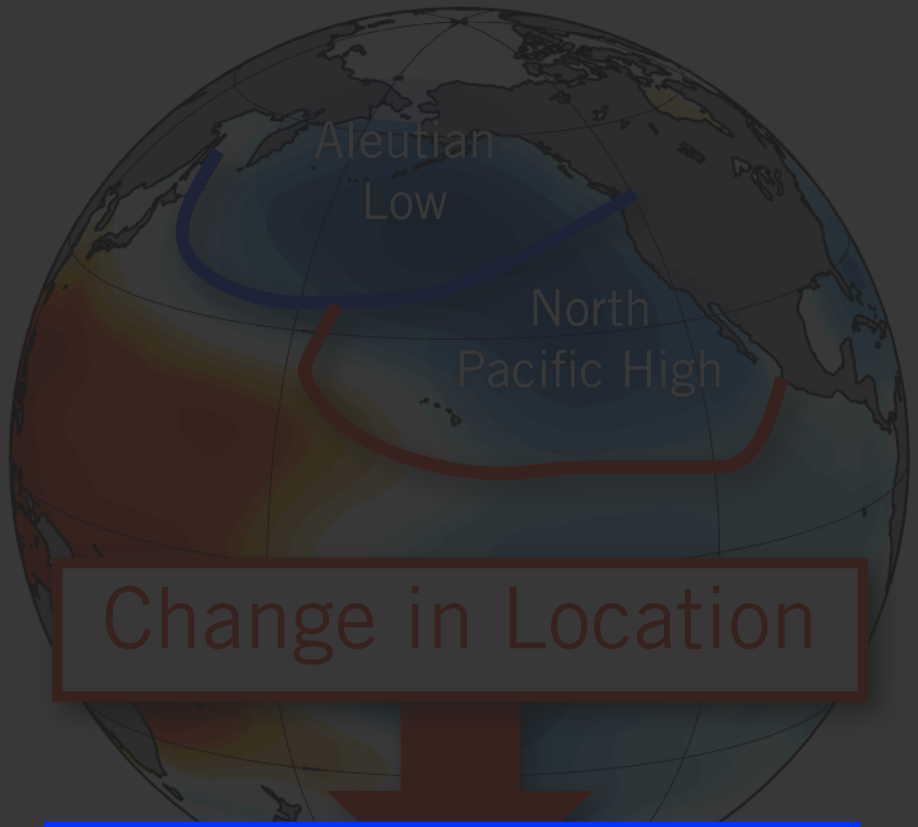
Winter
SSTa



NPGO-type
GOA Pattern

PDO-type
ARC Pattern

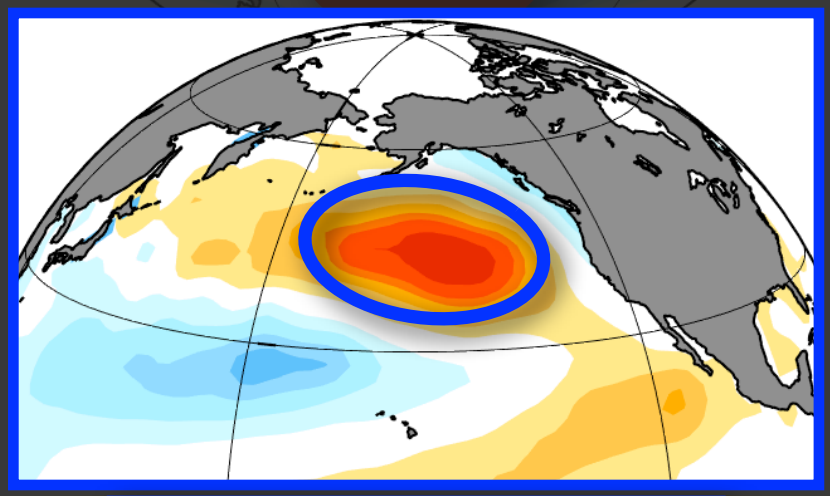
SLPa



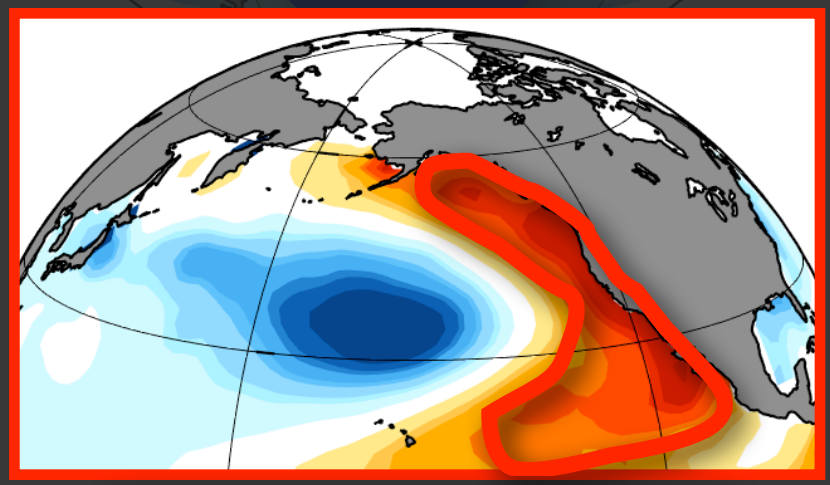
Change in Location

Change in Strength

SSTa



NPGO-type
GOA Pattern

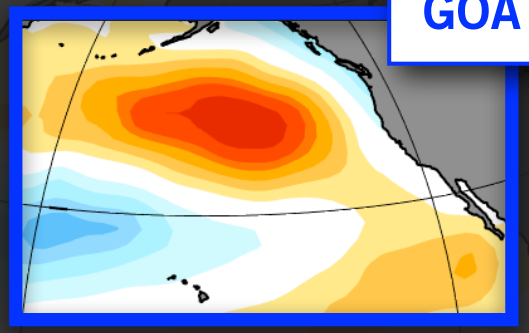


PDO-type
ARC Pattern

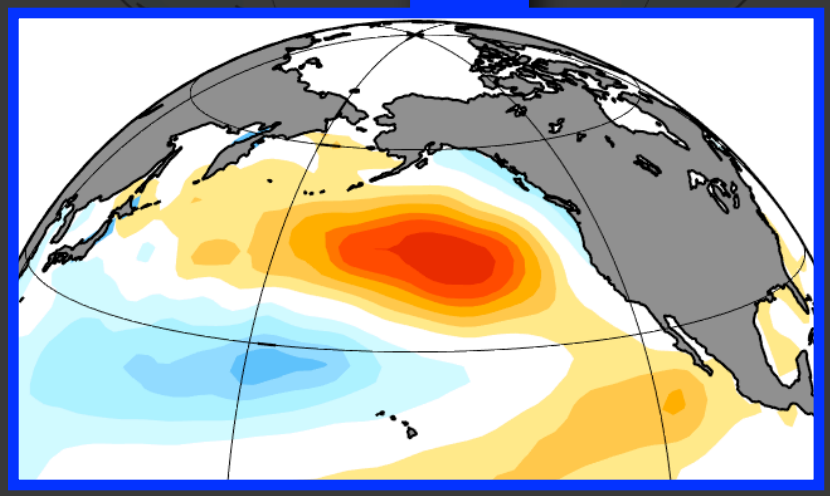
WINTER (JFM)

SSTA

NPGO-type
GOA Pattern



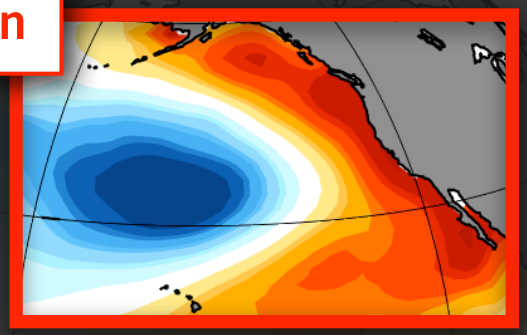
EOF2 Winter SSTa



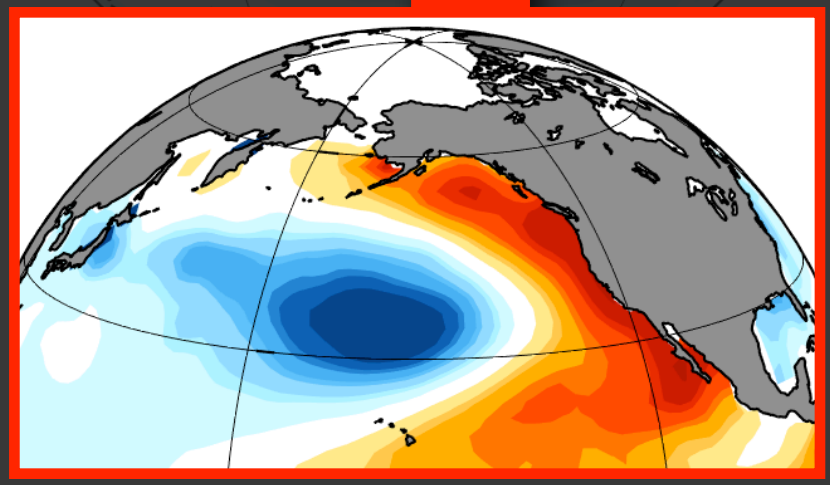
WINTER (JFM) NEXT YEAR

SSTA

PDO-type
ARC Pattern



EOF1 Winter SSTa

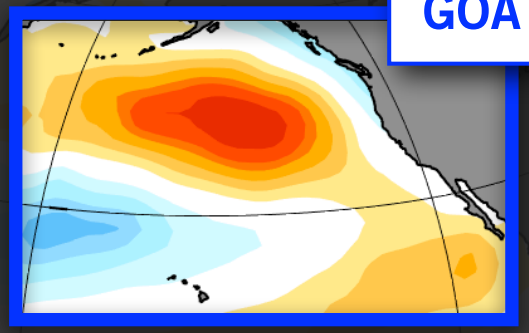


SSTA RANGE [-0.8C +0.8C]

WINTER (JFM)

SSTA

NPGO-type
GOA Pattern

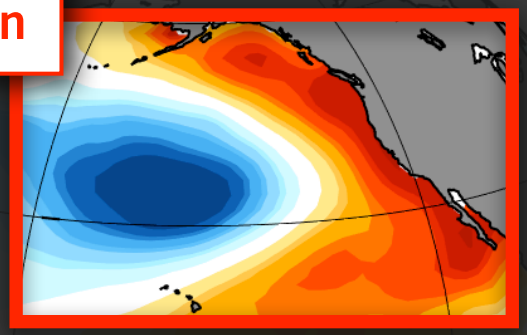


EOF2 Winter SSTa

WINTER (JFM) NEXT YEAR

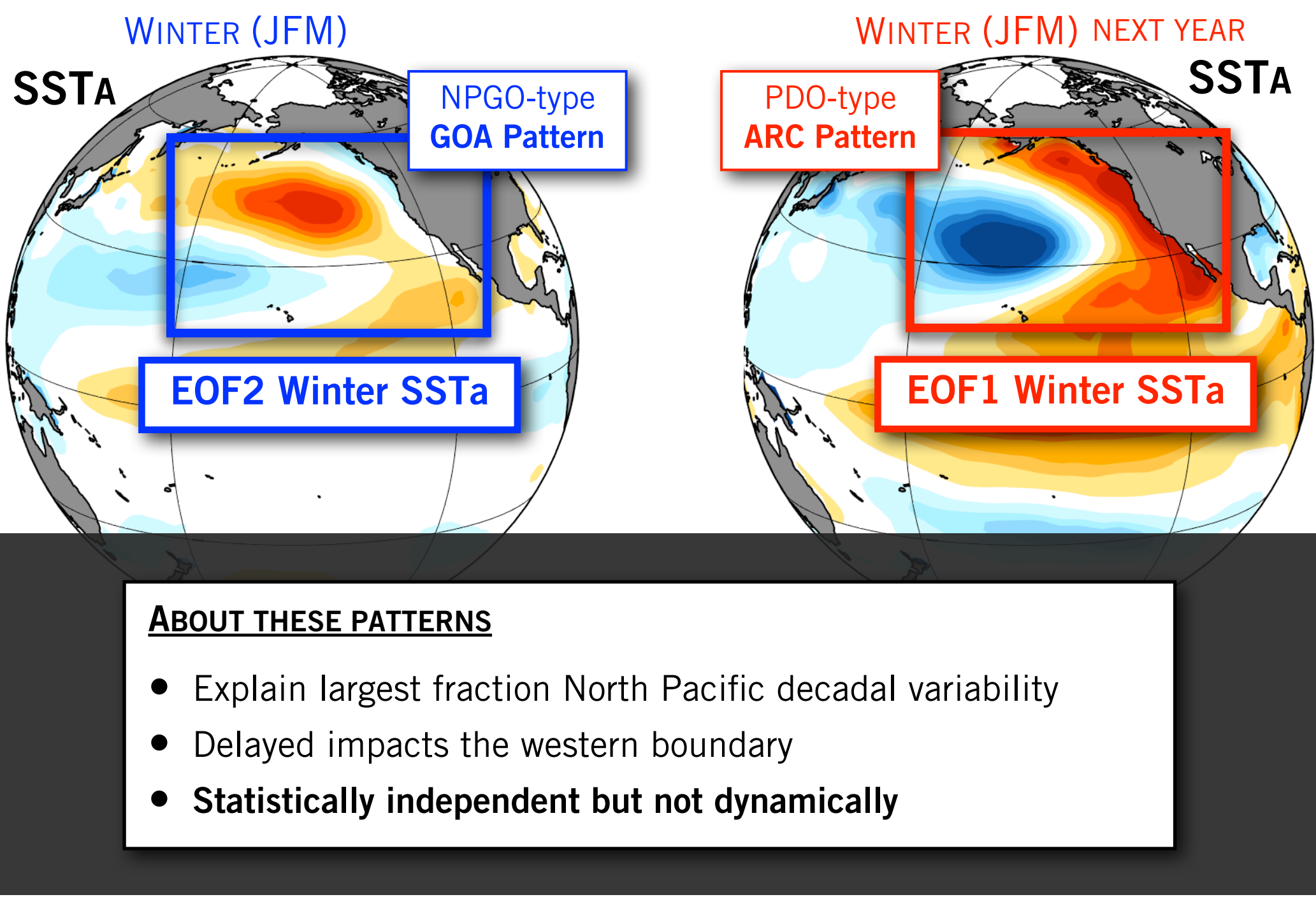
SSTA

PDO-type
ARC Pattern



EOF1 Winter SSTa

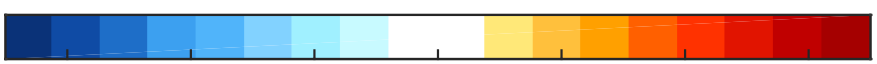
SSTA RANGE [-0.8C +0.8C]



ABOUT THESE PATTERNS

- Explain largest fraction North Pacific decadal variability
- Delayed impacts the western boundary
- **Statistically independent but not dynamically**

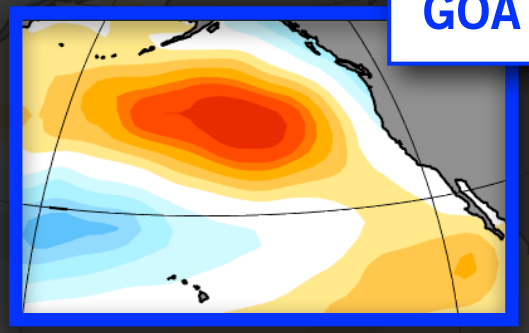
SSTA RANGE [-0.8C +0.8C]



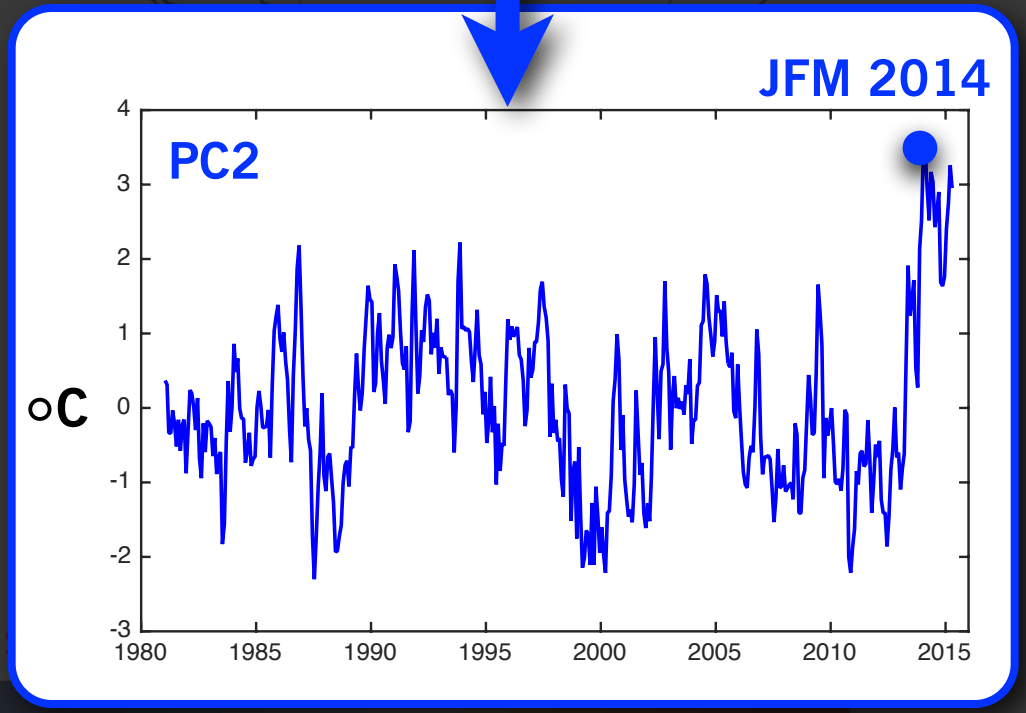
WINTER (JFM)

SSTA

NPGO-type
GOA Pattern



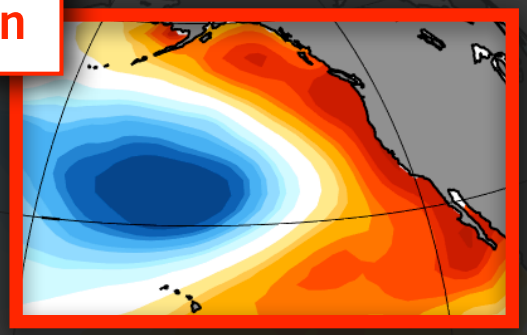
EOF2 Winter SSTa



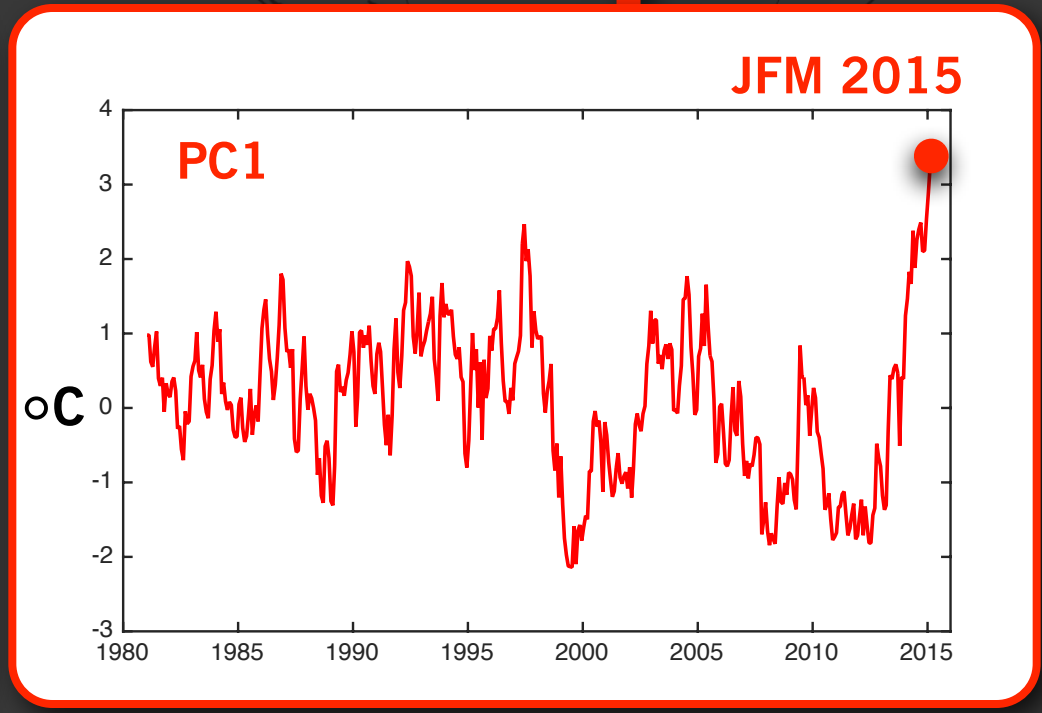
WINTER (JFM) NEXT YEAR

SSTA

PDO-type
ARC Pattern



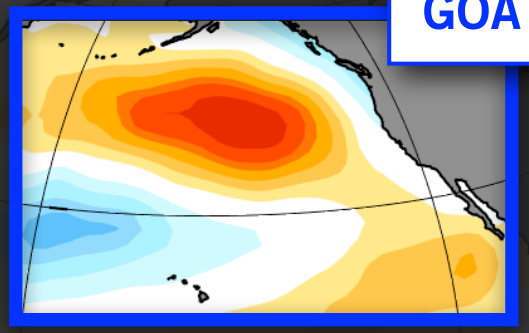
EOF1 Winter SSTa



WINTER (JFM)

SSTA

NPGO-type
GOA Pattern

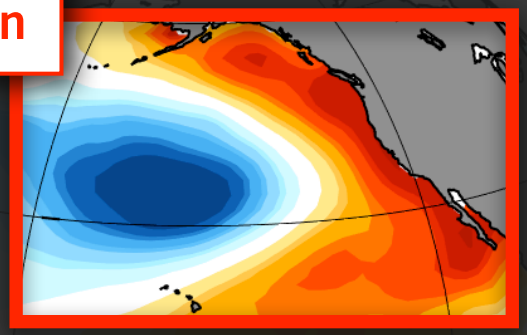


EOF2 Winter SSTa

WINTER (JFM) NEXT YEAR

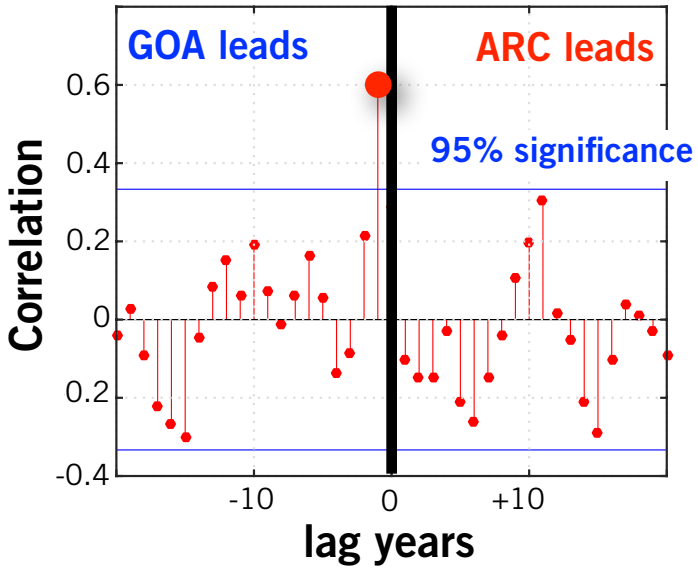
SSTA

PDO-type
ARC Pattern



EOF1 Winter SSTa

Cross Correlation
EOF2 (year 0) vs. EOF1 (year +1)

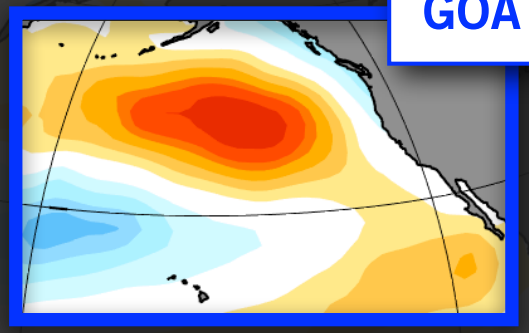


SSTA RANGE [-0.8C +0.8C]

WINTER (JFM)

SSTA

NPGO-type
GOA Pattern

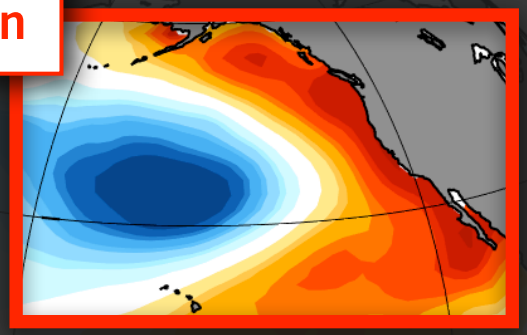


EOF2 Winter SSTa

WINTER (JFM) NEXT YEAR

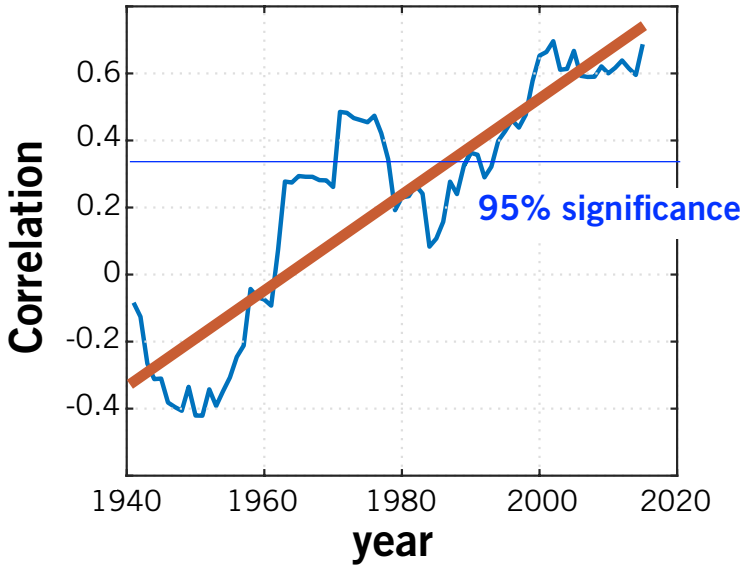
SSTA

PDO-type
ARC Pattern



EOF1 Winter SSTa

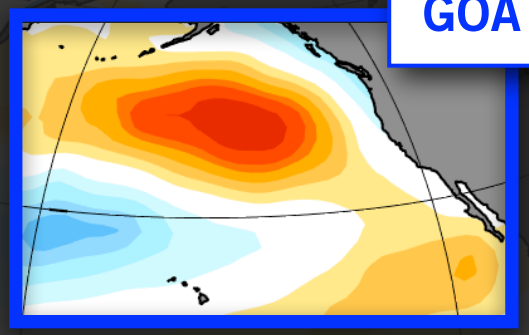
20-year Running Correlation
EOF2 (year 0) vs. EOF1 (year +1)



SSTA RANGE [-0.8C +0.8C]

WINTER (JFM)

SSTA

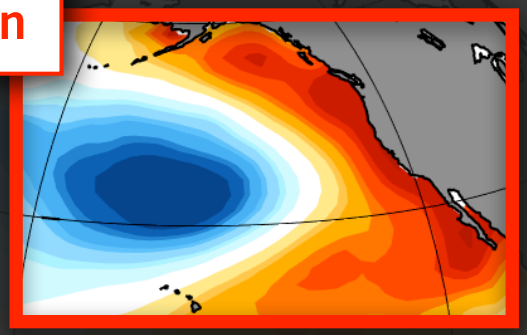


NPGO-type
GOA Pattern

EOF2 Winter SSTa

WINTER (JFM) NEXT YEAR

SSTA



PDO-type
ARC Pattern

EOF1 Winter SSTa

QUESTION

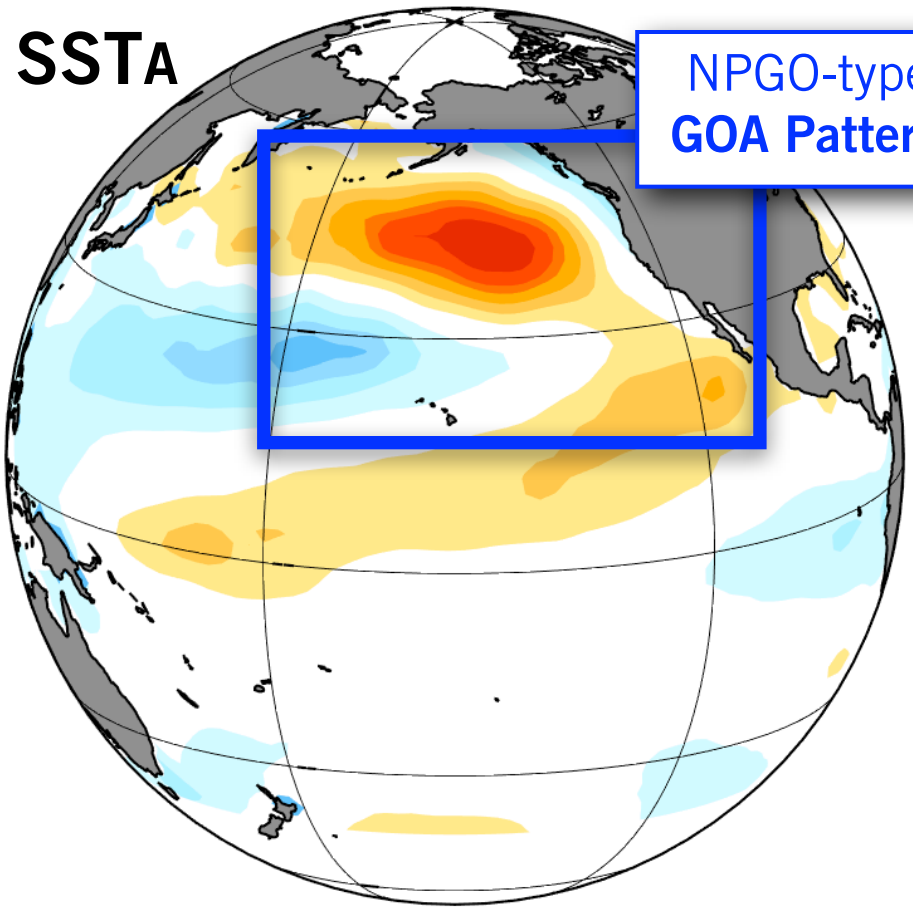
What is the mechanism linking these two patterns?

SSTA RANGE [-0.8C +0.8C]

WINTER (JFM)

SSTA

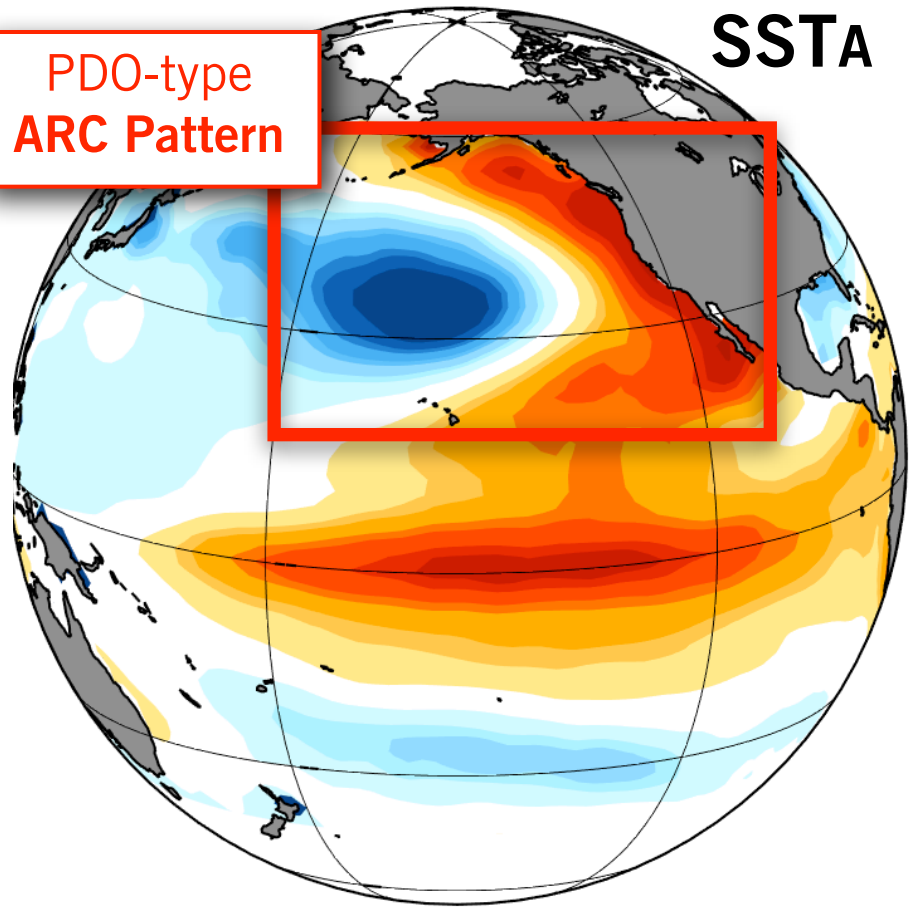
NPGO-type
GOA Pattern



WINTER (JFM) NEXT YEAR

SSTA

PDO-type
ARC Pattern



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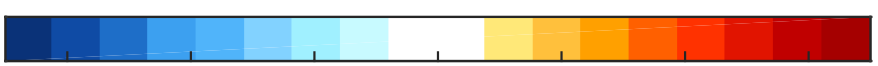
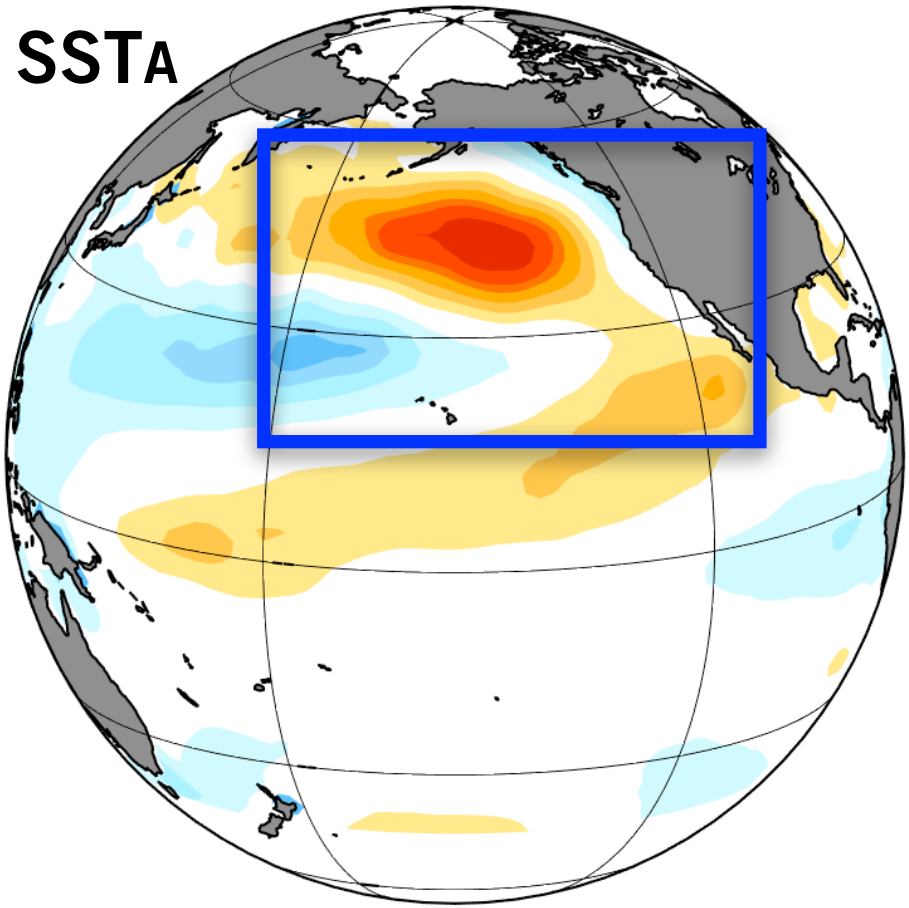


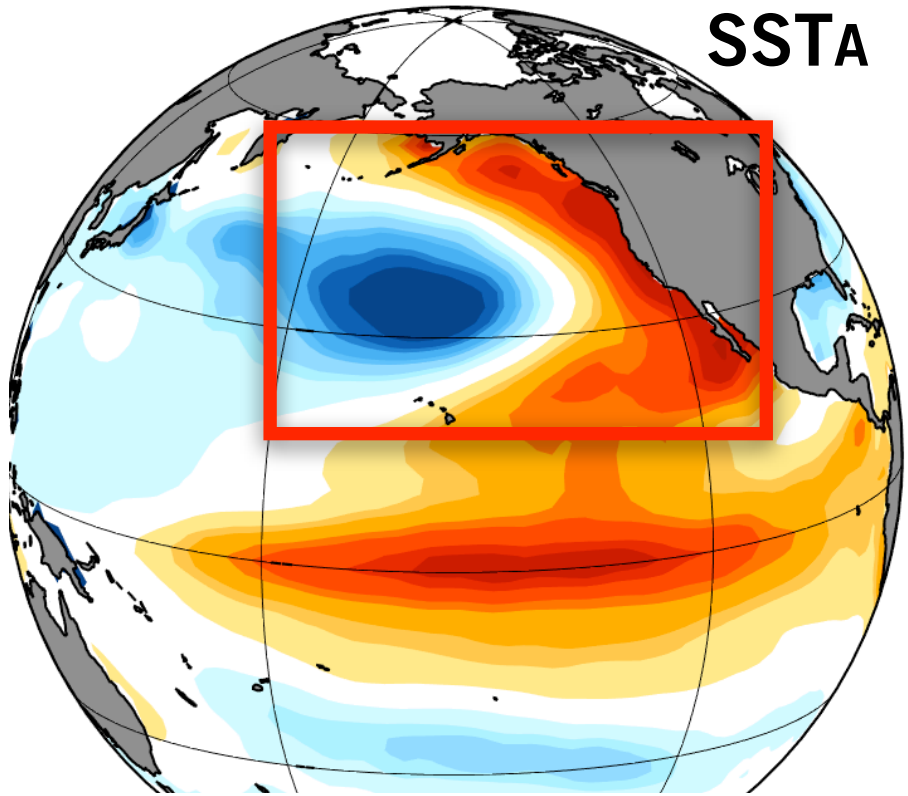
WINTER (JFM)

SSTA

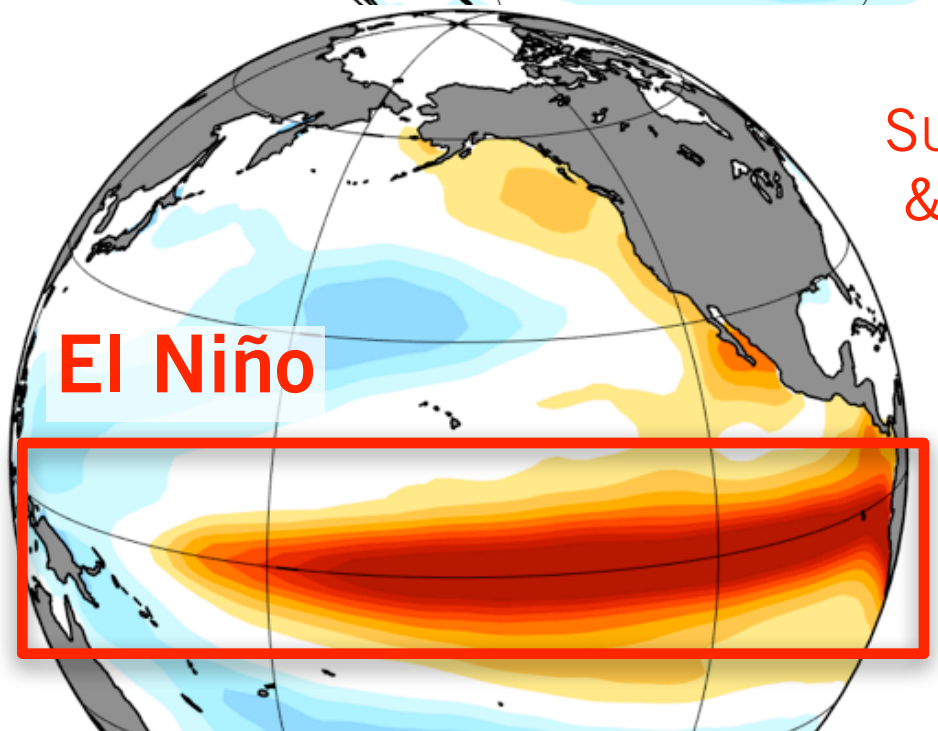


WINTER (JFM) NEXT YEAR

SSTA



SUMMER & FALL



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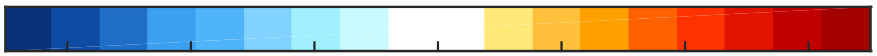
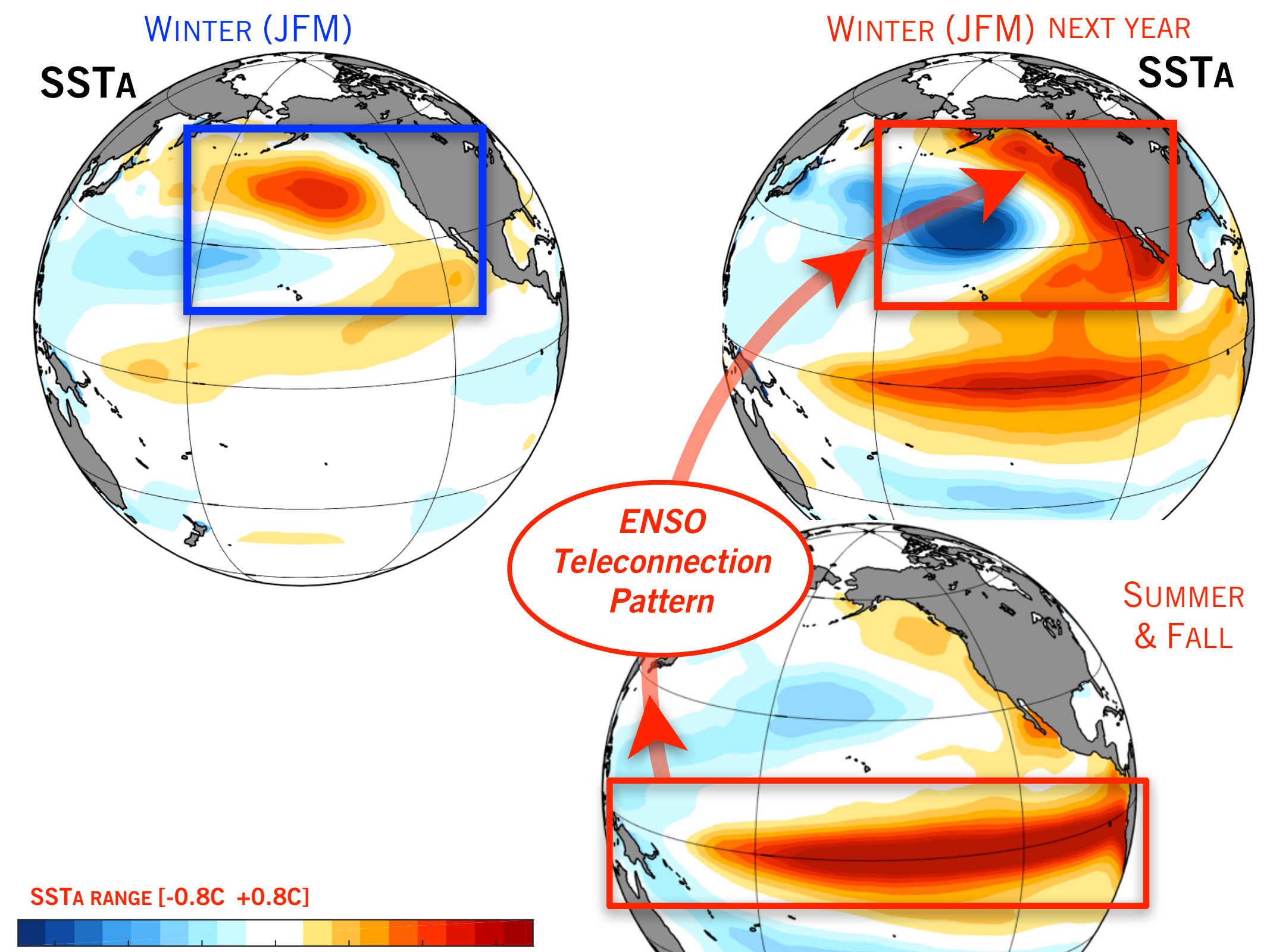
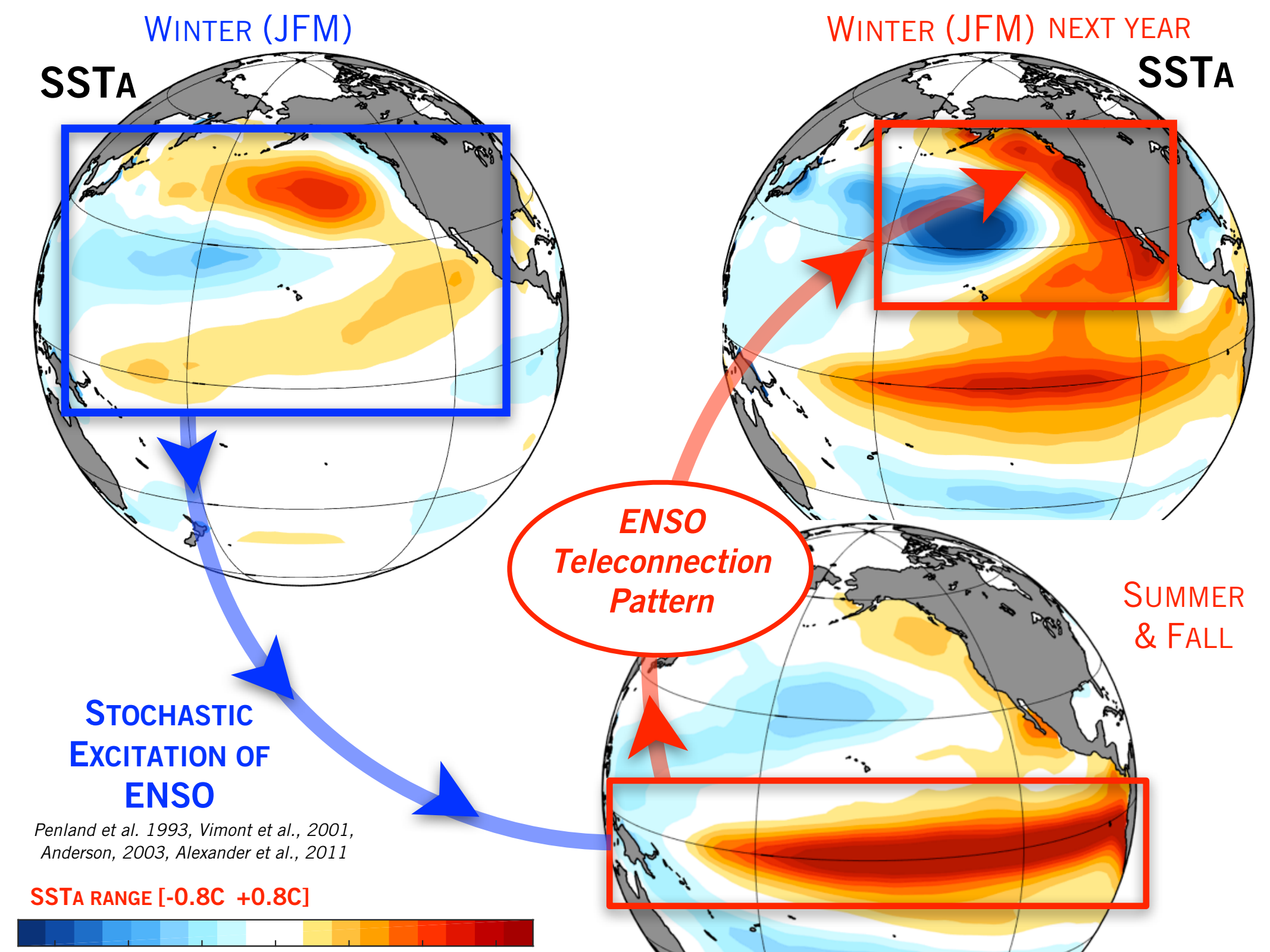
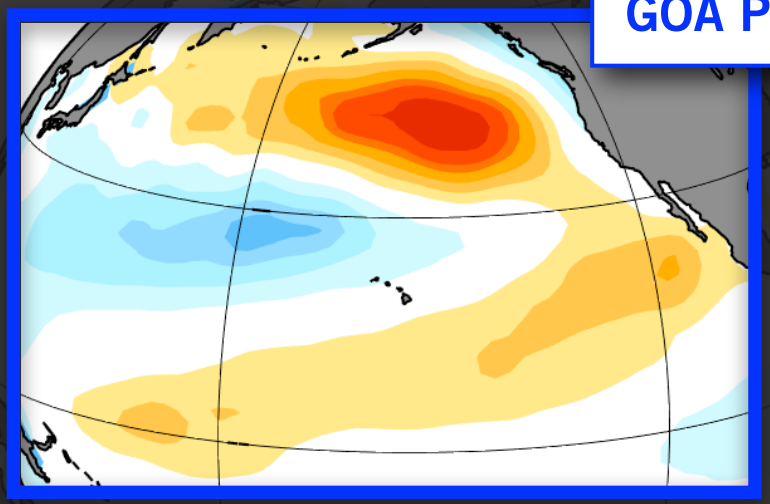



WINTER (JFM)
SSTA
WINTER (JFM) NEXT YEAR
SSTA
ENSO
Teleconnection
Pattern
SUMMER
& FALL
SSTA RANGE [-0.8C +0.8C]


WINTER (JFM)
SSTA
WINTER (JFM) NEXT YEAR
SSTA
ENSO
Teleconnection
Pattern
SUMMER
& FALL
STOCHASTIC
EXCITATION OF
ENSO
Penland et al. 1993, Vimont et al., 2001,
Anderson, 2003, Alexander et al., 2011
SSTA RANGE [-0.8C +0.8C]

WINTER (JFM)

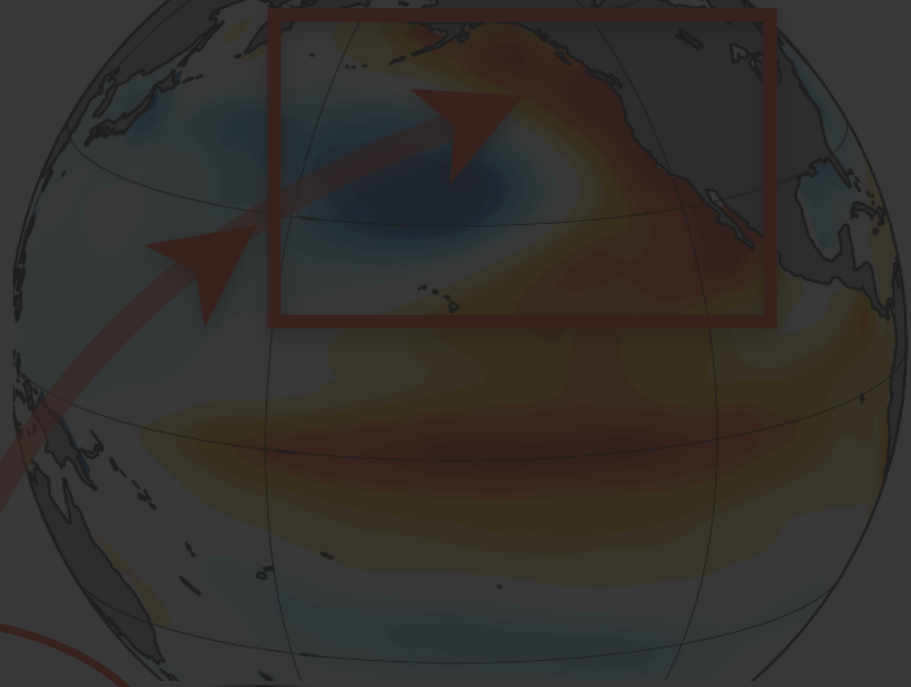
SSTA



NPGO-type
GOA Pattern

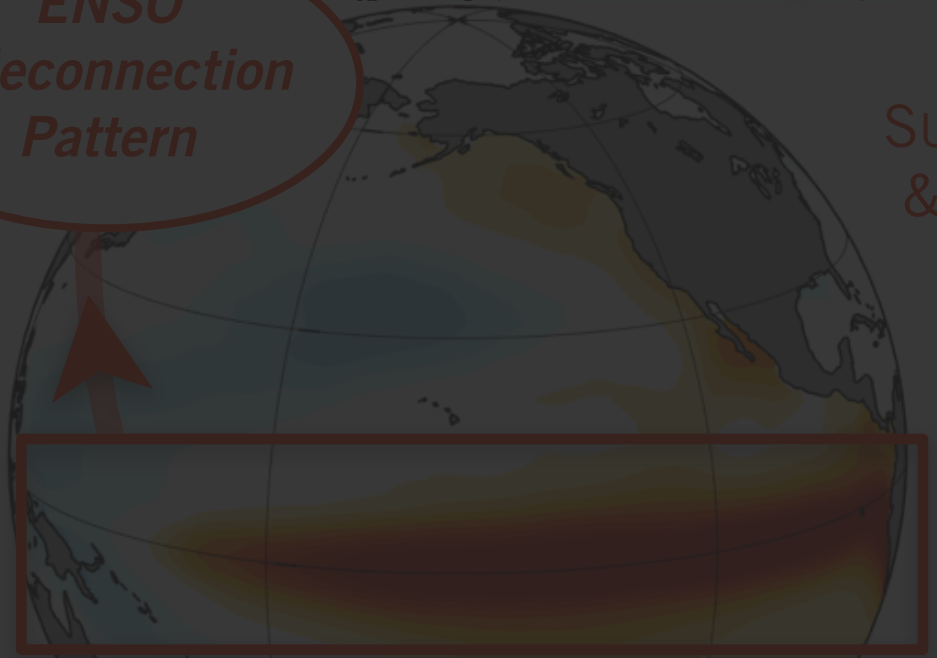
WINTER (JFM) NEXT YEAR

SSTA

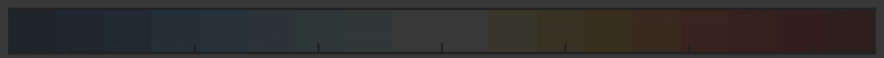


ENSO Teleconnection Pattern

SUMMER & FALL



SSTA RANGE [-0.8C +0.8C]

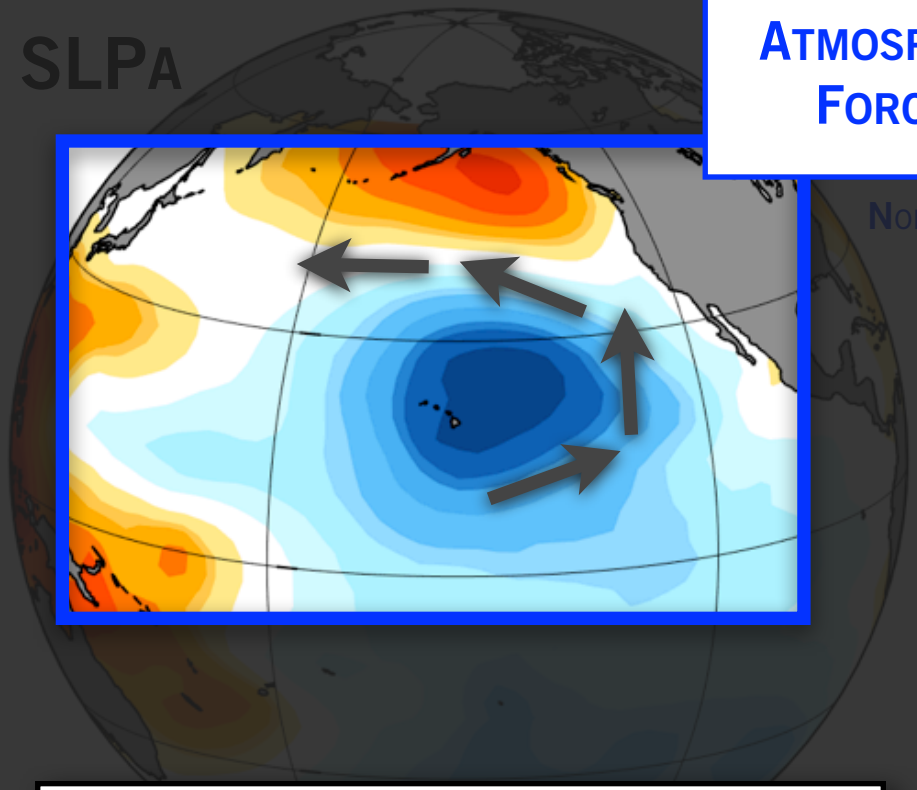


QUESTION

So how does this pattern trigger ENSO?

WINTER (JFM)

SLPA



ATMOSPHERIC FORCING

North Pacific Oscillation

QUESTION

So how does this pattern trigger ENSO?

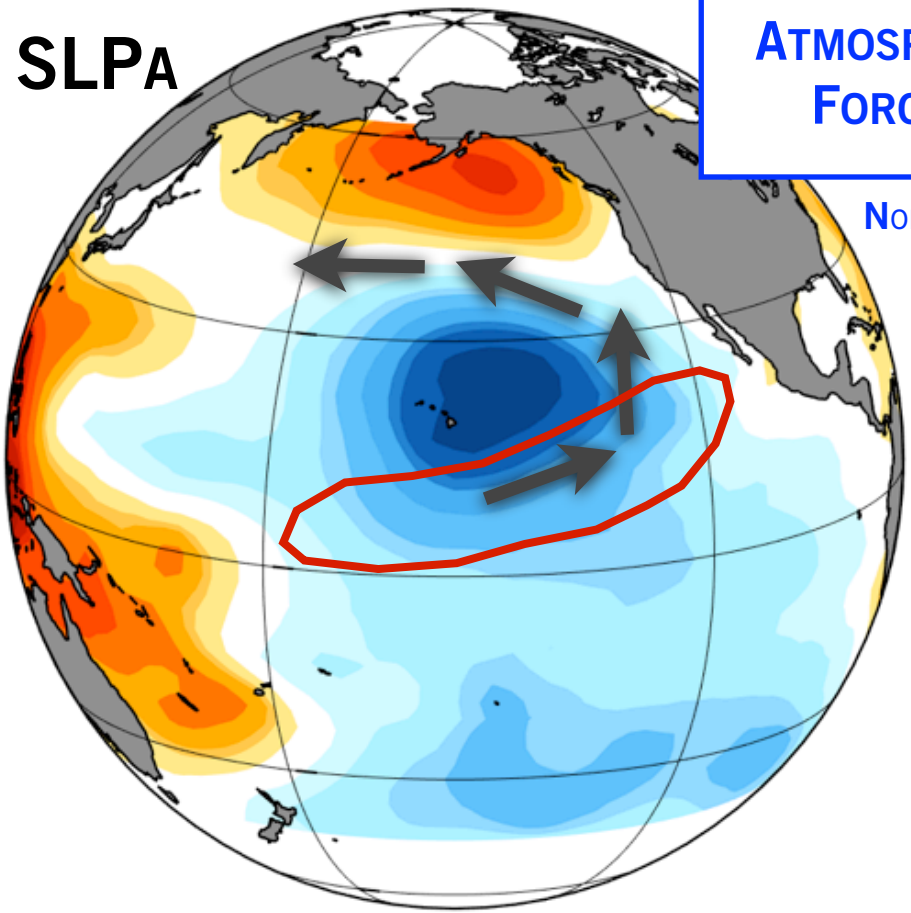
SLP ANOMALY

-2 0 +2

UNITS OF STD

WINTER (JFM)

SLPA



ATMOSPHERIC FORCING

North Pacific Oscillation

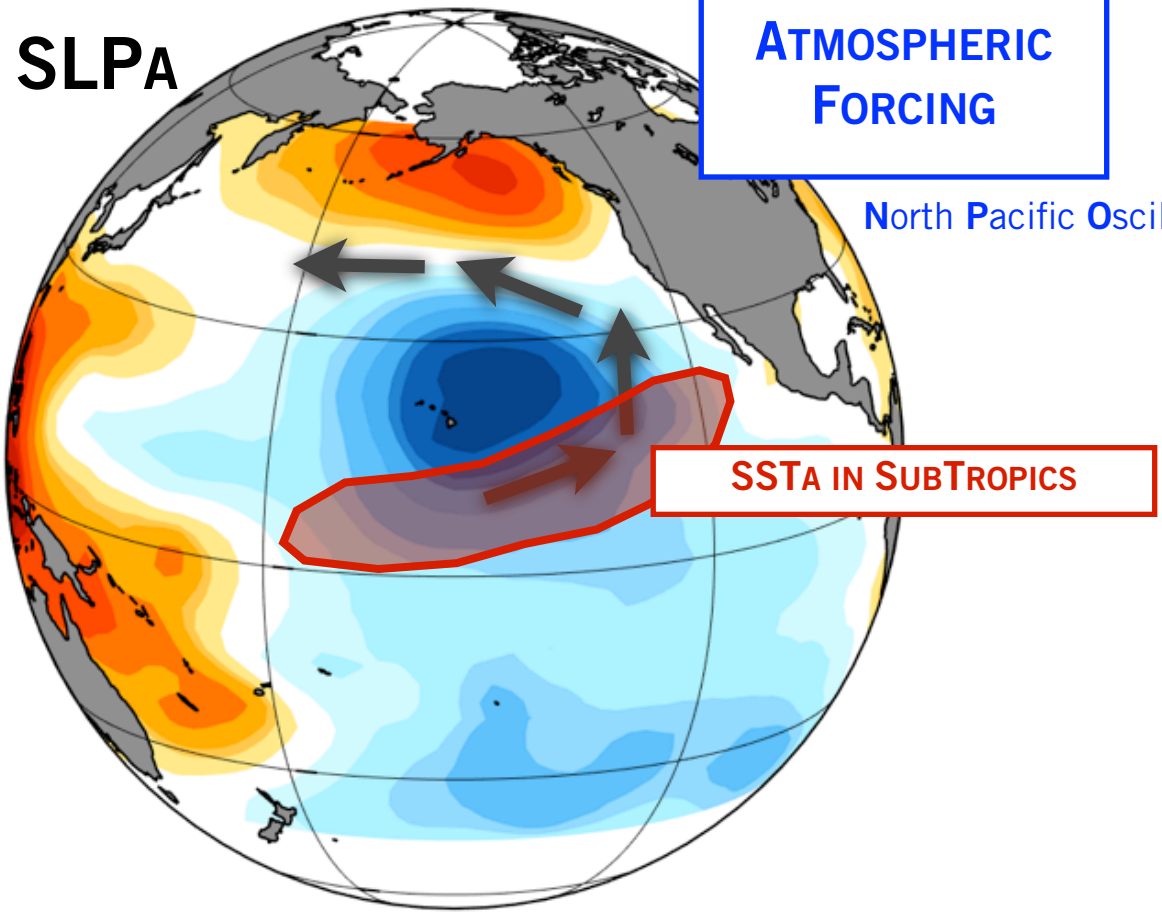
SLP ANOMALY

-2 0 +2

UNITS OF STD

WINTER (JFM)

SLPA



ATMOSPHERIC FORCING

North Pacific Oscillation

SSTA IN SUBTROPICS

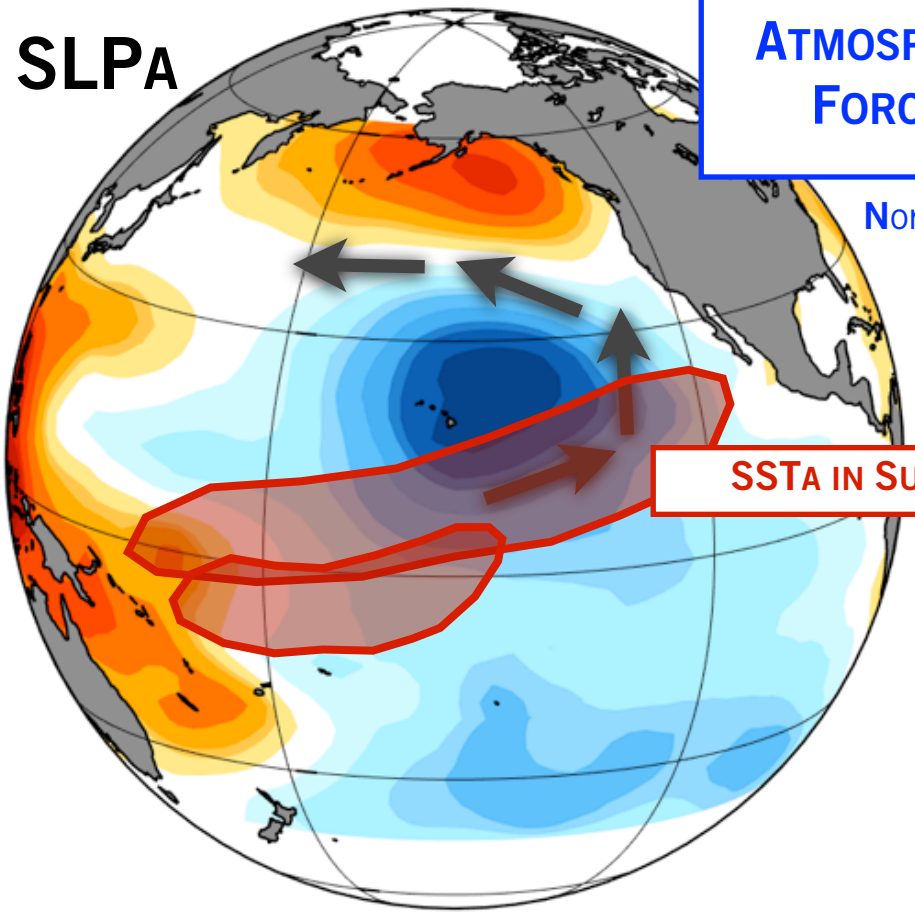
SLP ANOMALY

-2 0 +2

UNITS OF STD

WINTER (JFM)

SLPA



ATMOSPHERIC FORCING

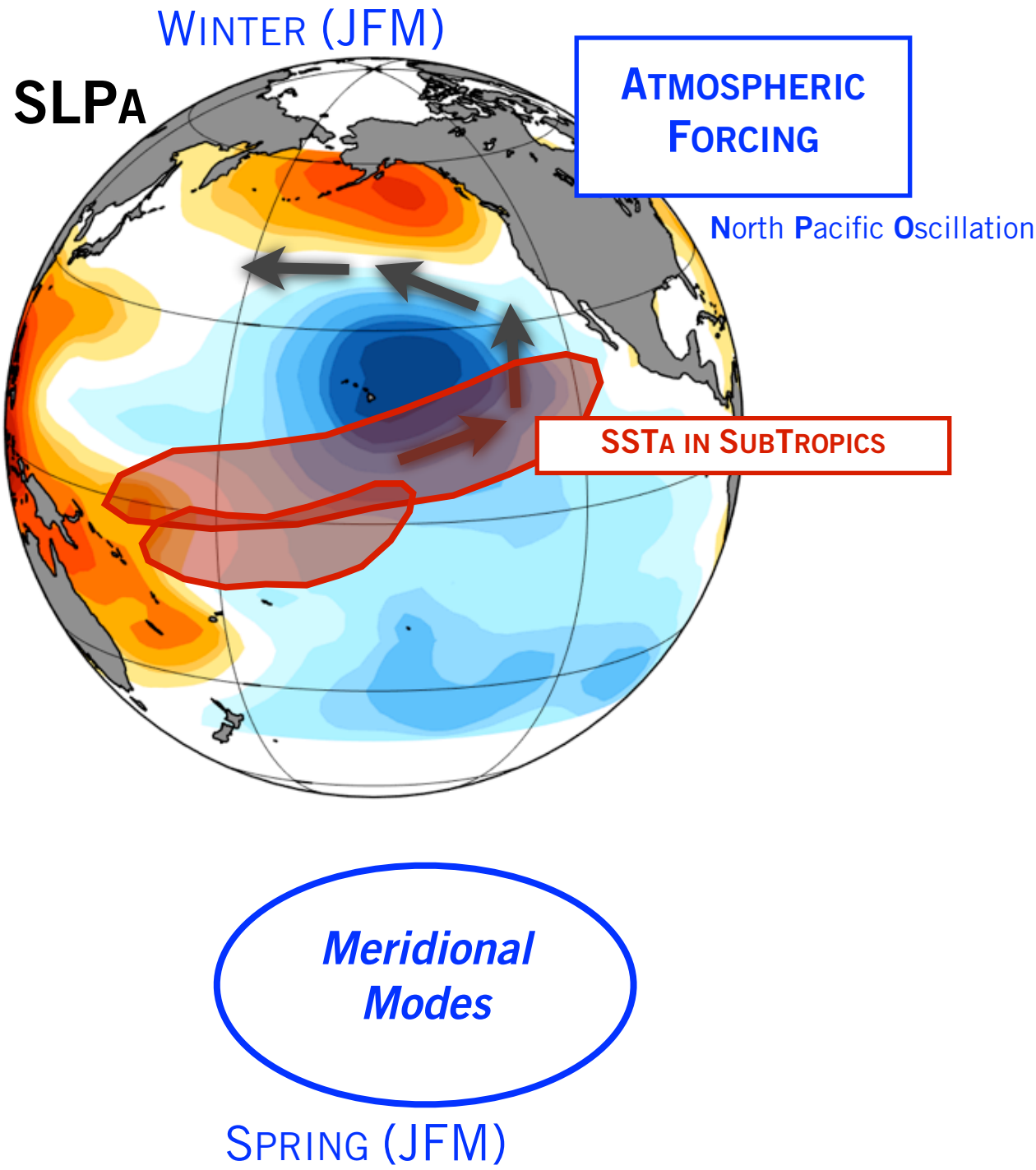
North Pacific Oscillation

SSTA IN SUBTROPICS

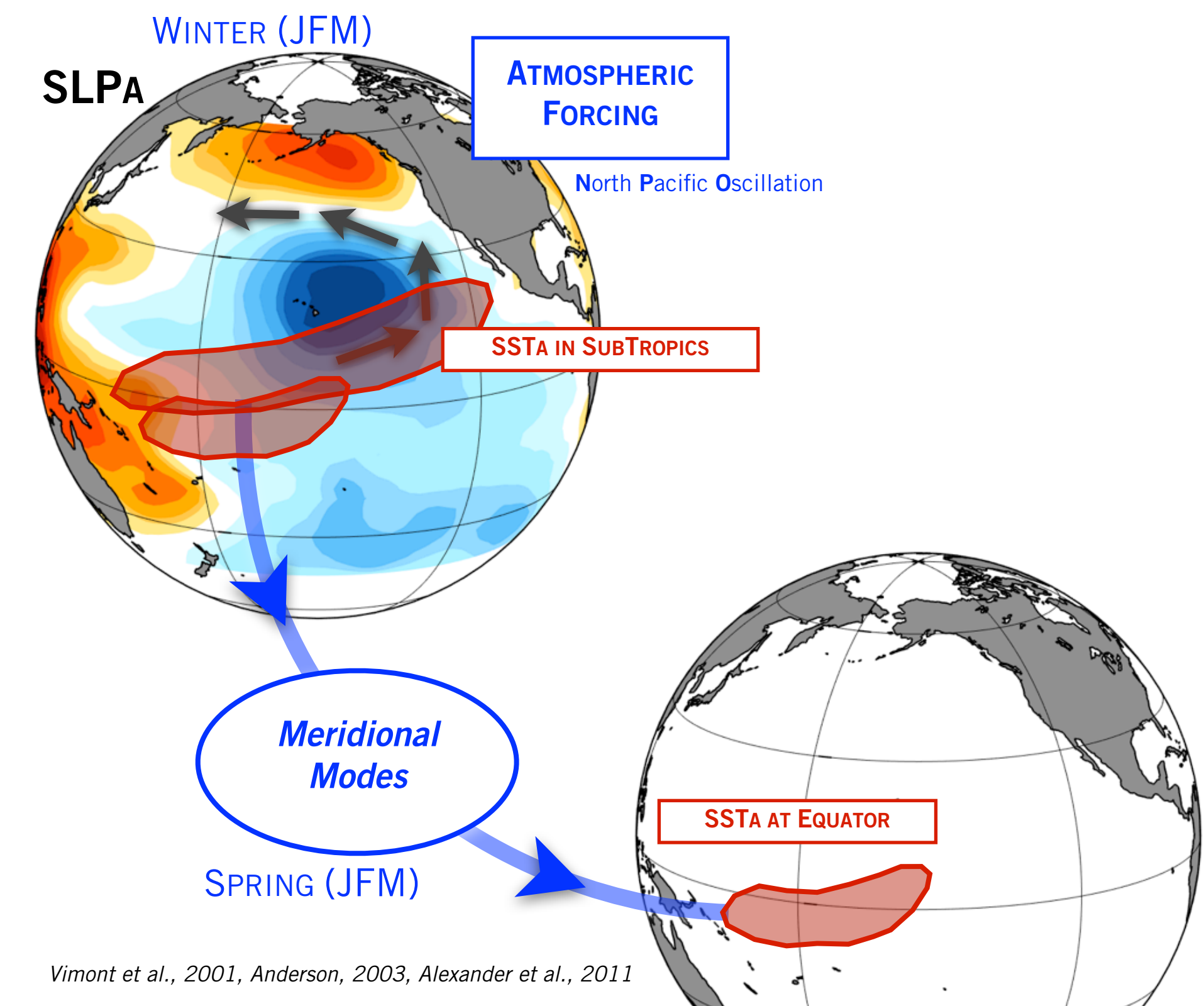
SLP ANOMALY

-2 0 +2

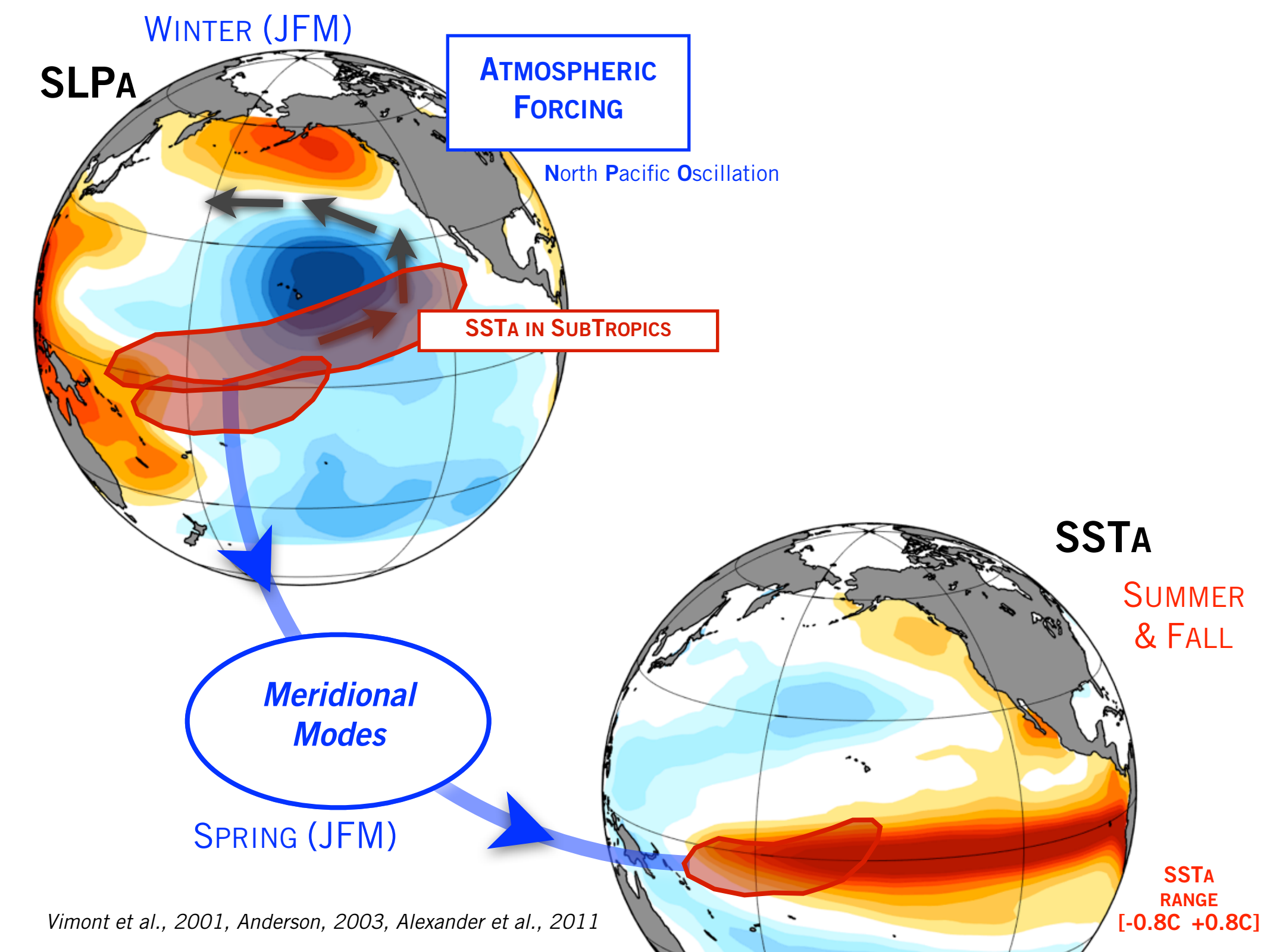
UNITS OF STD



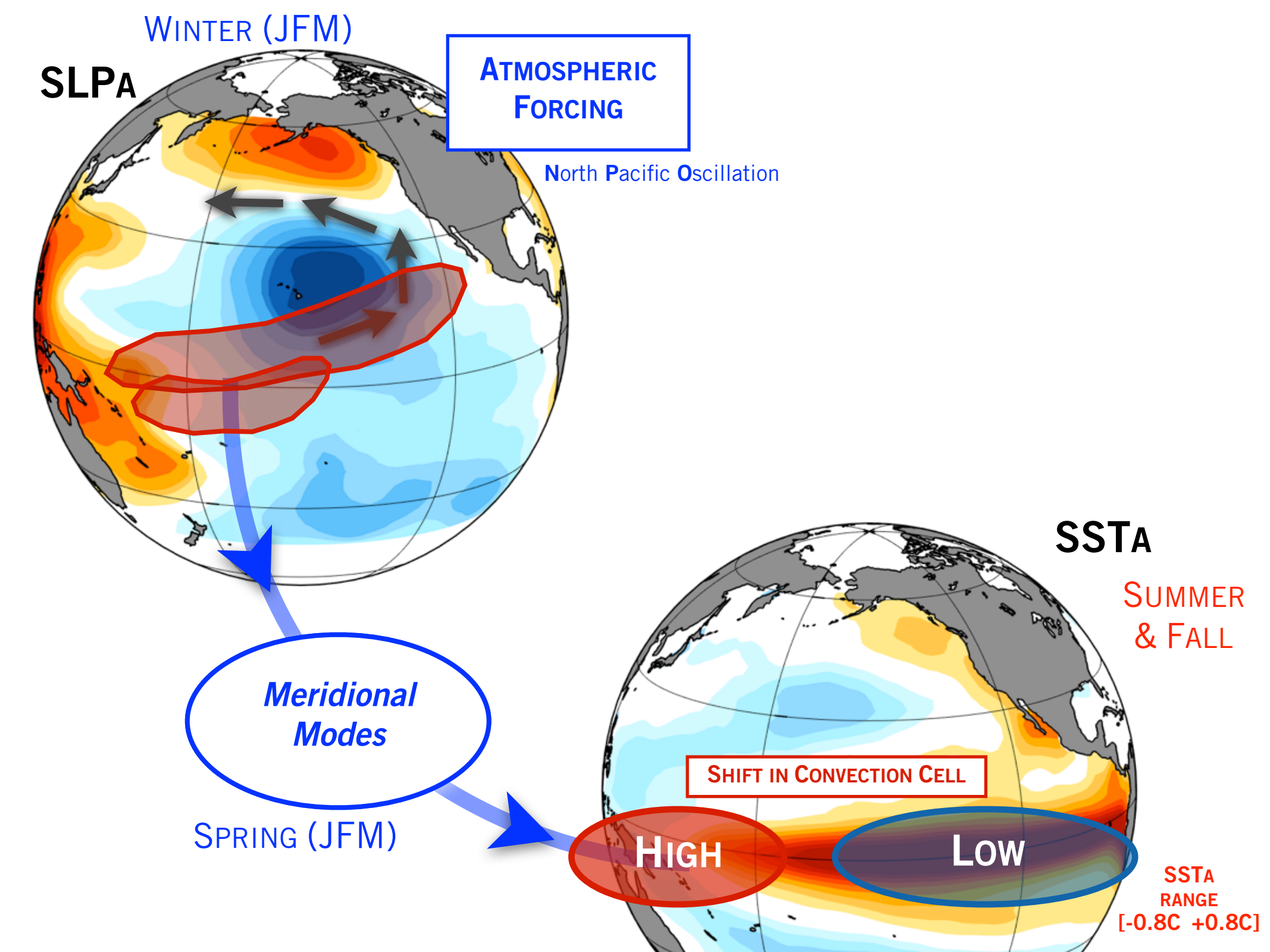
Vimont et al., 2001, Anderson, 2003, Alexander et al., 2011

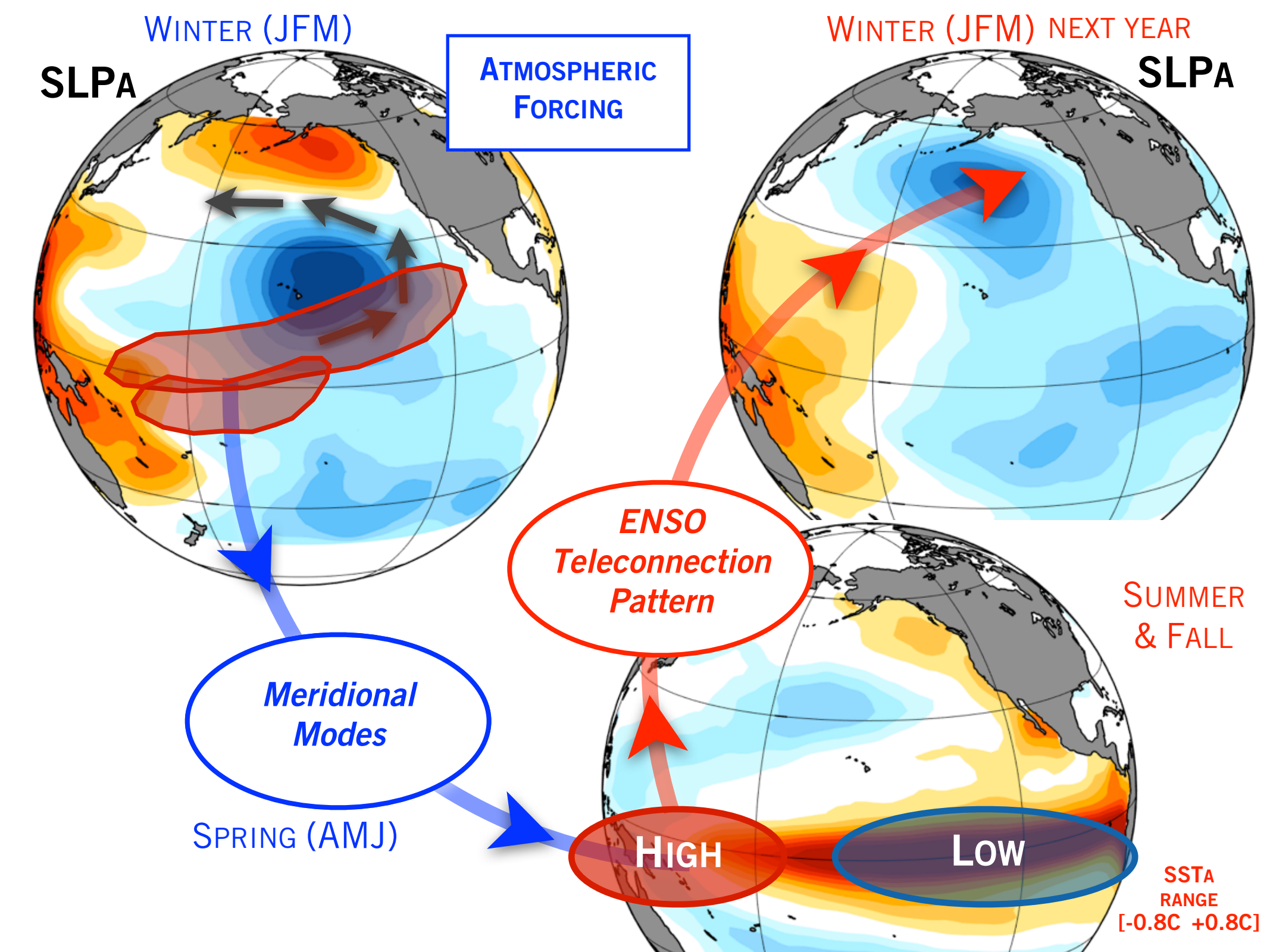


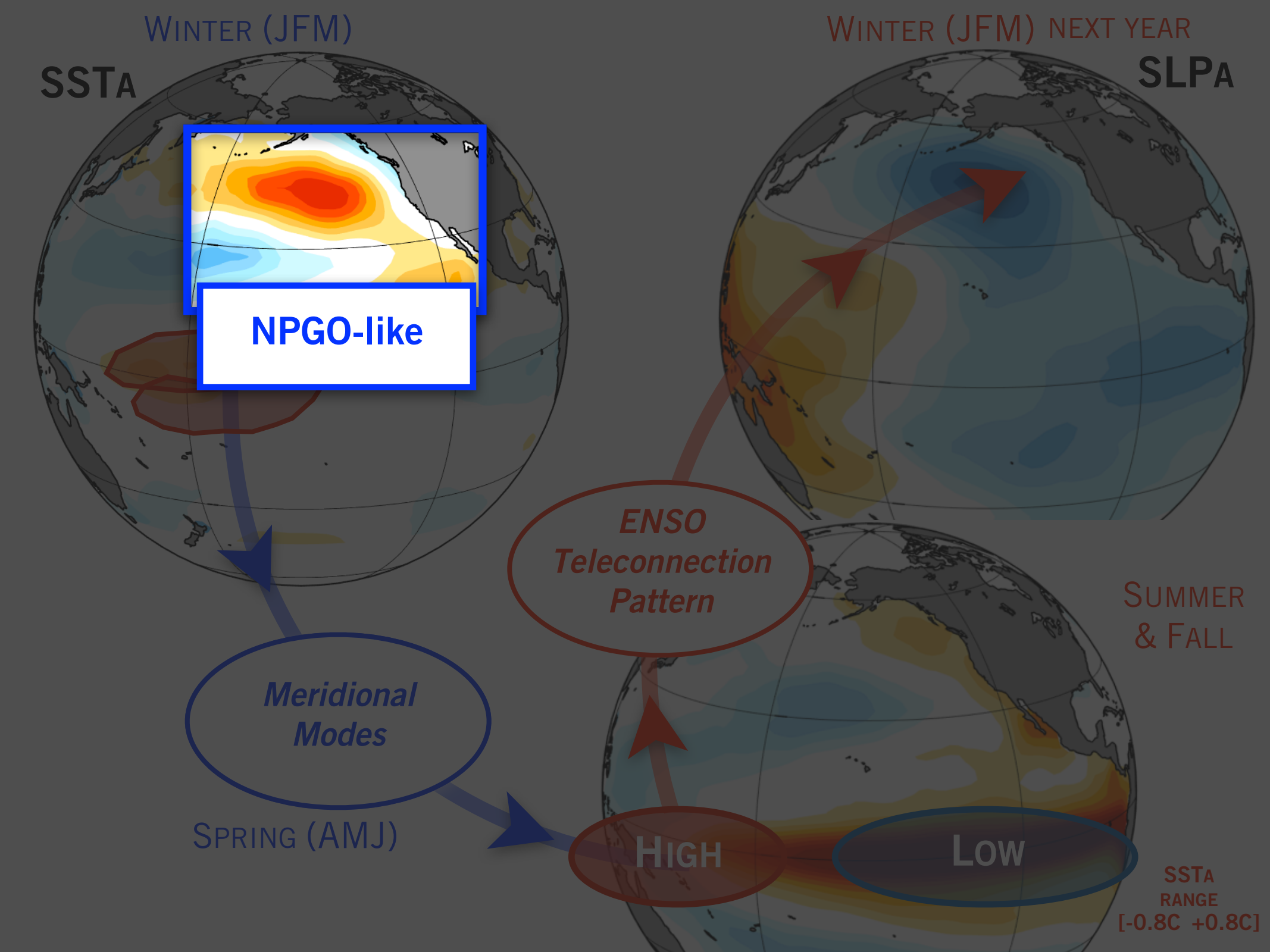
Vimont et al., 2001, Anderson, 2003, Alexander et al., 2011

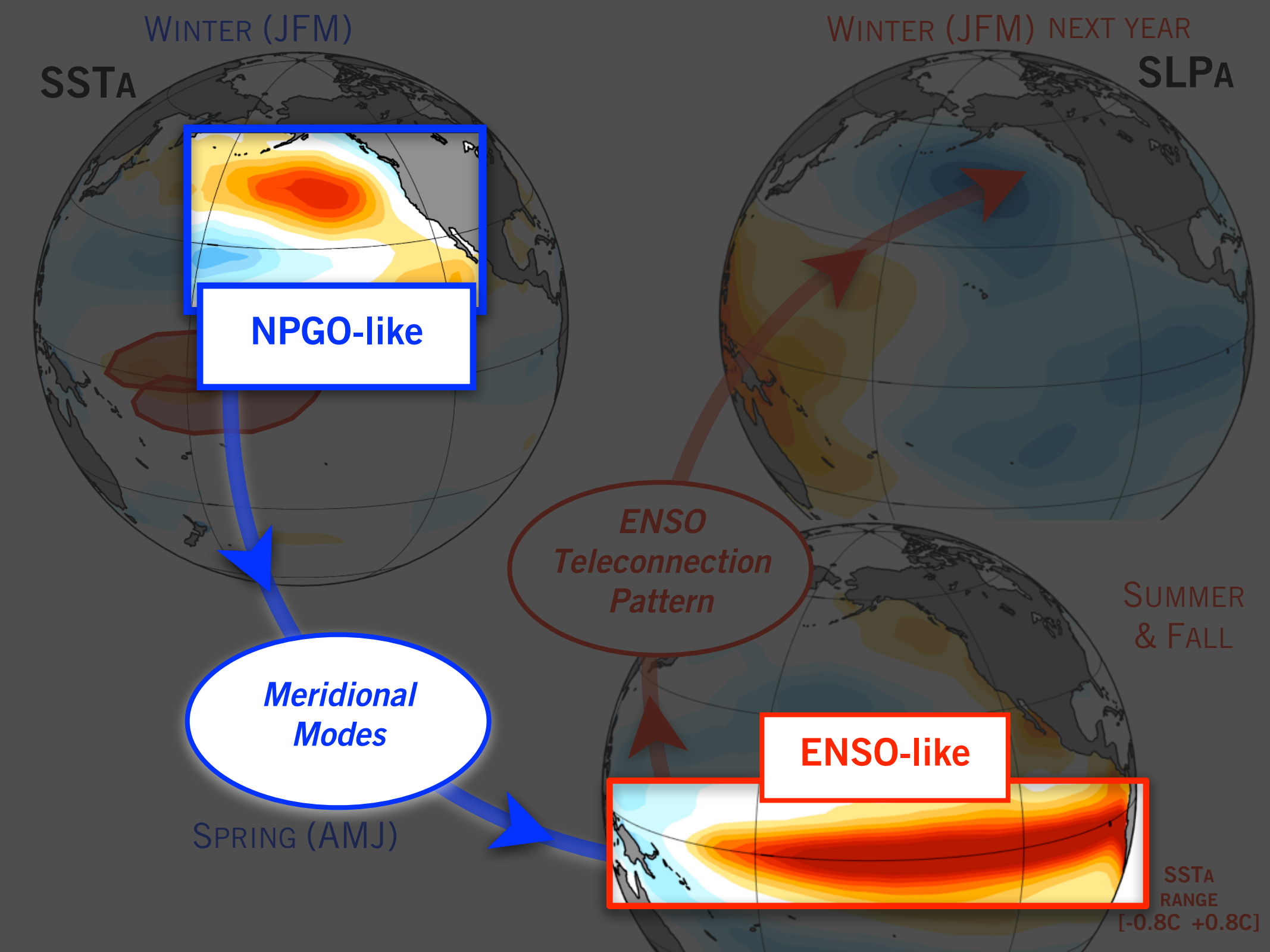


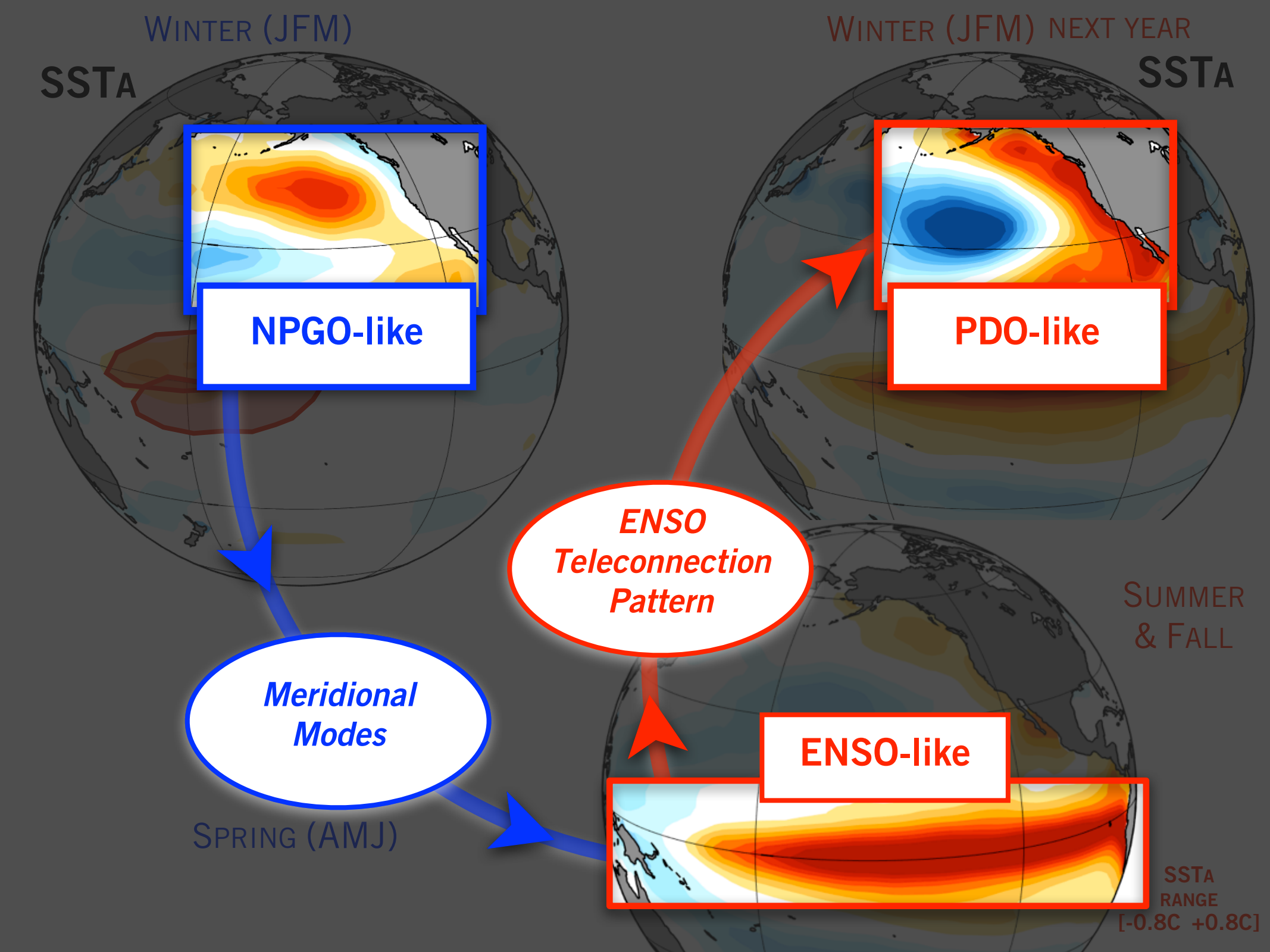
Vimont et al., 2001, Anderson, 2003, Alexander et al., 2011


WINTER (JFM)
SLPA
ATMOSPHERIC FORCING
North Pacific Oscillation
SSTA
SUMMER & FALL
Meridional Modes
SPRING (JFM)
SHIFT IN CONVECTION CELL
HIGH
LOW
SSTA RANGE [-0.8C +0.8C]


WINTER (JFM)
SLPA
ATMOSPHERIC FORCING
WINTER (JFM) NEXT YEAR
SLPA
ENSO Teleconnection Pattern
SUMMER & FALL
Meridional Modes
SPRING (AMJ)
HIGH
LOW
SSTA RANGE [-0.8C +0.8C]

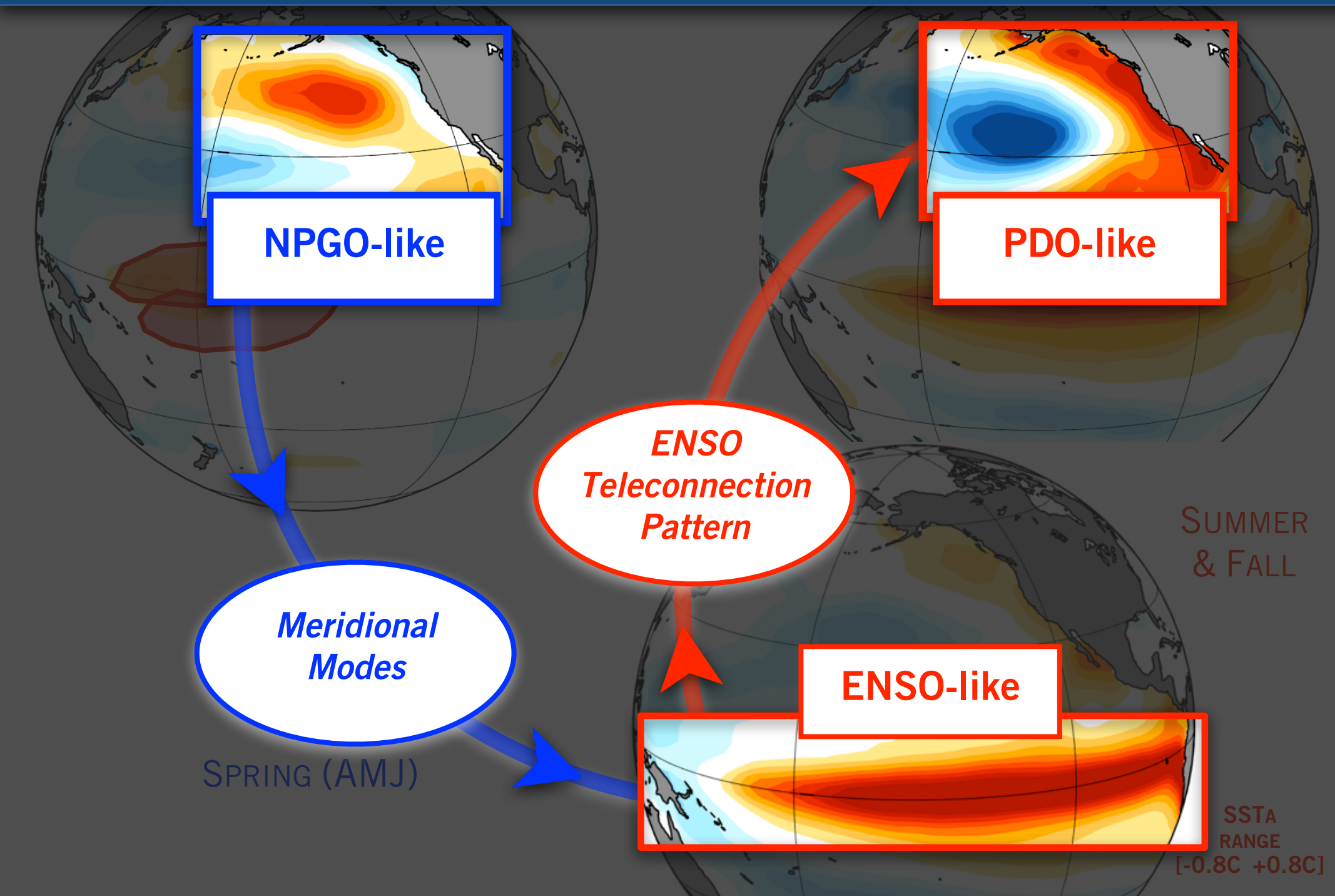

WINTER (JFM)
SSTA
NPGO-like
WINTER (JFM) NEXT YEAR
SLPA
ENSO
Teleconnection
Pattern
SUMMER
& FALL
Meridional
Modes
SPRING (AMJ)
HIGH
LOW
SSTA
RANGE
[-0.8C +0.8C]


WINTER (JFM)
SSTA
NPGO-like
WINTER (JFM) NEXT YEAR
SLPA
ENSO
Teleconnection
Pattern
SUMMER
& FALL
Meridional
Modes
SPRING (AMJ)
ENSO-like
SSTA
RANGE
[-0.8C +0.8C]


WINTER (JFM)
SSTA
NPGO-like
WINTER (JFM) NEXT YEAR
SSTA
PDO-like
ENSO
Teleconnection
Pattern
SUMMER
& FALL
Meridional
Modes
SPRING (AMJ)
ENSO-like
SSTA
RANGE
[-0.8C +0.8C]

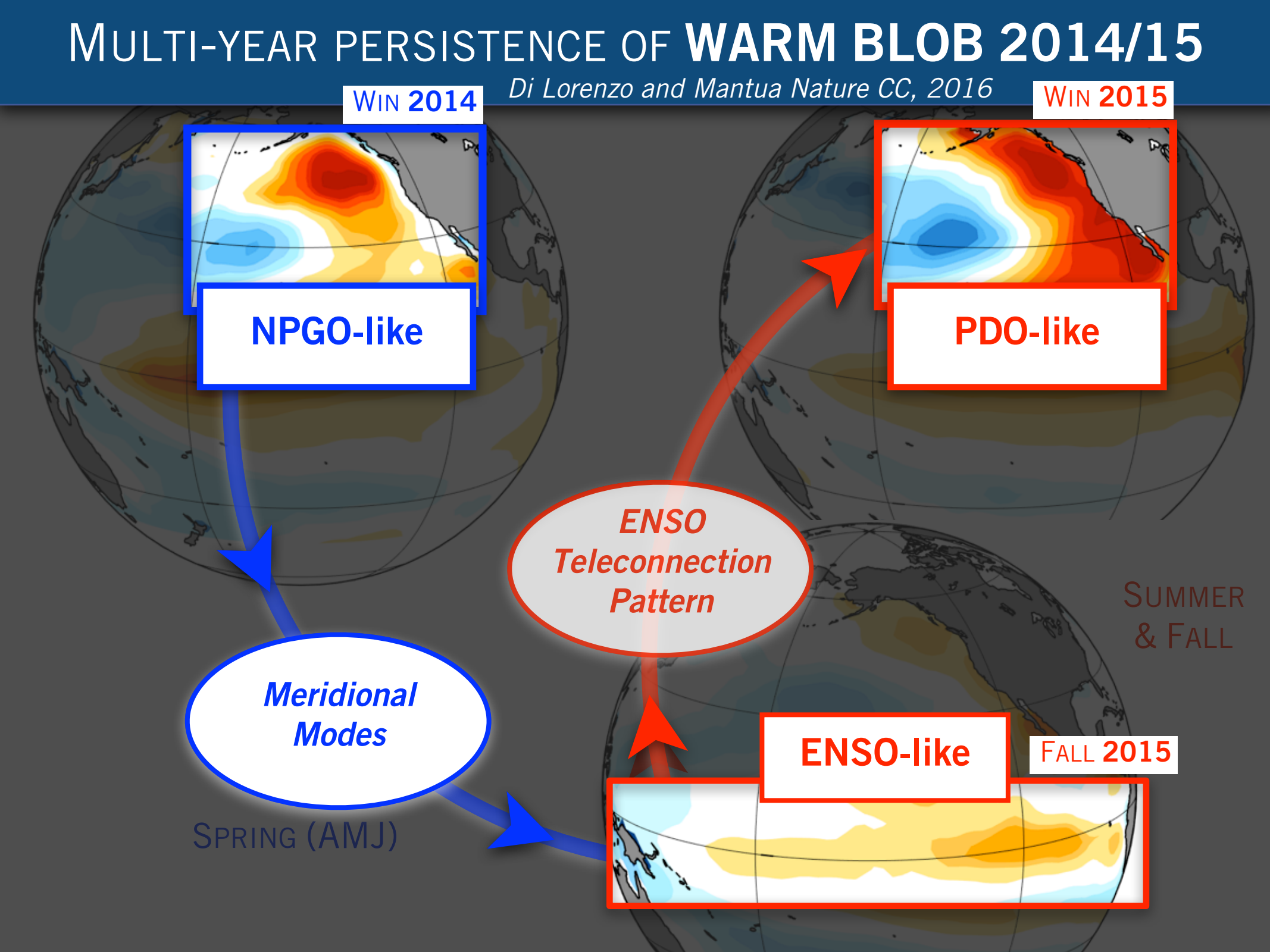
CLIMATE HYPOTHESIS for the DECADAL VARIABILITY

Di Lorenzo et al. GRL, 2015

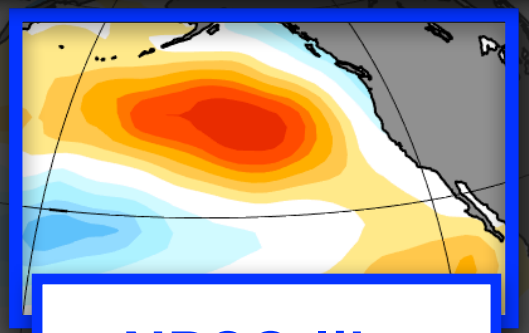


MULTI-YEAR PERSISTENCE OF **WARM BLOB 2014/15**

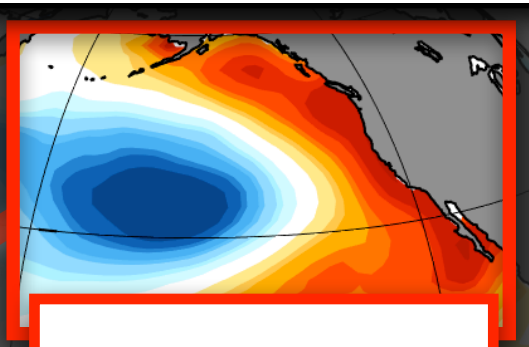
Di Lorenzo and Mantua Nature CC, 2016



Evidence for a Significant **INCREASE IN THE PDV VARIANCE**



NPGO-like



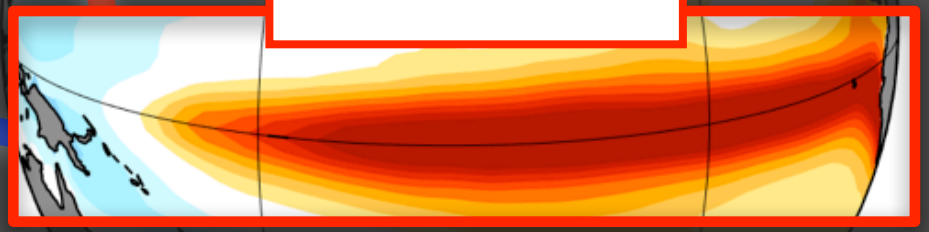
PDO-like

ENSO Teleconnection Pattern

Meridional Modes

SPRING (AMJ)

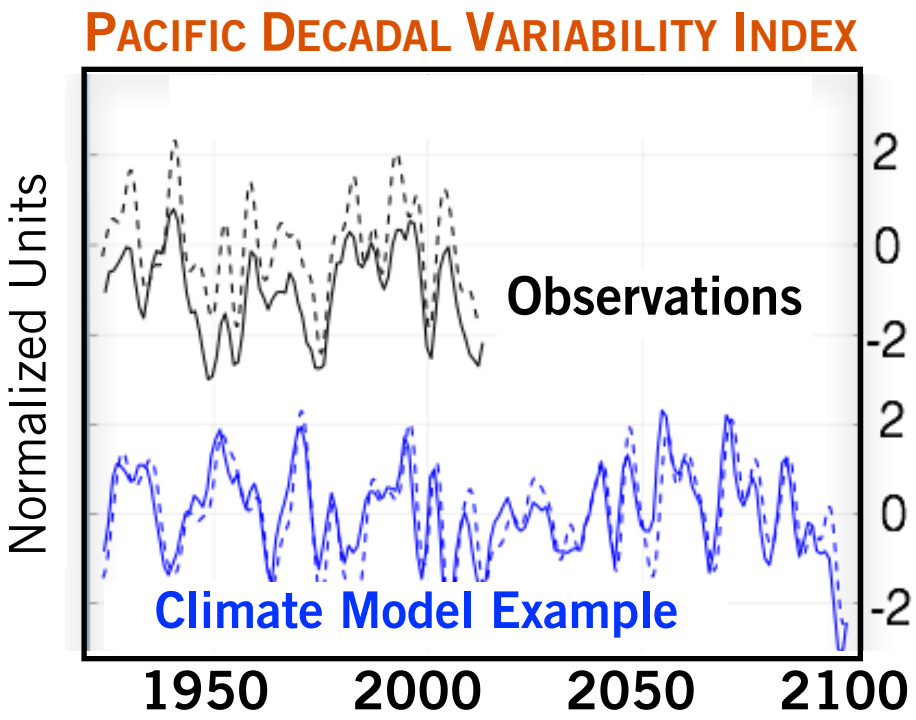
SUMMER & FALL



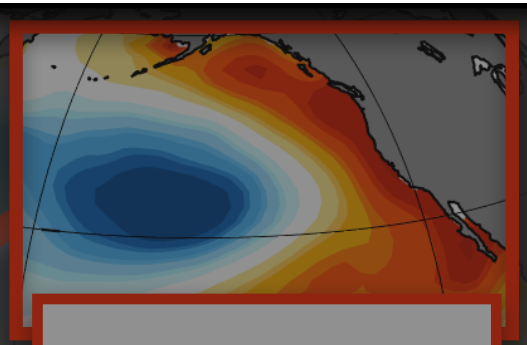
ENSO-like

SSTA RANGE [-0.8C +0.8C]

Evidence for a Significant **INCREASE IN THE PDV VARIANCE**



Liguori et al. GRL, 2016



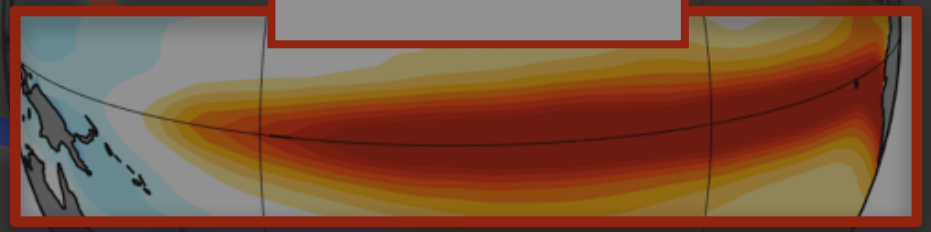
PDO-like

SUMMER & FALL

Meridional Modes

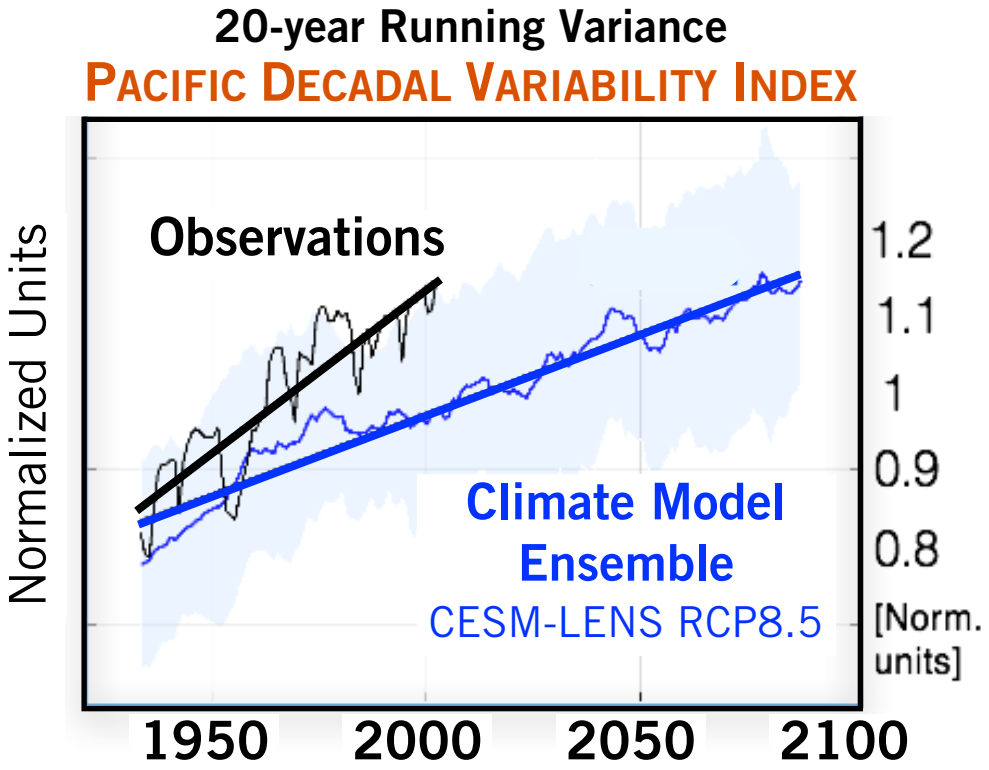
SPRING (AMJ)

ENSO-like

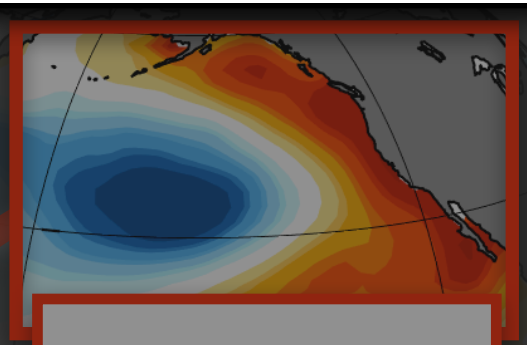


SSTA RANGE [-0.8C +0.8C]

Evidence for a Significant **INCREASE IN THE PDV VARIANCE**



Liguori et al. GRL, 2016



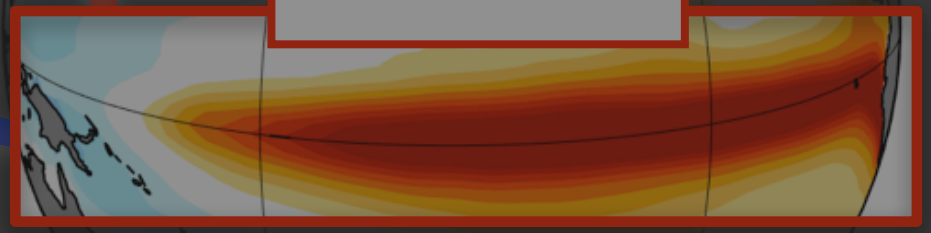
PDO-like

SUMMER & FALL

Meridional Modes

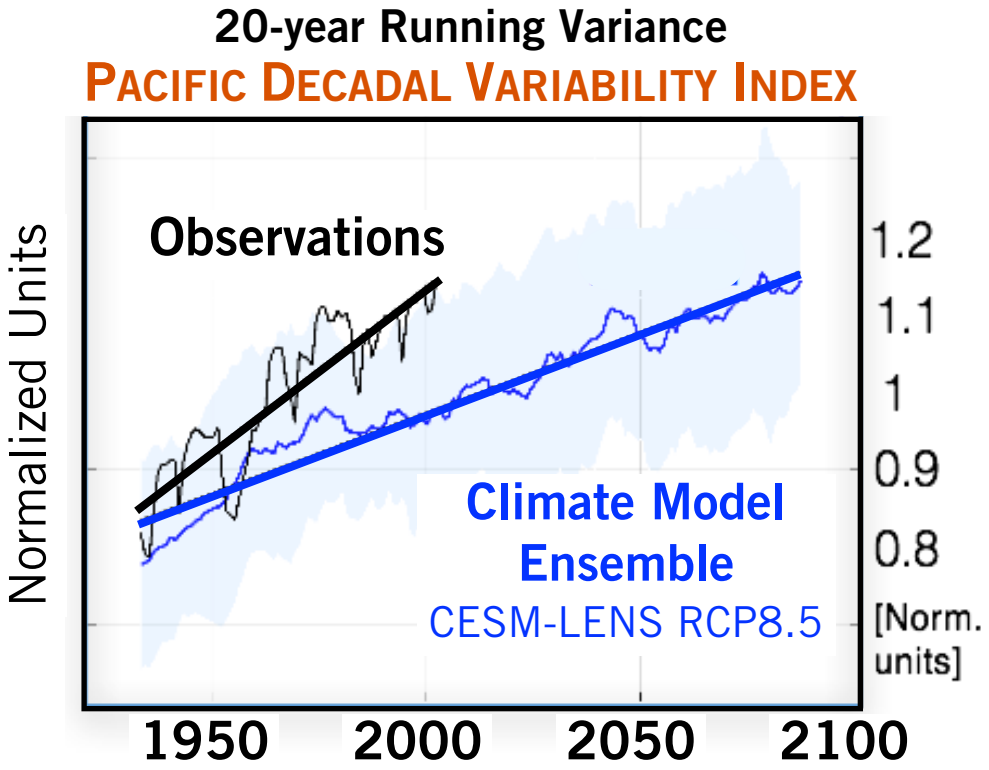
SPRING (AMJ)

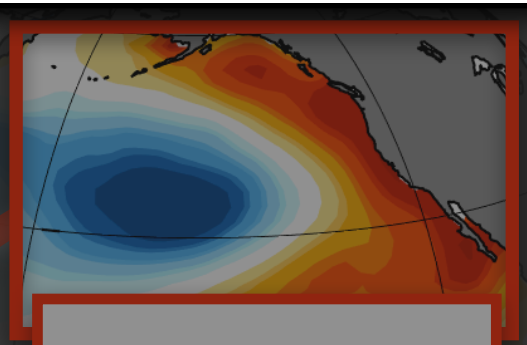
ENSO-like



SSTA RANGE [-0.8C +0.8C]

Evidence for a Significant **INCREASE IN THE PDV VARIANCE**



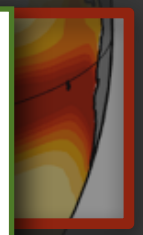


PDO-like

SUMMER & FALL

Meridional Modes

ENSO-like



SSTA RANGE [-0.8C +0.8C]

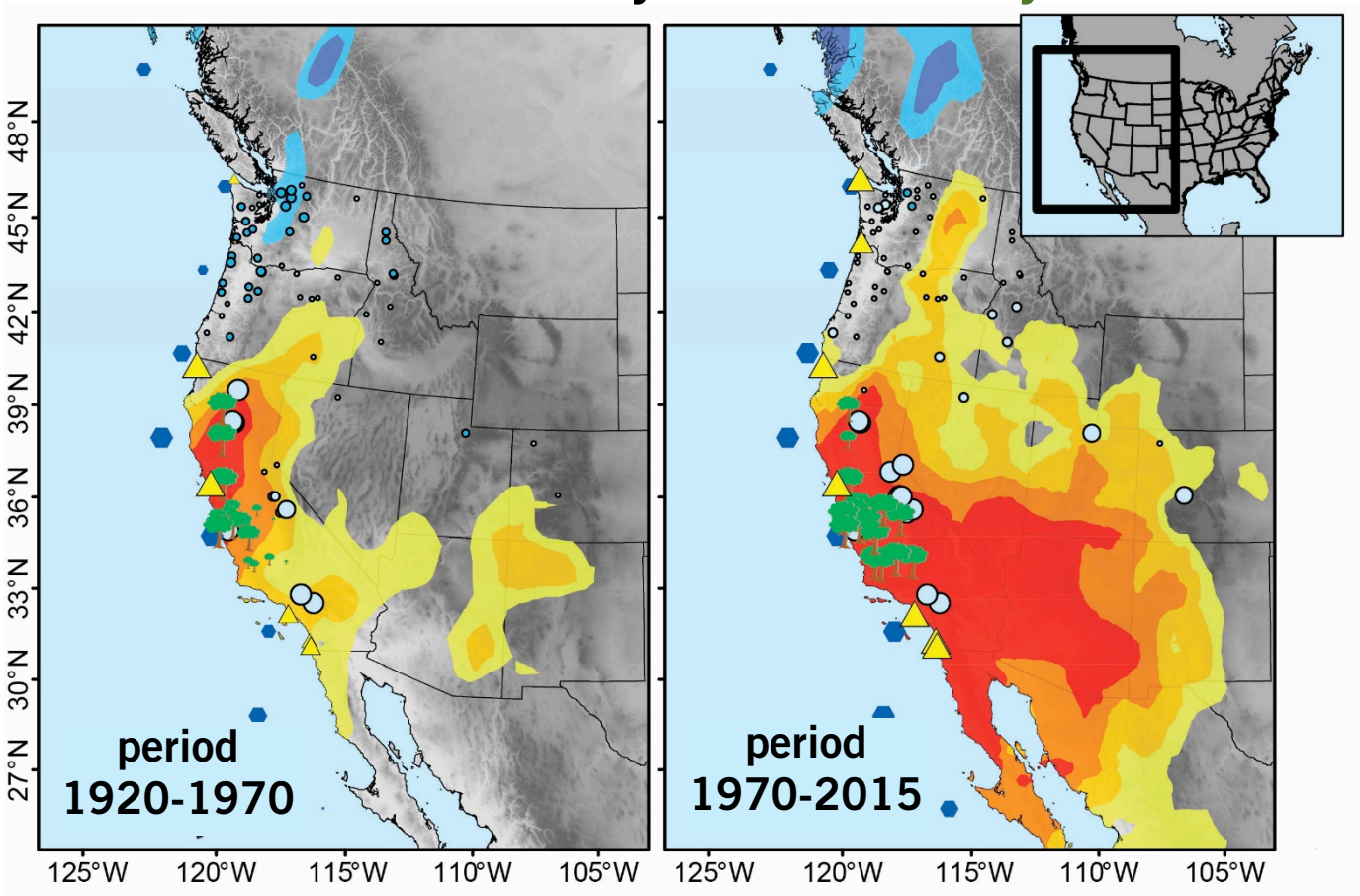
INCREASE IN THE VARIANCE ECOSYSTEM DRIVERS

(e.g. Upwelling, Sea Level, Rivers, Drought)

CORRELATIONS

Black et al., 2016

Pacific Decadal Variability Index vs. Ecosystem Drivers



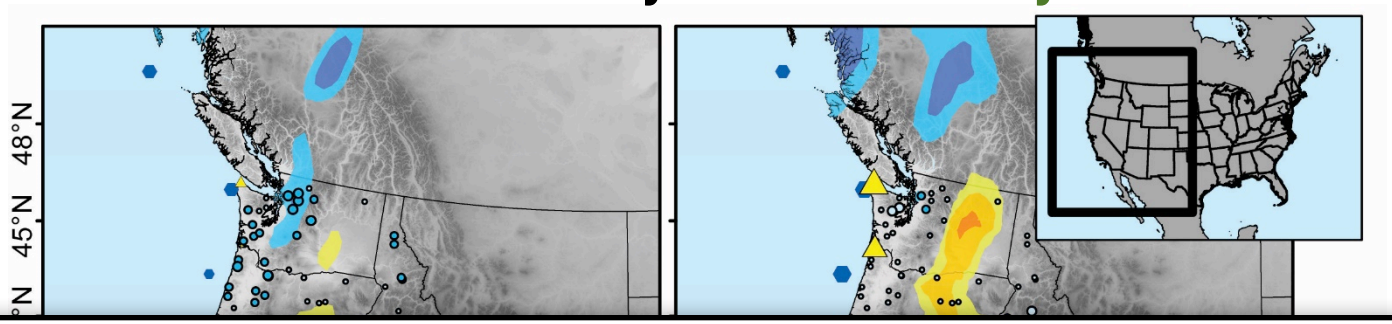
Long-term in-situ observations of Ecosystem Drivers

Precipitation	Sea level	Upwelling	Rivers	Blue oak
-0.60 - -0.80	-0.77 - -0.70	-0.23 - 0.20	-0.51 - -0.40	-0.55 - -0.50
-0.59 - -0.50	-0.69 - -0.60	0.21 - 0.30	-0.39 - -0.30	-0.49 - -0.40
-0.49 - -0.40	-0.59 - -0.50	0.31 - 0.40	-0.29 - -0.20	-0.39 - -0.30
-0.39 - -0.30	-0.49 - -0.40	0.41 - 0.50	-0.19 - 0.20	-0.29 - -0.20
0.31 - 0.40	-0.39 - -0.30	0.51 - 0.60	0.21 - 0.30	-0.19 - 0.10
0.41 - 0.52	-0.29 - -0.20	0.61 - 0.85	0.31 - 0.40	

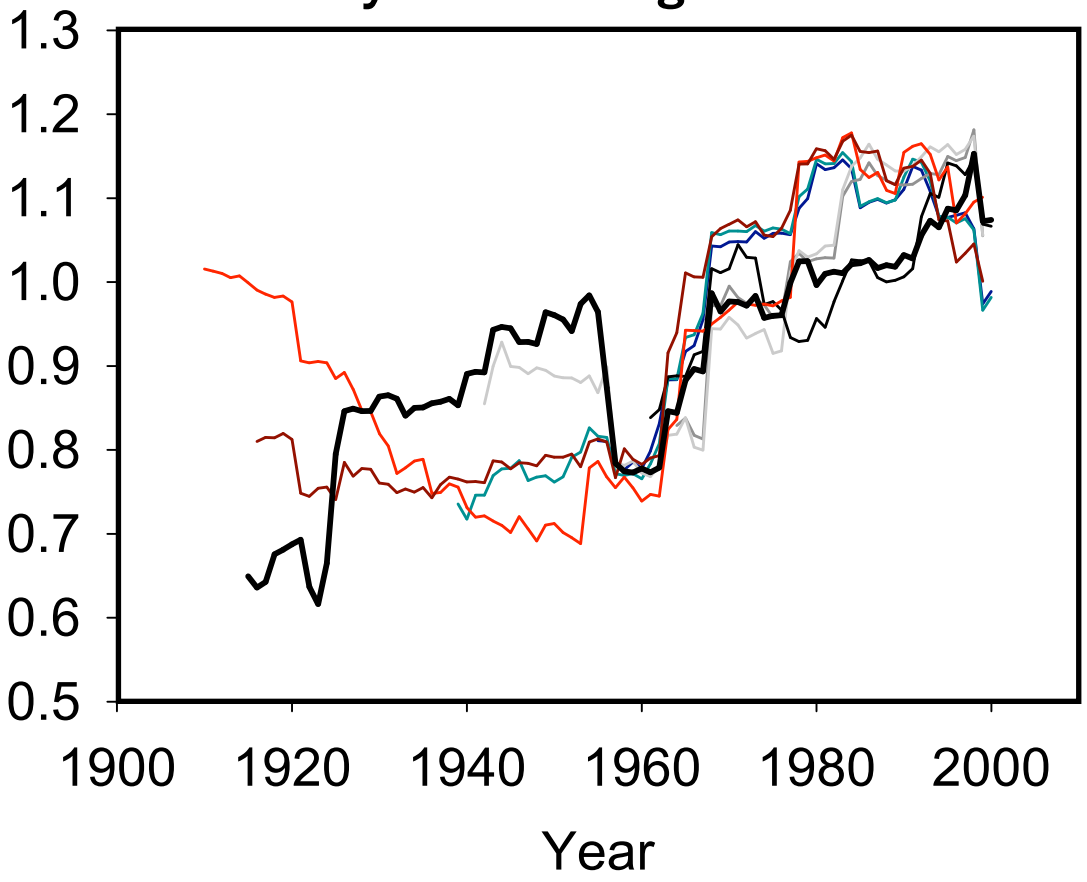
CORRELATIONS

Black et al., 2016

Pacific Decadal Variability Index vs. Ecosystem Drivers



20-year Running Variance



PDV Index

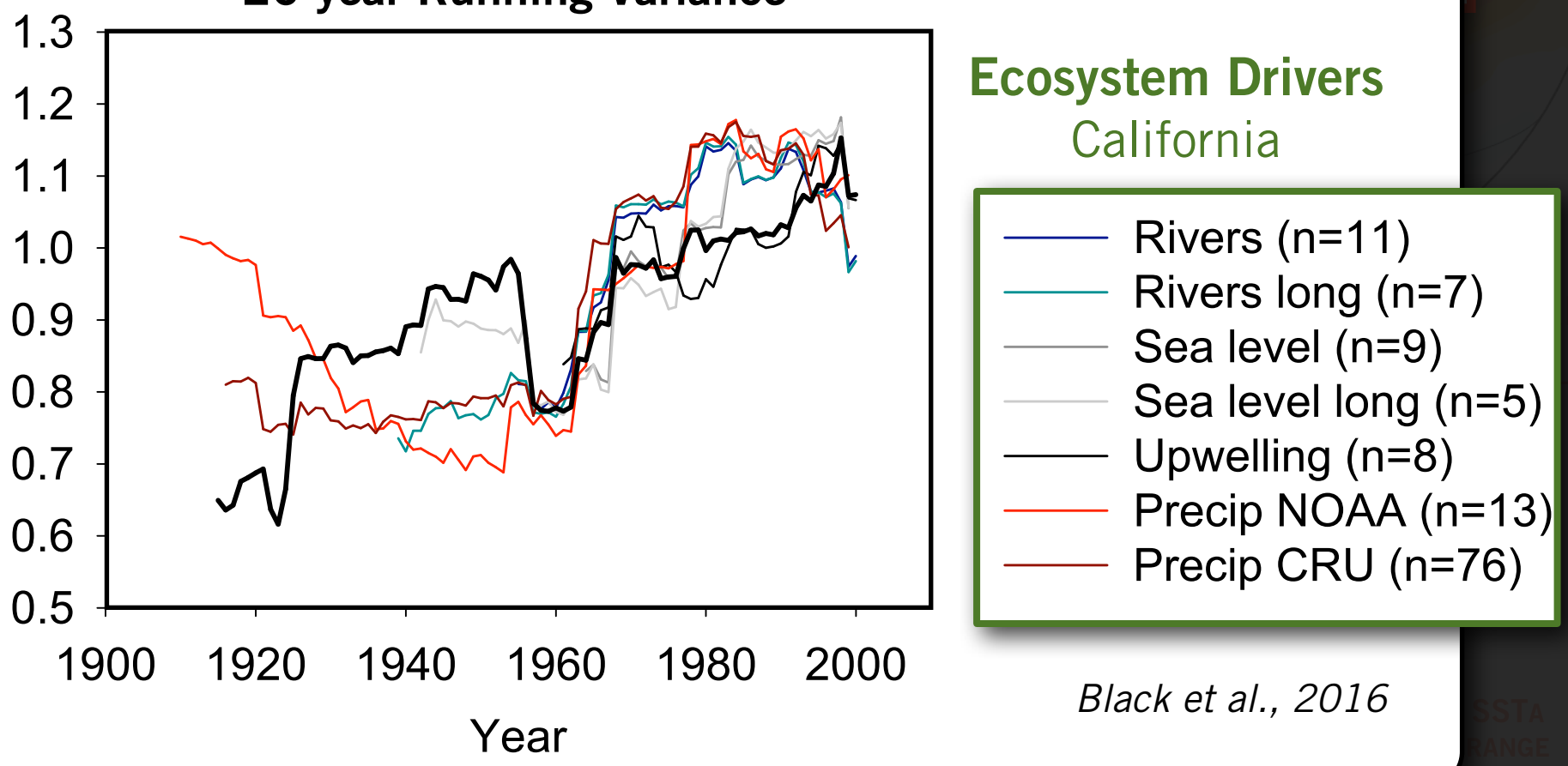
Ecosystem Drivers

California

- Rivers (n=11)
- Rivers long (n=7)
- Sea level (n=9)
- Sea level long (n=5)
- Upwelling (n=8)
- Precip NOAA (n=13)
- Precip CRU (n=76)

Significant **INCREASE IN THE PDV VARIANCE**

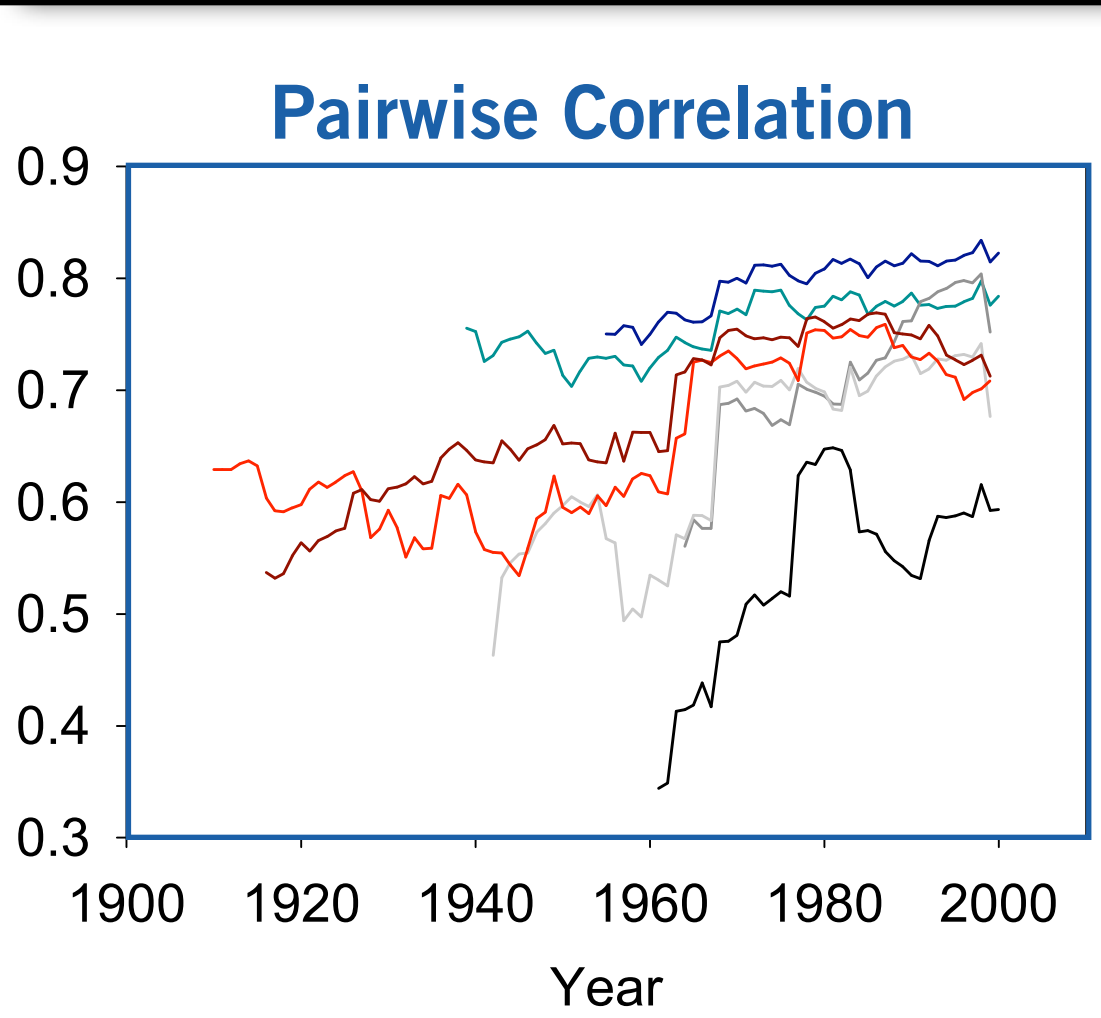
INCREASE IN THE VARIANCE OF ECOSYSTEM DRIVERS



Black et al., 2016

Significant **Increase in the PDV Variance**

Increase in the Variance of Ecosystem Drivers



PDV Index

Ecosystem Drivers
California

- Rivers (n=11)
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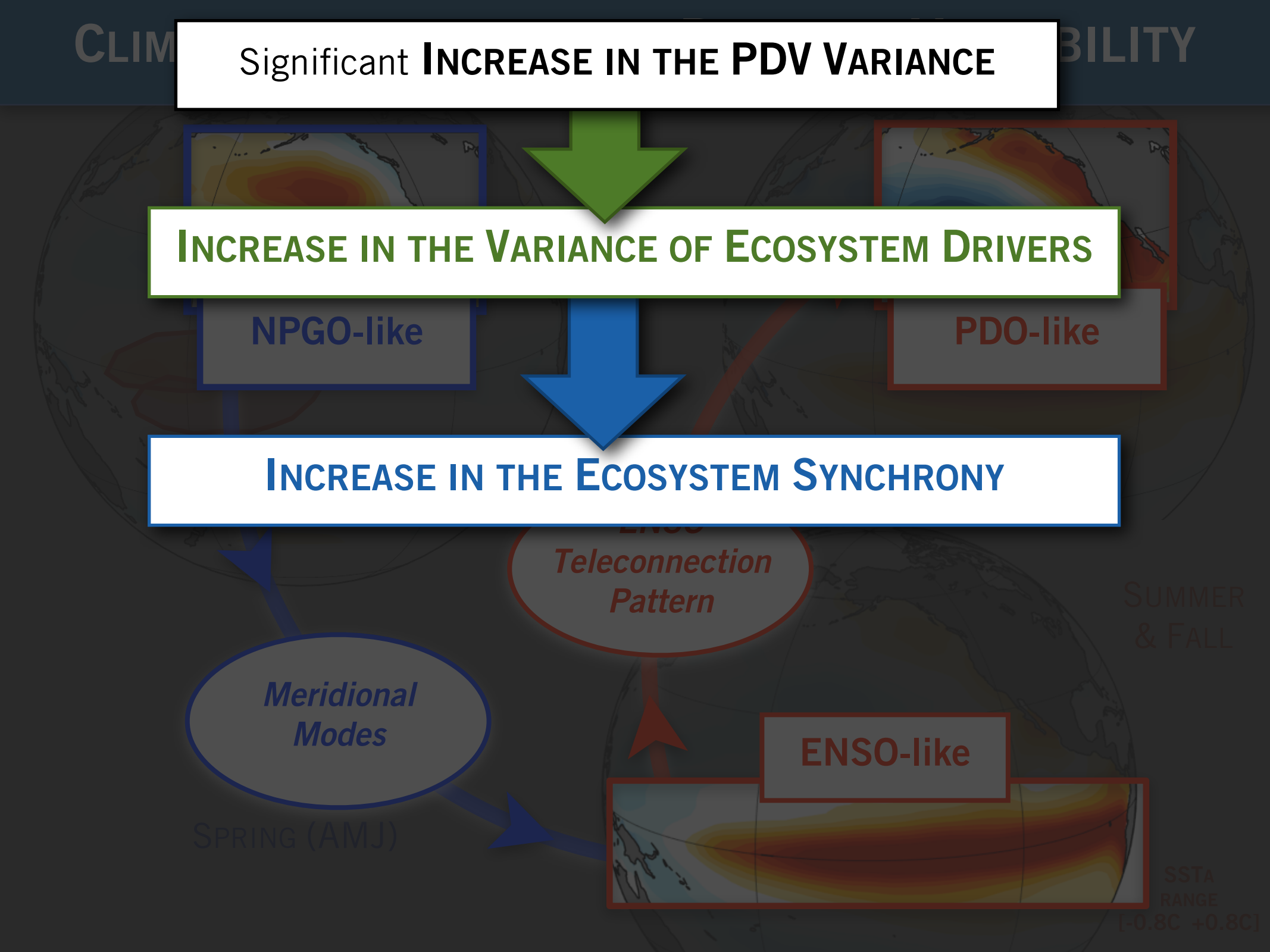
Black et al., 2016

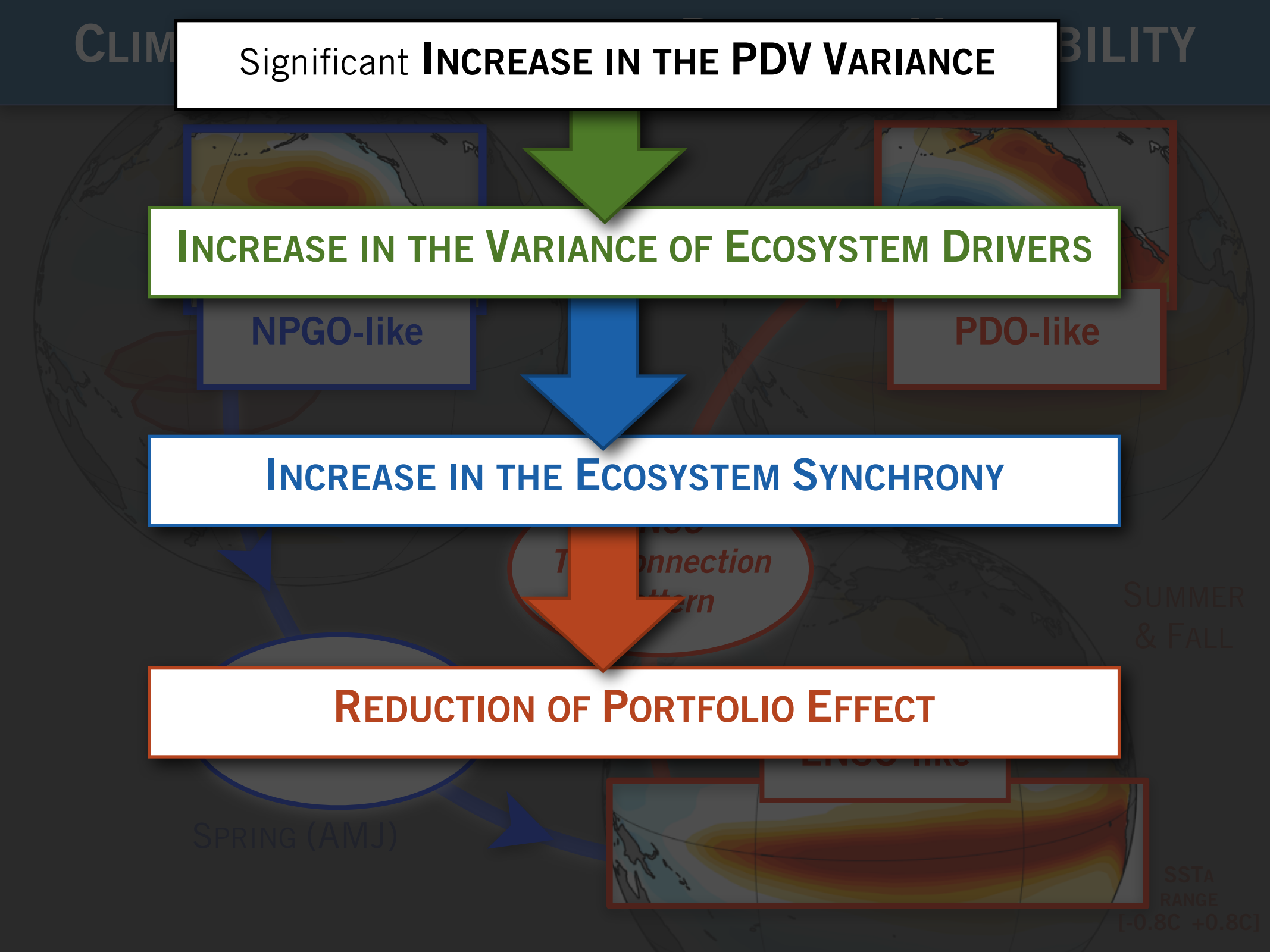

Significant INCREASE IN THE PDV VARIANCE
INCREASE IN THE VARIANCE OF ECOSYSTEM DRIVERS
NPGO-like
PDO-like
INCREASE IN THE ECOSYSTEM SYNCHRONY
Teleconnection Pattern
Meridional Modes
ENSO-like
SPRING (AMJ)
SUMMER & FALL
SSTA RANGE

Significant **INCREASE IN THE PDV VARIANCE**

INCREASE IN THE VARIANCE OF ECOSYSTEM DRIVERS

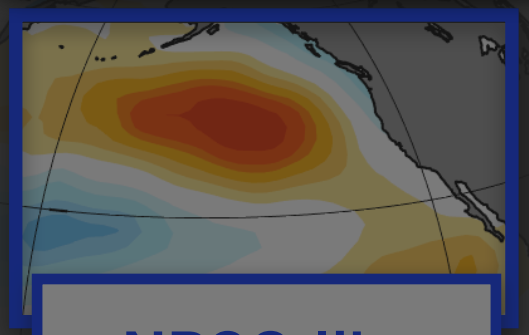
INCREASE IN THE ECOSYSTEM SYNCHRONY

REDUCTION OF PORTFOLIO EFFECT

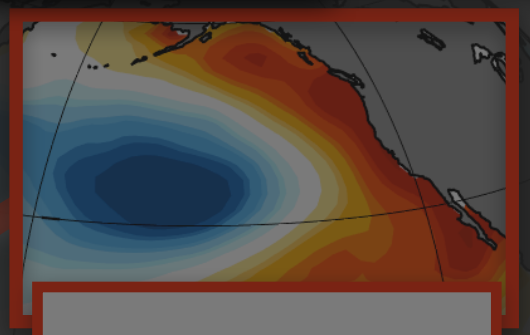


CLIM BILITY

Significant INCREASE IN THE PDV VARIANCE



NPGO-like



PDO-like

QUESTIONS

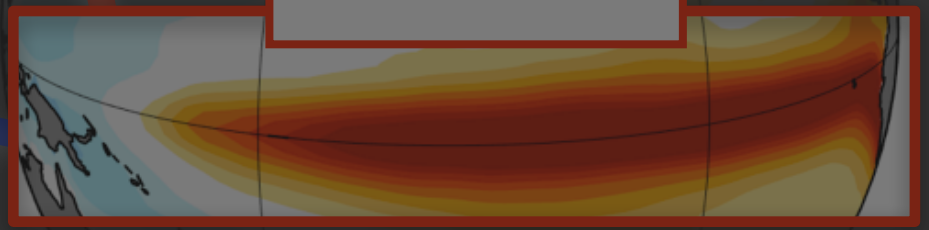
Why is Pacific Decadal Variance increasing?

Is this related to greenhouse forcing?

SUMMER & FALL

Meridional Modes

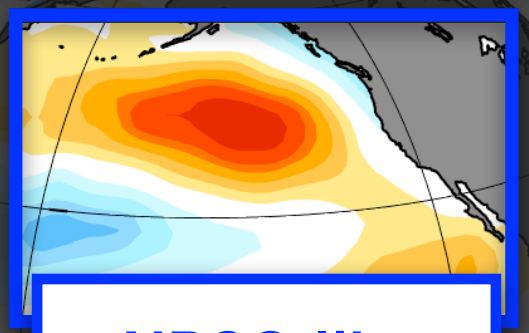
SPRING (AMJ)



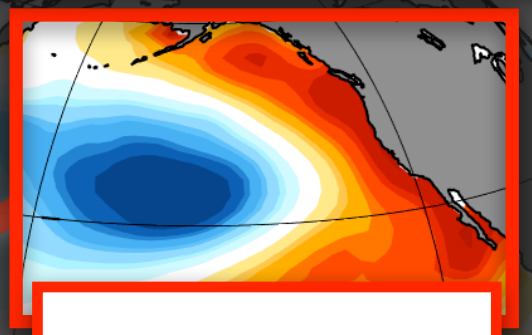
ENSO-like

SSTA RANGE [-0.8C +0.8C]

Climate Hypothesis for the Decadal Variability



NPGO-like



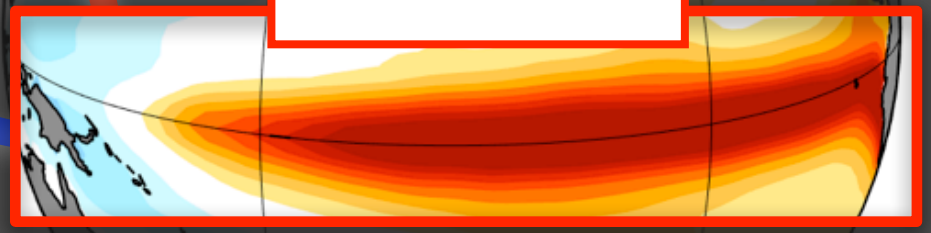
PDO-like

ENSO Teleconnection Pattern

Meridional Modes

Spring (AMJ)

Summer & Fall



ENSO-like

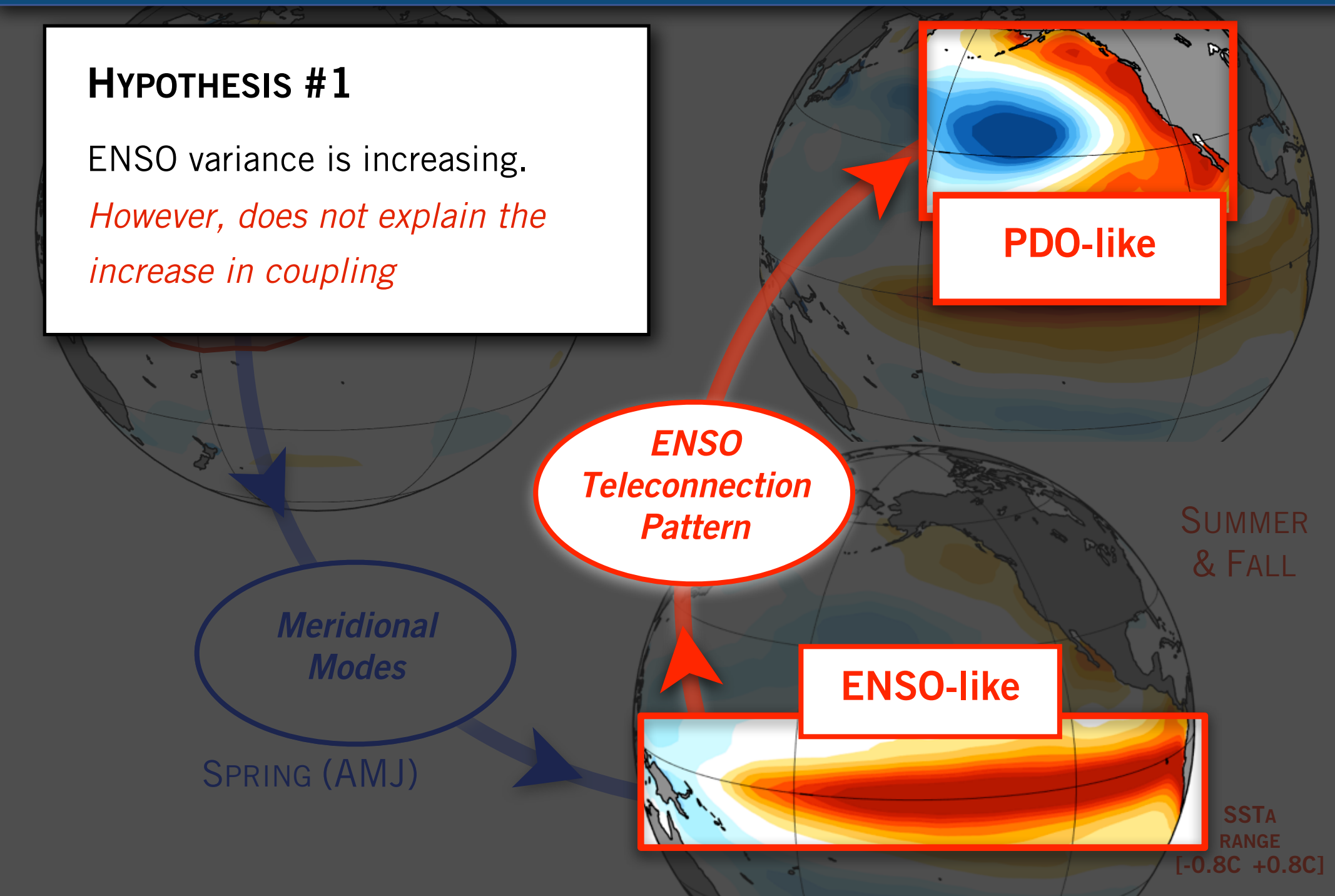
SSTA RANGE [-0.8C +0.8C]

Climate Hypothesis for the Decadal Variability

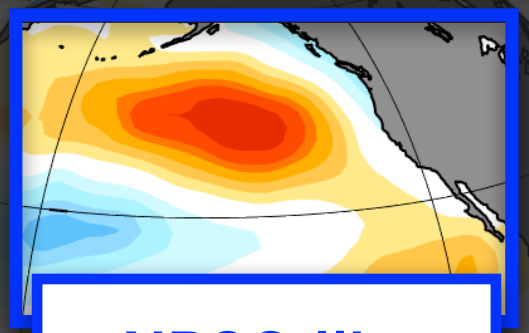
Hypothesis #1

ENSO variance is increasing.

However, does not explain the increase in coupling



CLIMATE HYPOTHESIS for the DECADAL VARIABILITY



NPGO-like

HYPOTHESIS #2

The Meridional Modes are getting stronger.

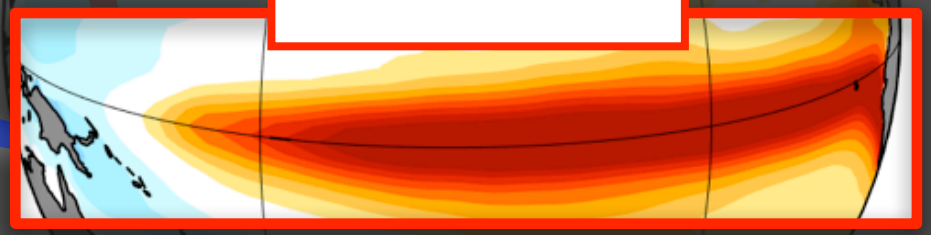
ENSO Teleconnection Pattern

SUMMER & FALL

Meridional Modes

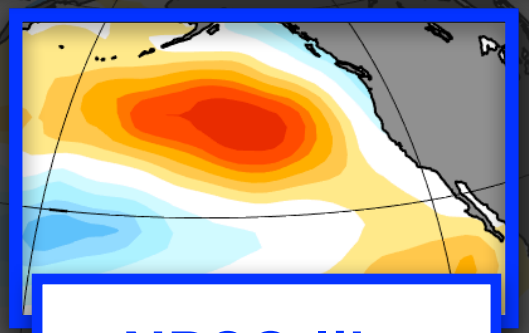
SPRING (AMJ)

ENSO-like



SSTA RANGE [-0.8C +0.8C]

CLIMATE HYPOTHESIS for the DECADAL VARIABILITY



NPGO-like

HYPOTHESIS #2

The Meridional Modes are getting stronger.

SSTa of Meridional Modes

Off-equatorial Trade Winds

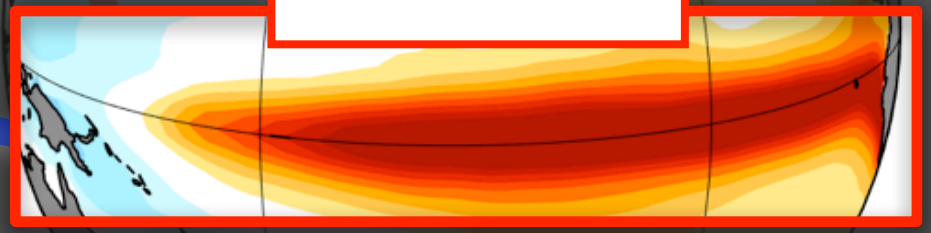
$$\frac{dSSTa(t)}{dt} = \alpha \cdot WINDS(t) - \gamma SSTa(t)$$

Sensitivity of SST to winds

Meridional Modes

SPRING (AMJ)

ENSO-like



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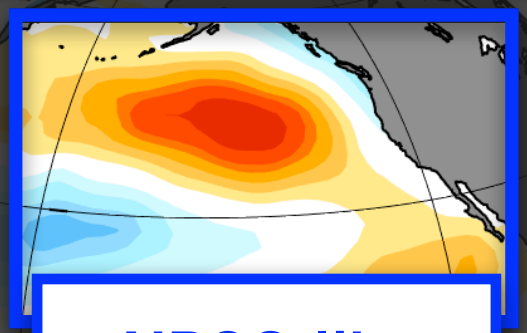
CLIMATE HYPOTHESIS for the DECADAL VARIABILITY



NPGO-like

HYPOTHESIS #2

The Meridional Modes are getting stronger.

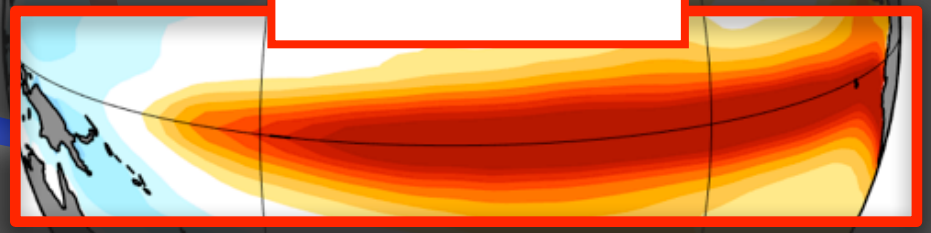
Variance SSTa of Meridional Modes

$$\mathrm{var}(SSTa) \approx \frac{\overbrace{\alpha^2}^{\text{Sensitivity of SST to WINDS}} \cdot \overbrace{\mathrm{var}(WINDS)}^{\text{Variance of WINDS}}}{1 - \underbrace{(1-\gamma)^2}_{\text{Ocean Memory}}}$$

Meridional Modes

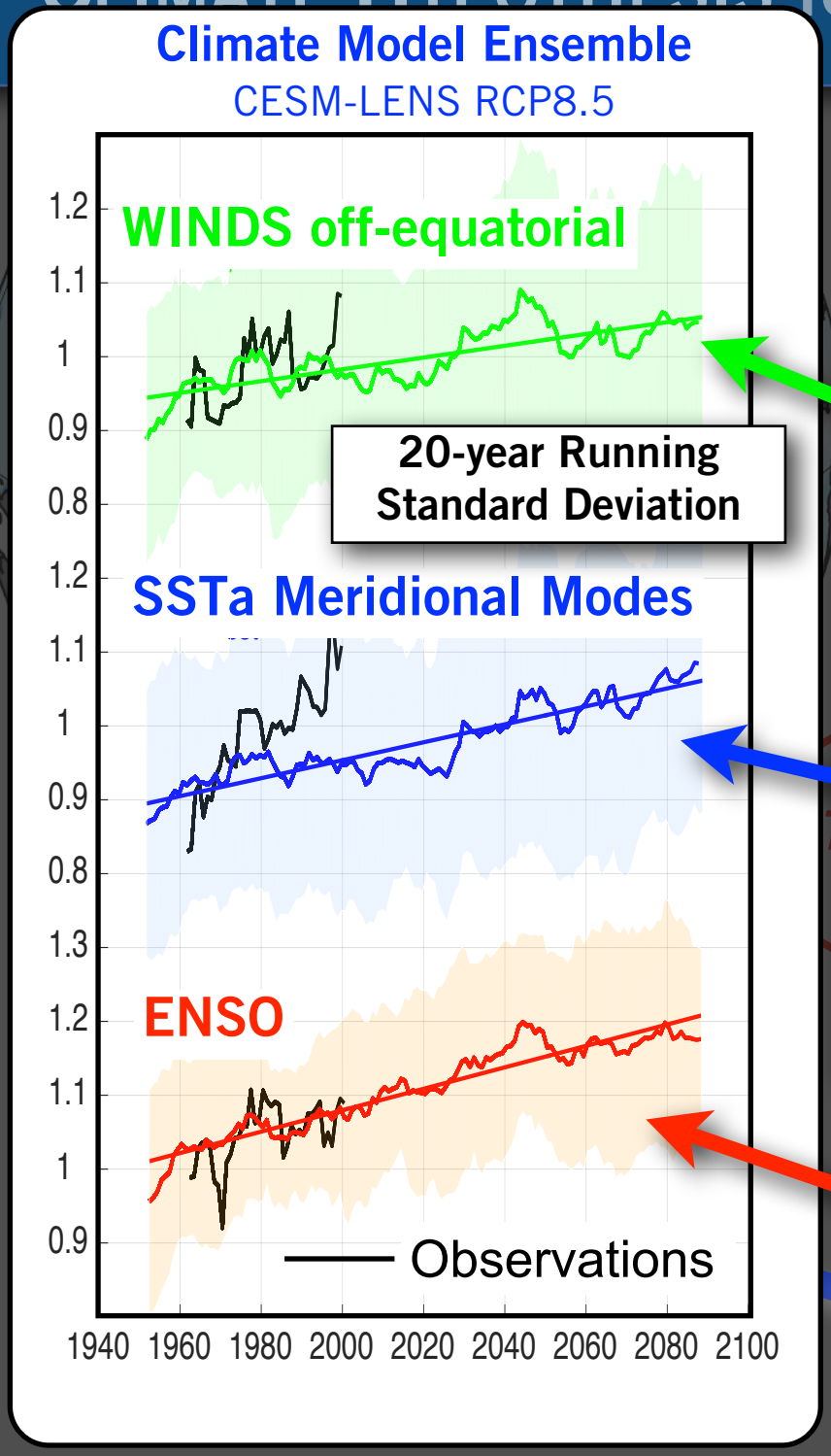
SPRING (AMJ)

ENSO-like



SSTA RANGE [-0.8C +0.8C]

Climate Hypothesis for the Decadal Variability



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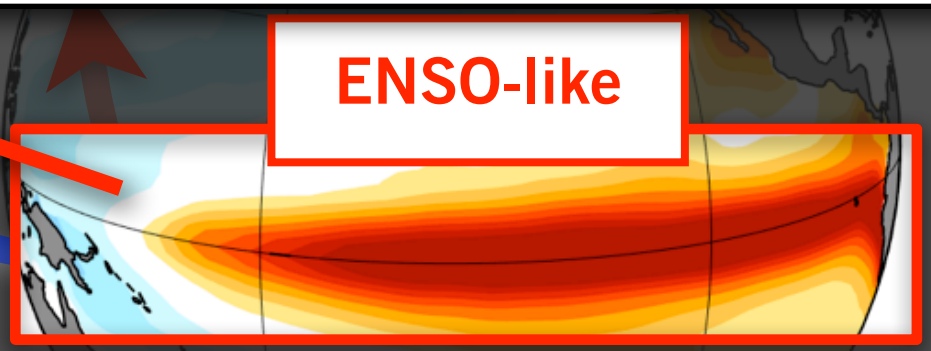
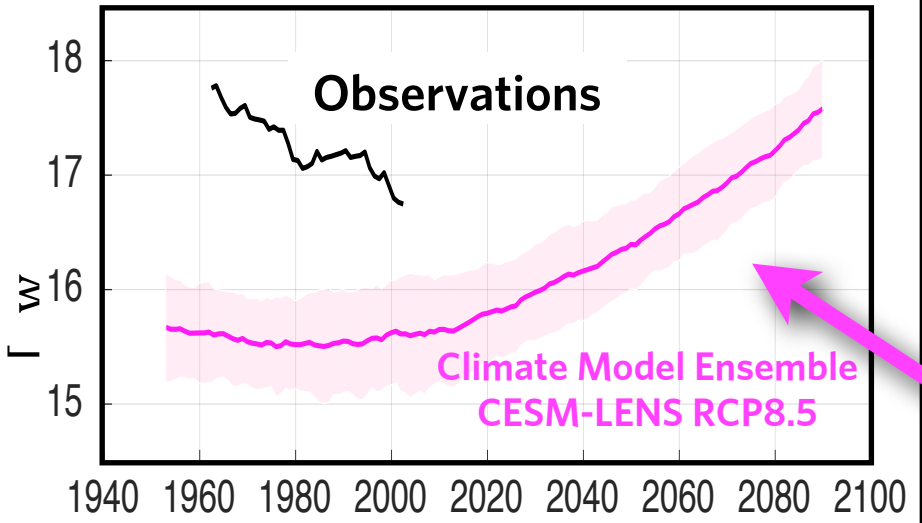


CLIMATE HYPOTHESIS for the DECADAL VARIABILITY

Sensitivity of SST to winds



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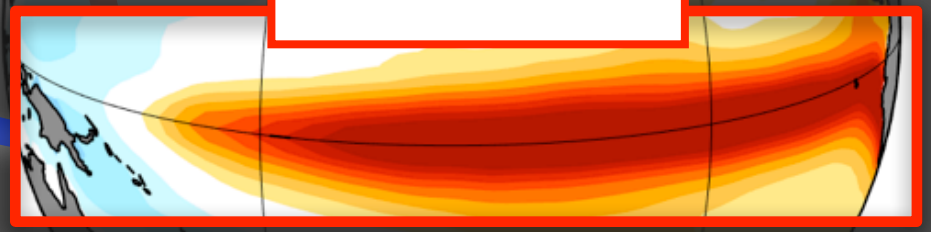
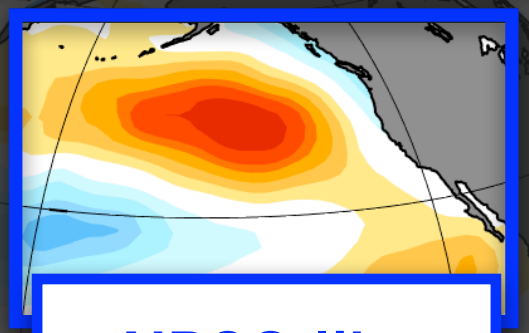
Meridional Modes

SPRING (AMJ)

ENSO-like



CLIMATE HYPOTHESIS for the DECADAL VARIABILITY



NPGO-like

HYPOTHESIS #2

The Meridional Modes are getting stronger.

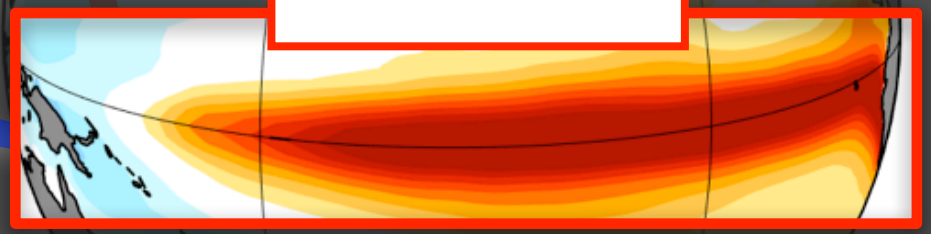
ENSO Teleconnection Pattern

SUMMER & FALL

Meridional Modes

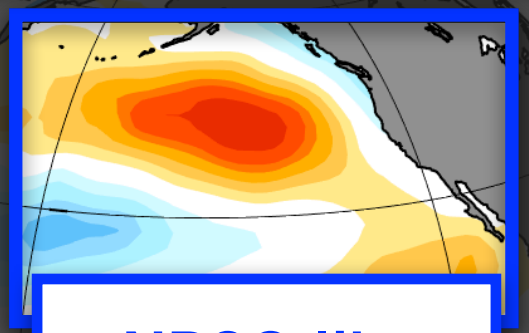
SPRING (AMJ)

ENSO-like

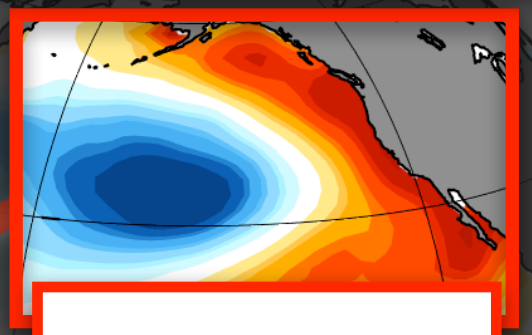


SSTA RANGE [-0.8C +0.8C]

Climate Hypothesis for the Decadal Variability



NPGO-like



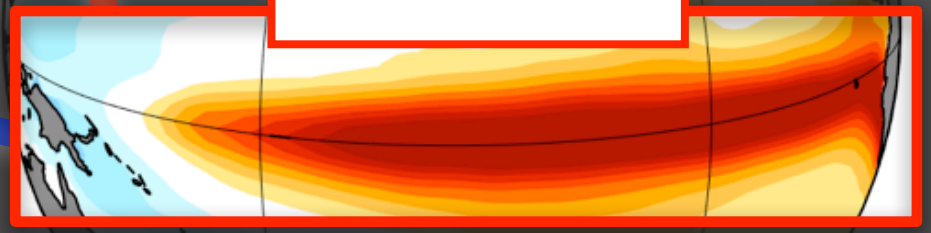
PDO-like

ENSO Teleconnection Pattern

Meridional Modes

Spring (AMJ)

Summer & Fall



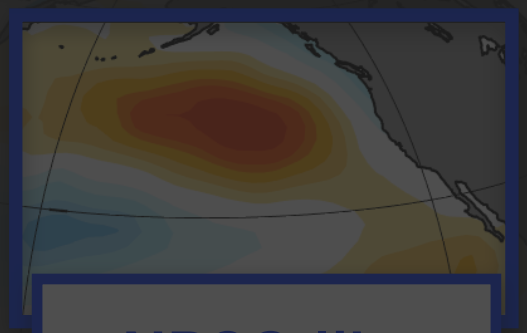
ENSO-like

SSTA RANGE [-0.8C +0.8C]

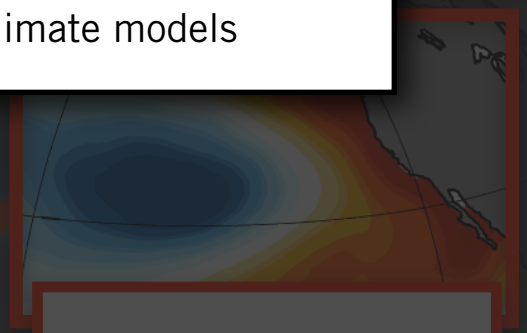
Climate Hypothesis for the Decadal Variability

Significant **Increase in the PDV Variance**

both observations and climate models



NPGO-like



PDO-like

ENSO Teleconnection Pattern

Meridional Modes

Spring (AMJ)

Summer & Fall

ENSO-like

SSTA RANGE
[-0.8C +0.8C]

Climate Hypothesis for the Decadal Variability

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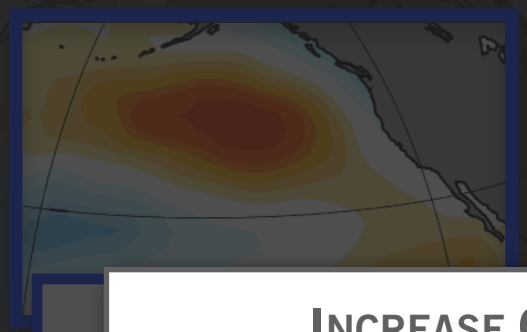


Increase Coupling between PDO/NPGO

both observations and climate models

Increase Variance in Ecosystem Drivers

long-term in situ observations

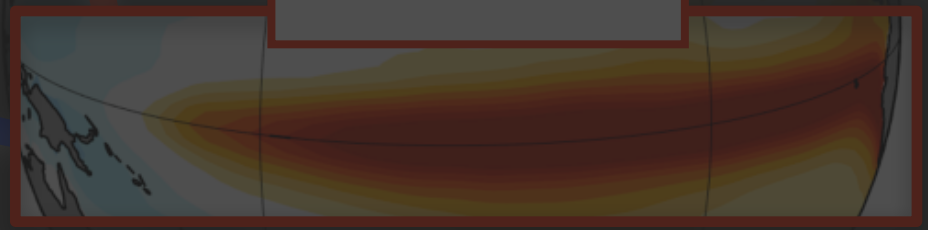
ENSO Teleconnection Pattern

Meridional Modes

Spring (AMJ)

Summer & Fall

ENSO-like



SSTA RANGE
[-0.8C +0.8C]

Climate Hypothesis for the Decadal Variability

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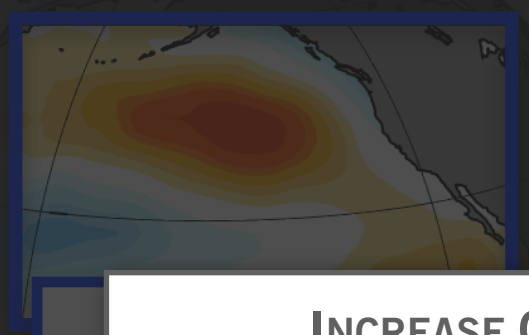

Increase Coupling between PDO/NPGO

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Increase Variance in Ecosystem Drivers

long-term in situ observations

Increase in the Ecosystem Synchrony

long-term in situ observations

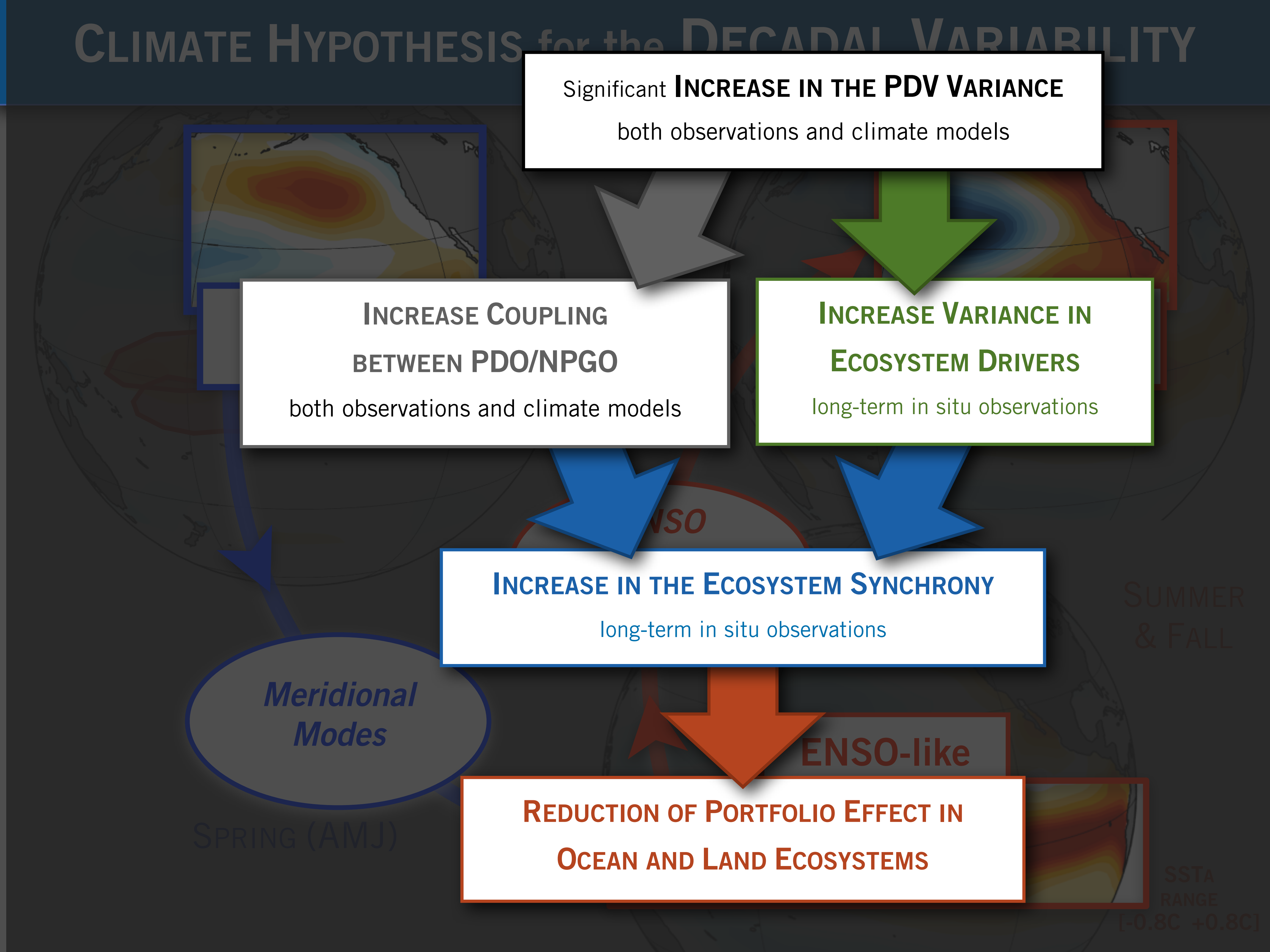
Meridional Modes

Spring (AMJ)

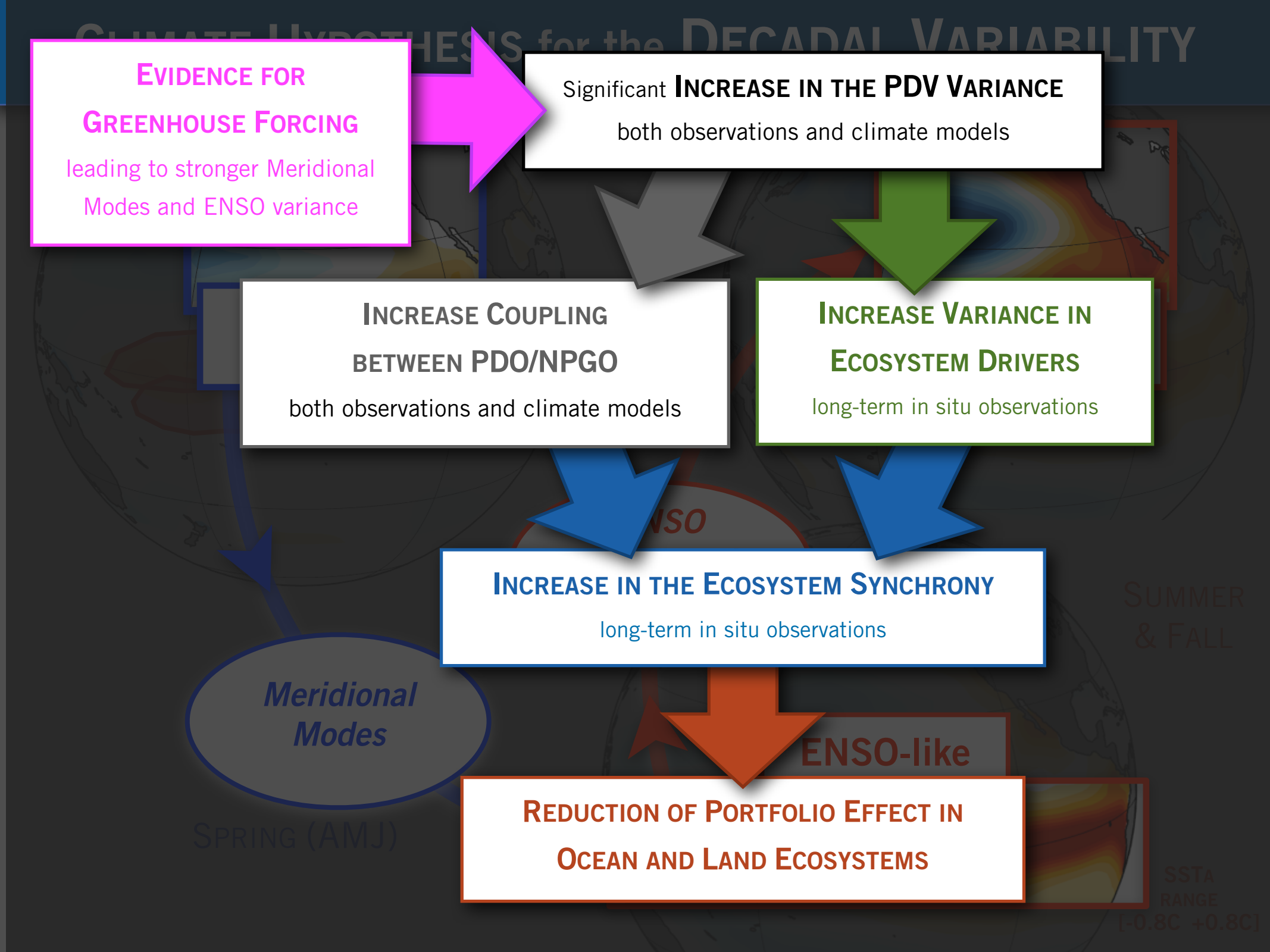
ENSO-like

Summer & Fall

SSTA range [-0.8C, +0.8C]



CLIMATE HYPOTHESIS for the DECADAL VARIABILITY
Significant INCREASE IN THE PDV VARIANCE
both observations and climate models
INCREASE COUPLING BETWEEN PDO/NPGO
both observations and climate models
INCREASE VARIANCE IN ECOSYSTEM DRIVERS
long-term in situ observations
INCREASE IN THE ECOSYSTEM SYNCHRONY
long-term in situ observations
REDUCTION OF PORTFOLIO EFFECT IN OCEAN AND LAND ECOSYSTEMS
Meridional Modes
ENSO-like
SPRING (AMJ)
SUMMER & FALL


Climate Hypothesis for the Decadal Variability
Evidence for Greenhouse Forcing
leading to stronger Meridional Modes and ENSO variance
Significant Increase in the PDV Variance
both observations and climate models
Increase Coupling between PDO/NPGO
both observations and climate models
Increase Variance in Ecosystem Drivers
long-term in situ observations
Increase in the Ecosystem Synchrony
long-term in situ observations
Reduction of Portfolio Effect in Ocean and Land Ecosystems
Meridional Modes
ENSO-like
Spring (AMJ)
Summer & Fall
SSTA RANGE
-0.8C +0.8C

Climate Hypothesis for the Decadal Variability

Evidence for Greenhouse Forcing

leading to stronger Meridional Modes and ENSO variance

Significant **Increase in the PDV Variance**

both observations and climate models

Increase Coupling between PDO/NPGO

both observations and climate models

Increase Variance in Ecosystem Drivers

long-term in situ observations

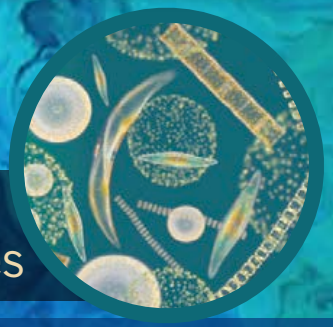
Increase in the Ecosystem Synchrony

long-term in situ observations

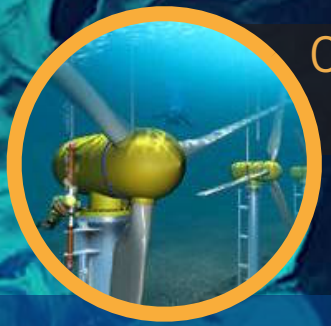
Reduction of Portfolio Effect in Ocean and Land Ecosystems

Thank you!

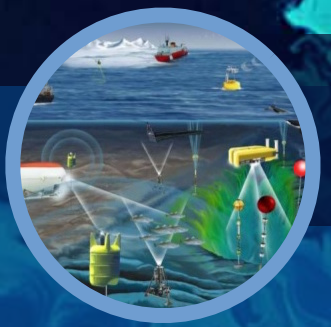
Georgia Tech Ocean Science & Engineering



Ocean Microbes

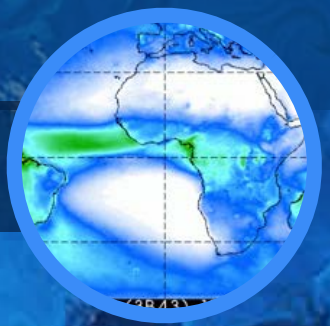


Ocean Energy & Resources



Observing Systems & Discovery

New Interdisciplinary Ph.D. Program



Ocean & Climate

Marine Ecology & Conservation

Coastal Hazards & Safety

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