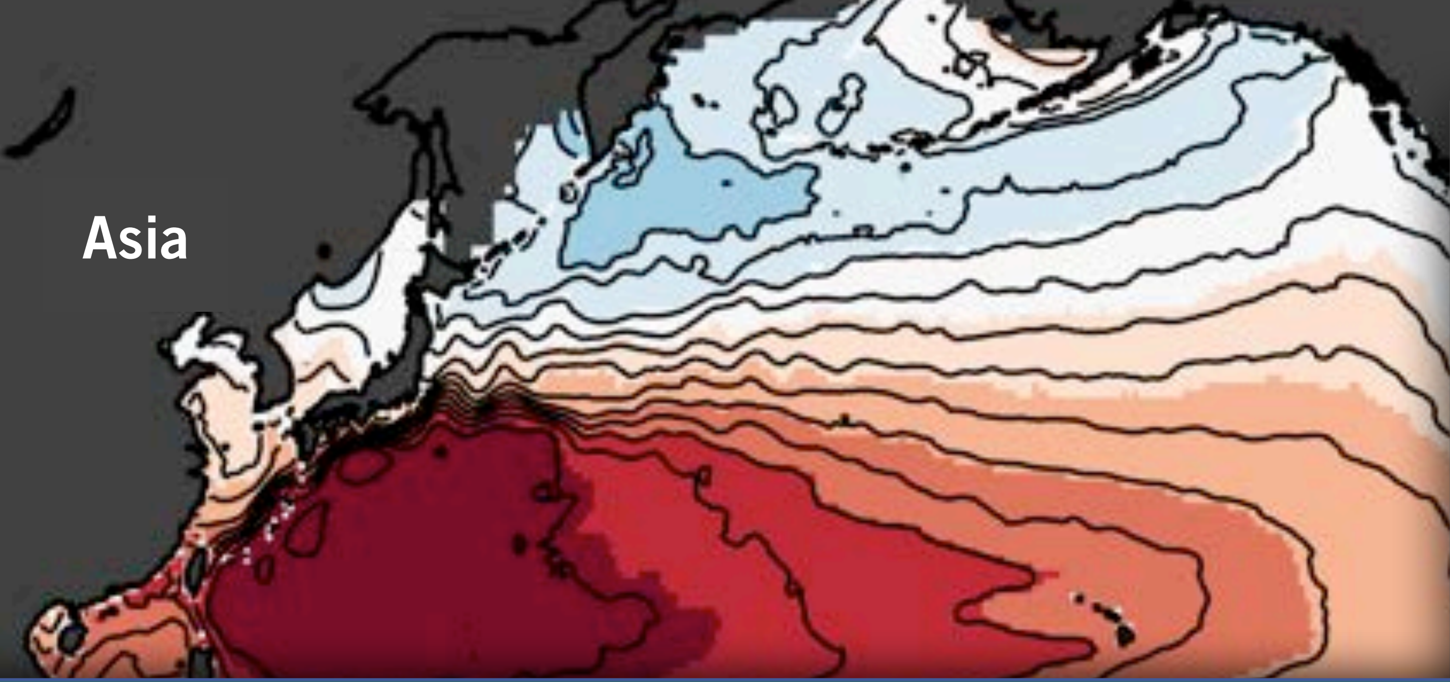
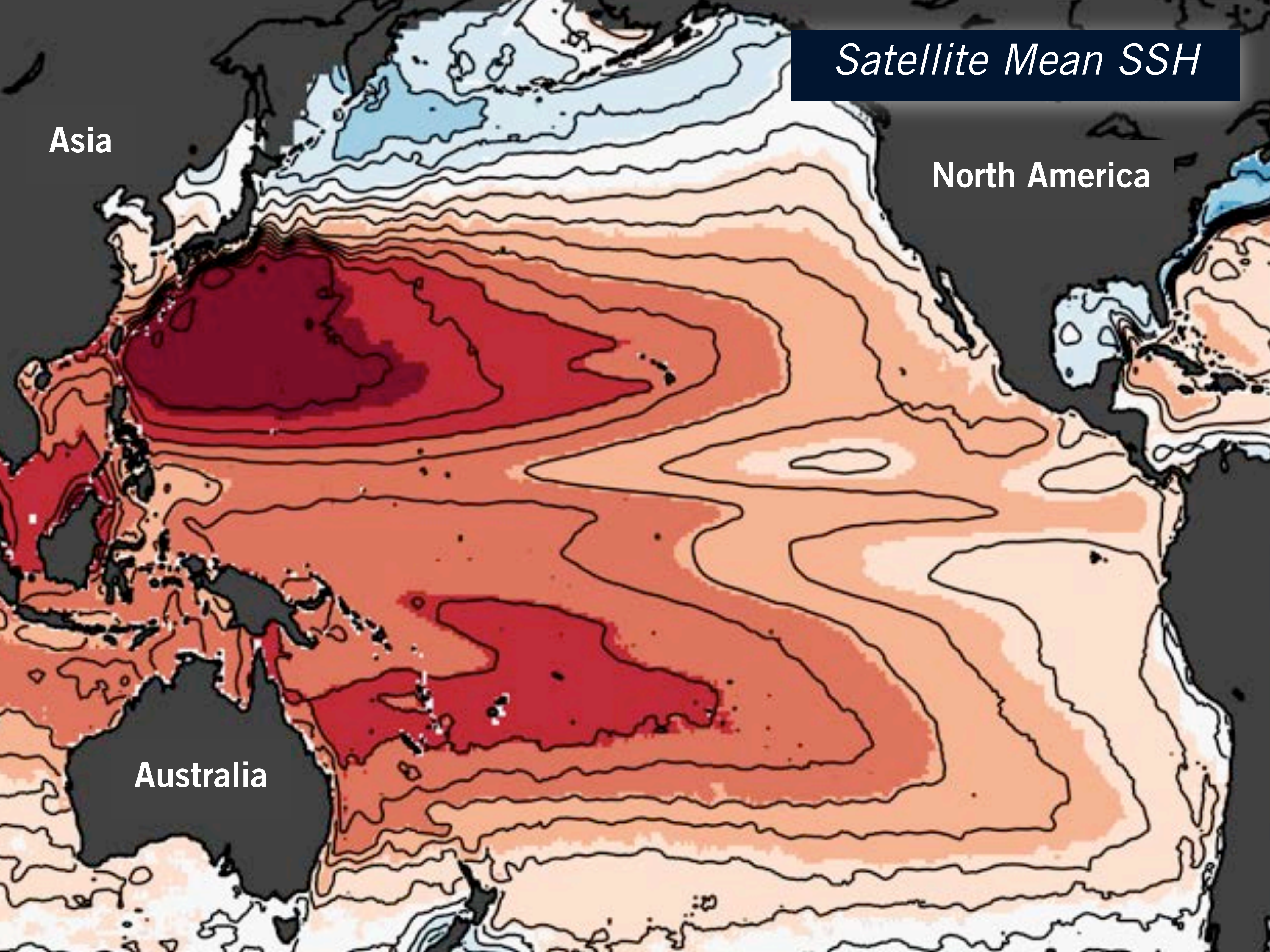


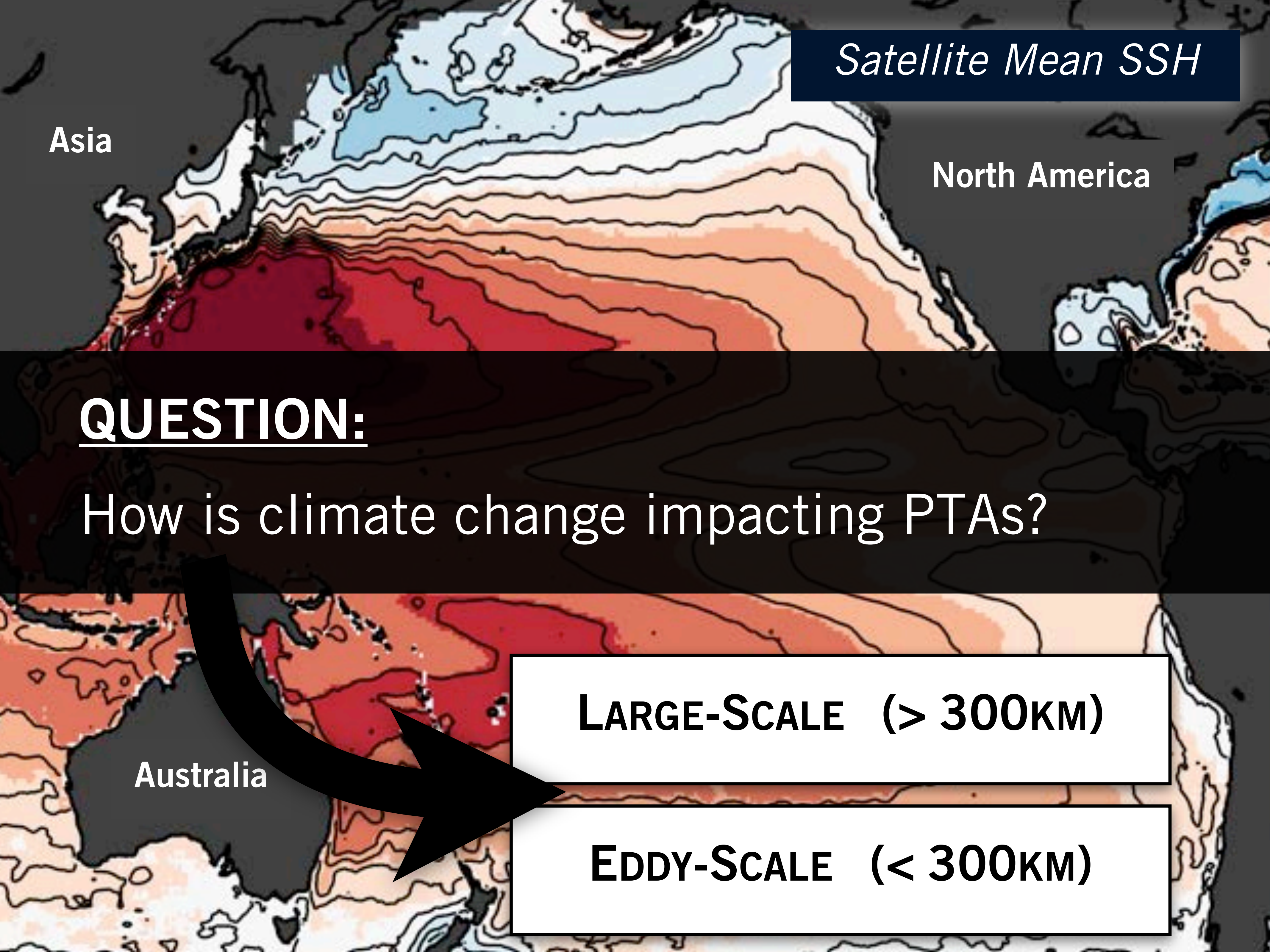
Multi-Scale Climate Impacts on Pacific Transition Areas

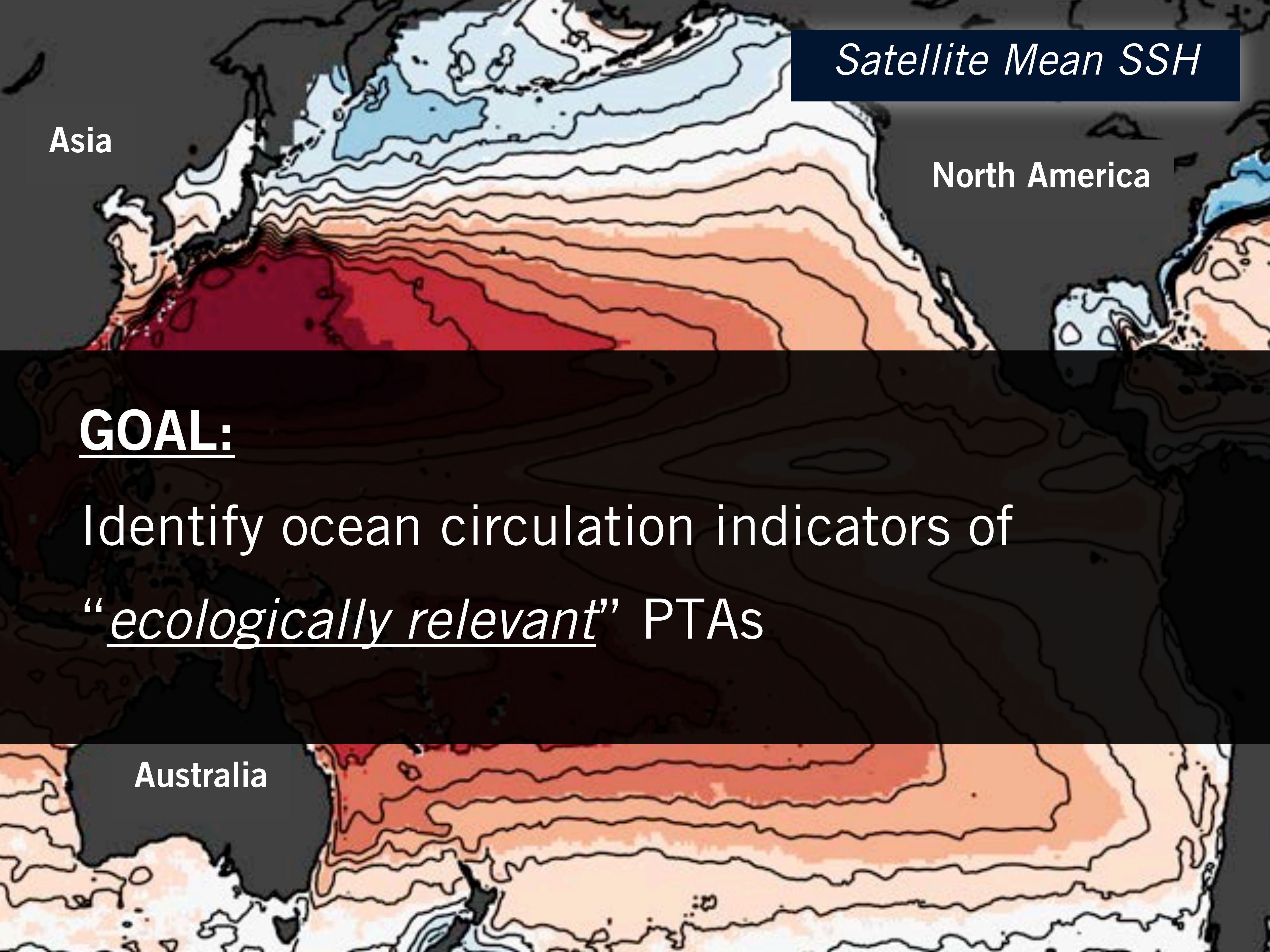
Georgia Tech | Ocean Science & Engineering

Emanuele Di Lorenzo

La Paz, April 26, 2018

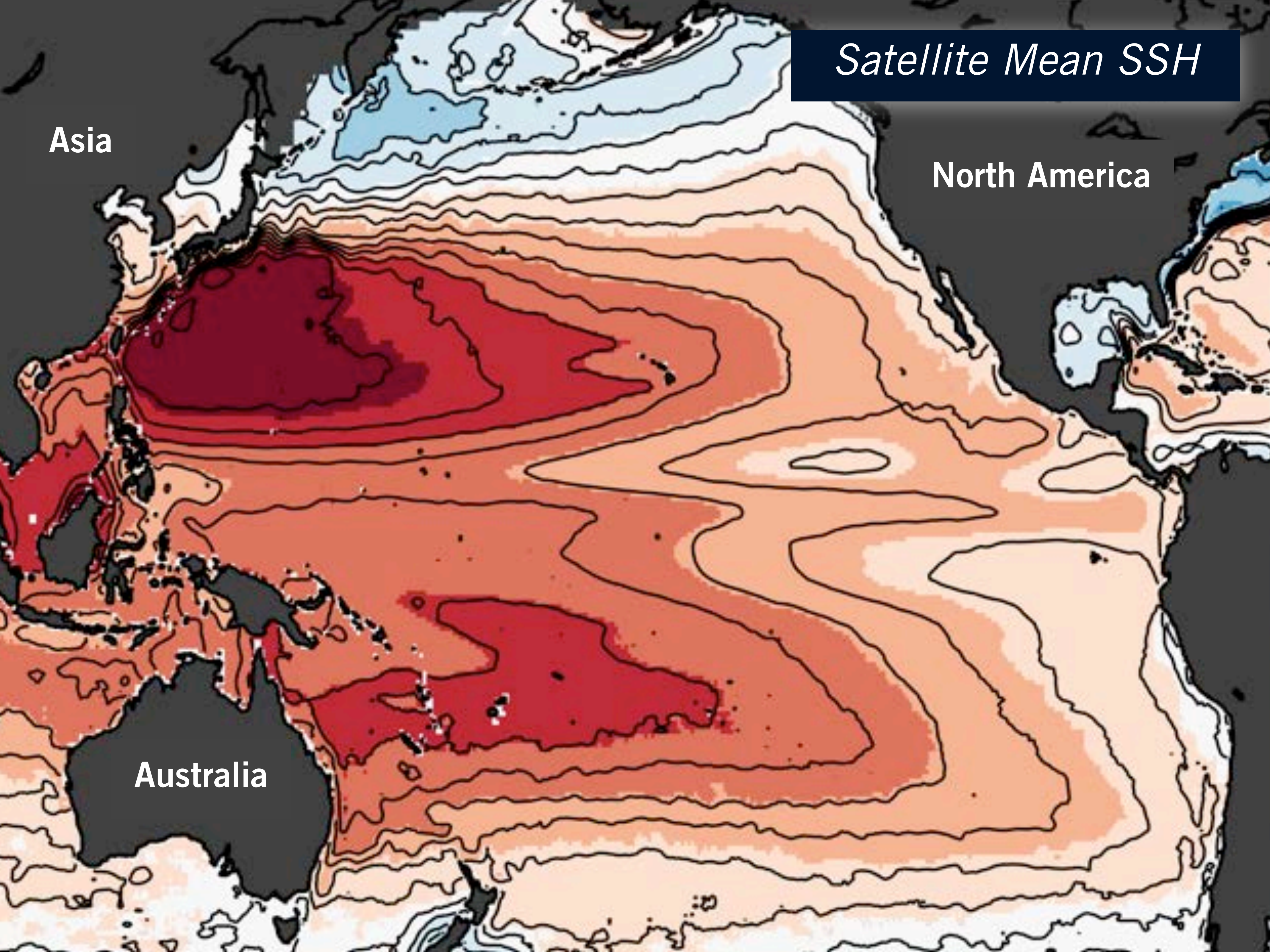

Satellite Mean SSH
Asia
North America
Australia

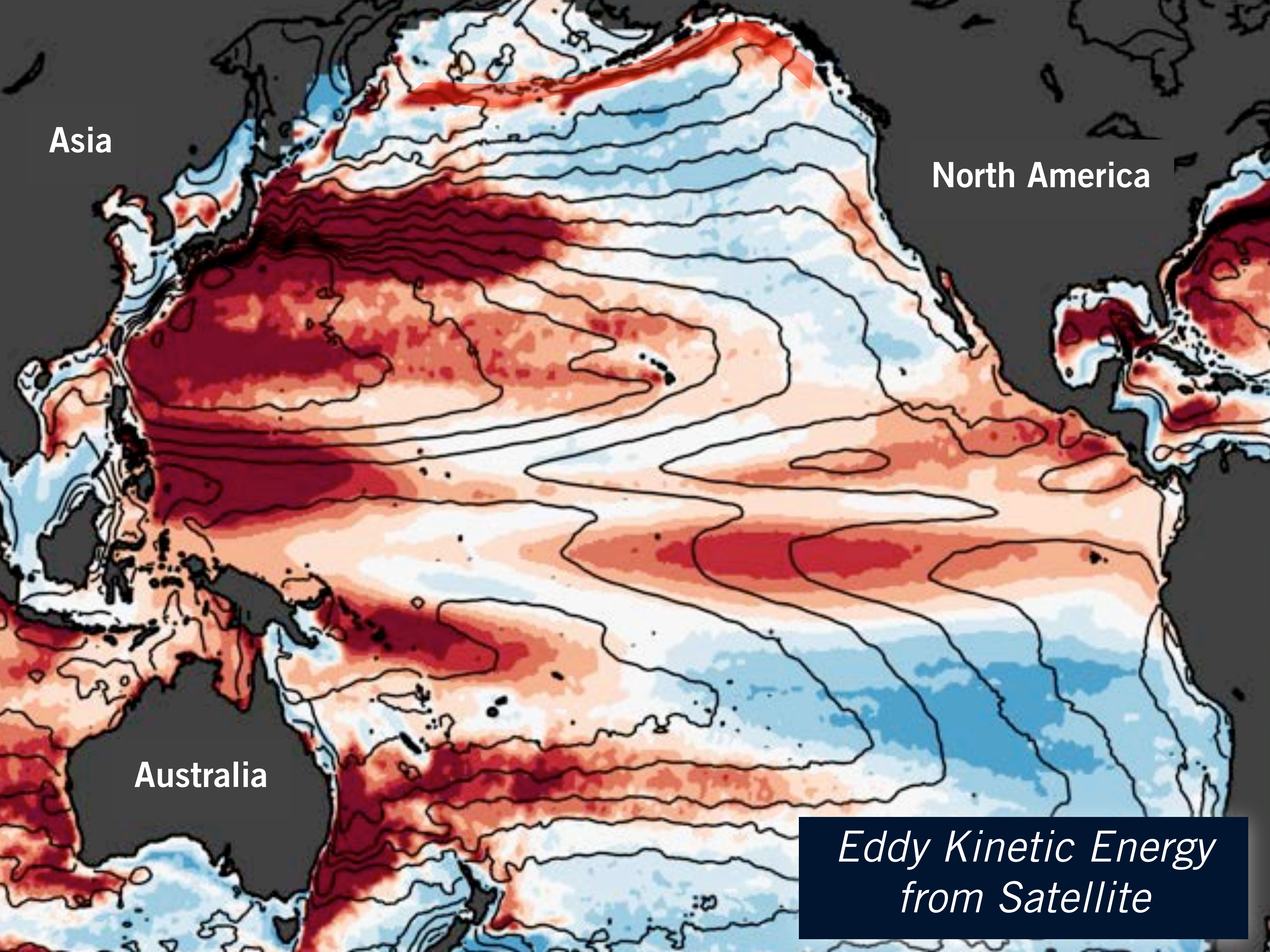

Satellite Mean SSH
Asia
North America
QUESTION:
How is climate change impacting PTAs?
Large-Scale (> 300km)
Eddy-Scale (< 300km)
Australia

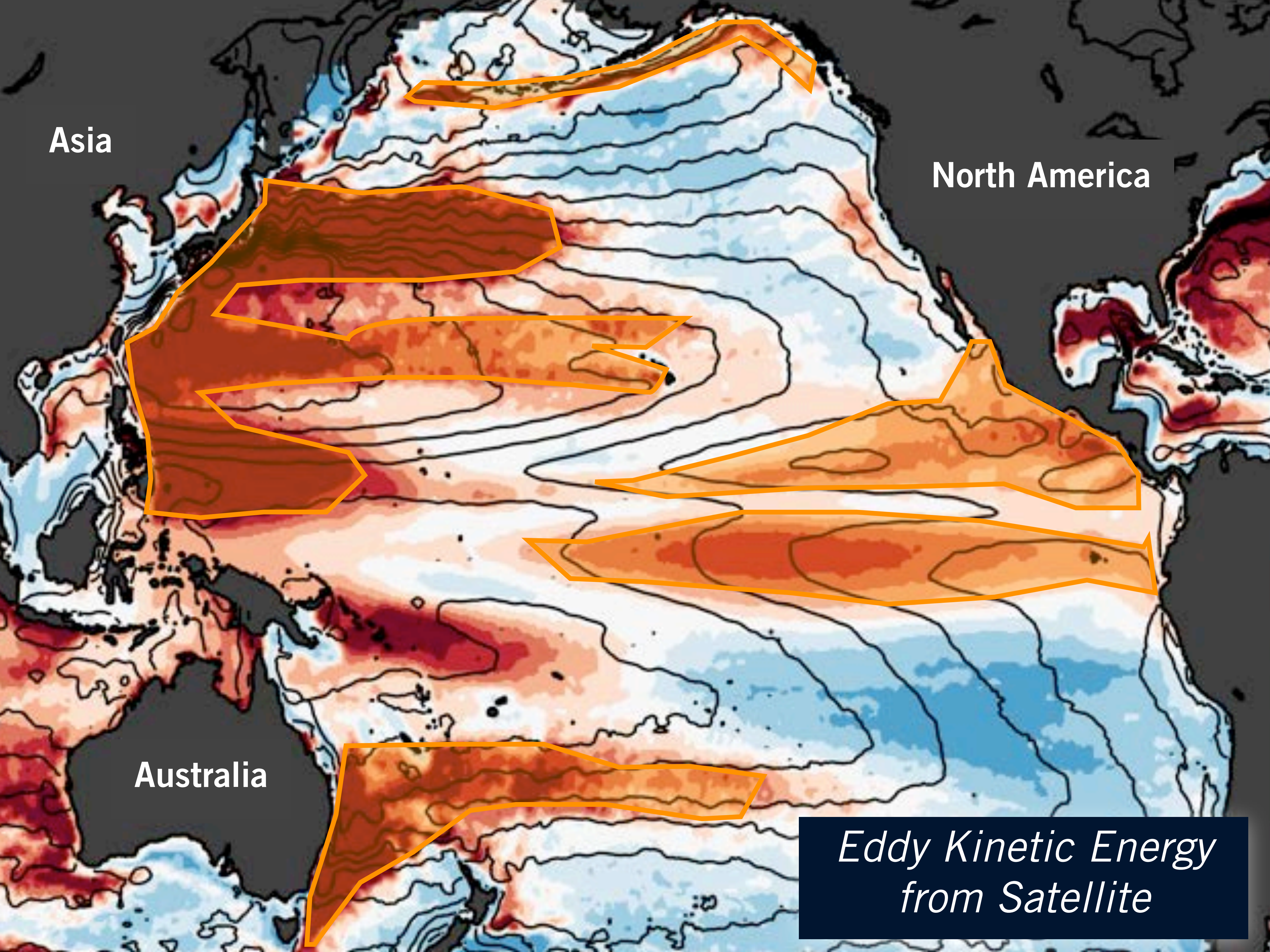


<u>GOAL:</u>

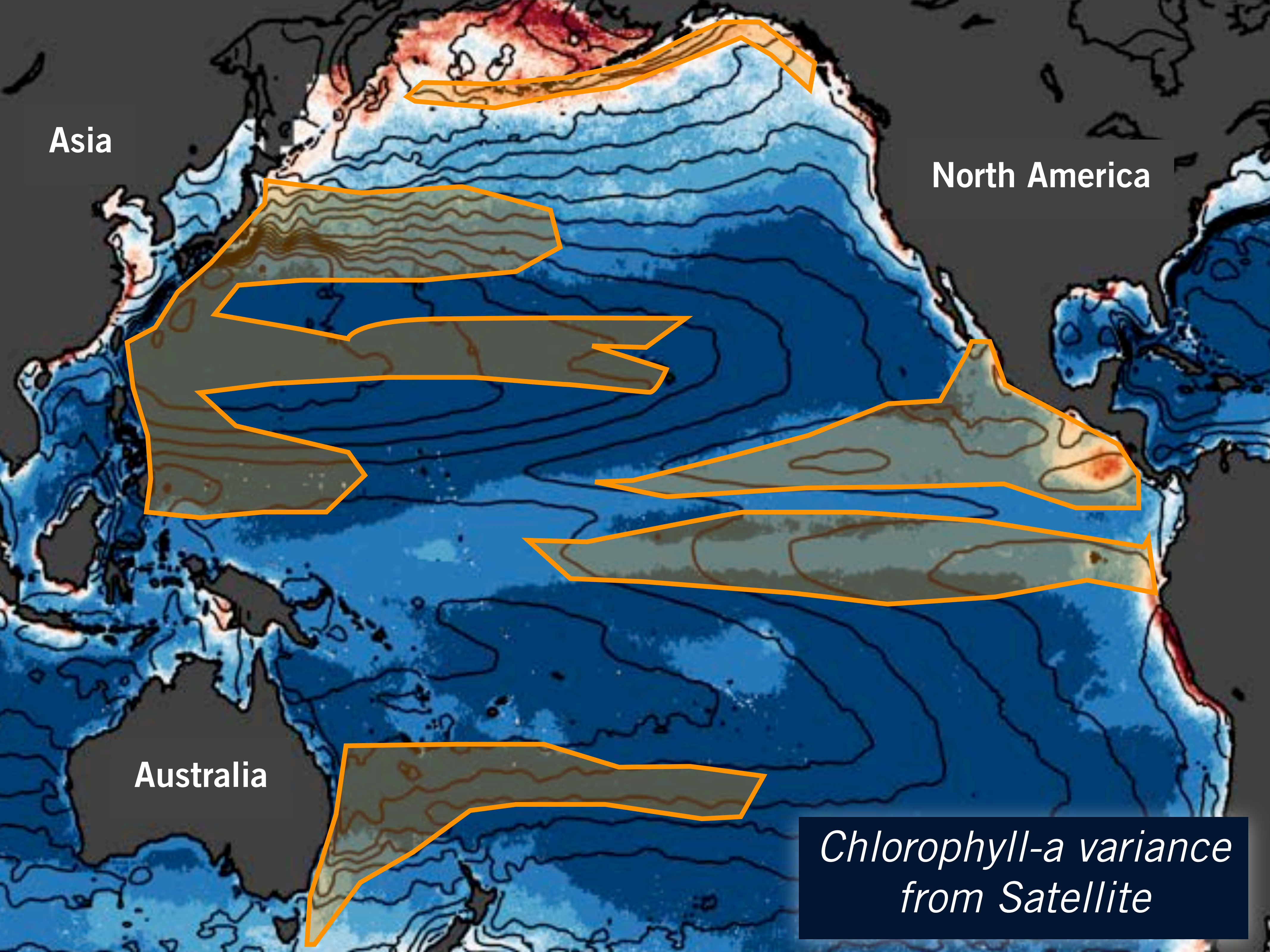
Identify ocean circulation indicators of "*<u>ecologically relevant</u>*" PTAs


Satellite Mean SSH
Asia
North America
Australia


Asia
North America
Australia
Eddy Kinetic Energy
from Satellite

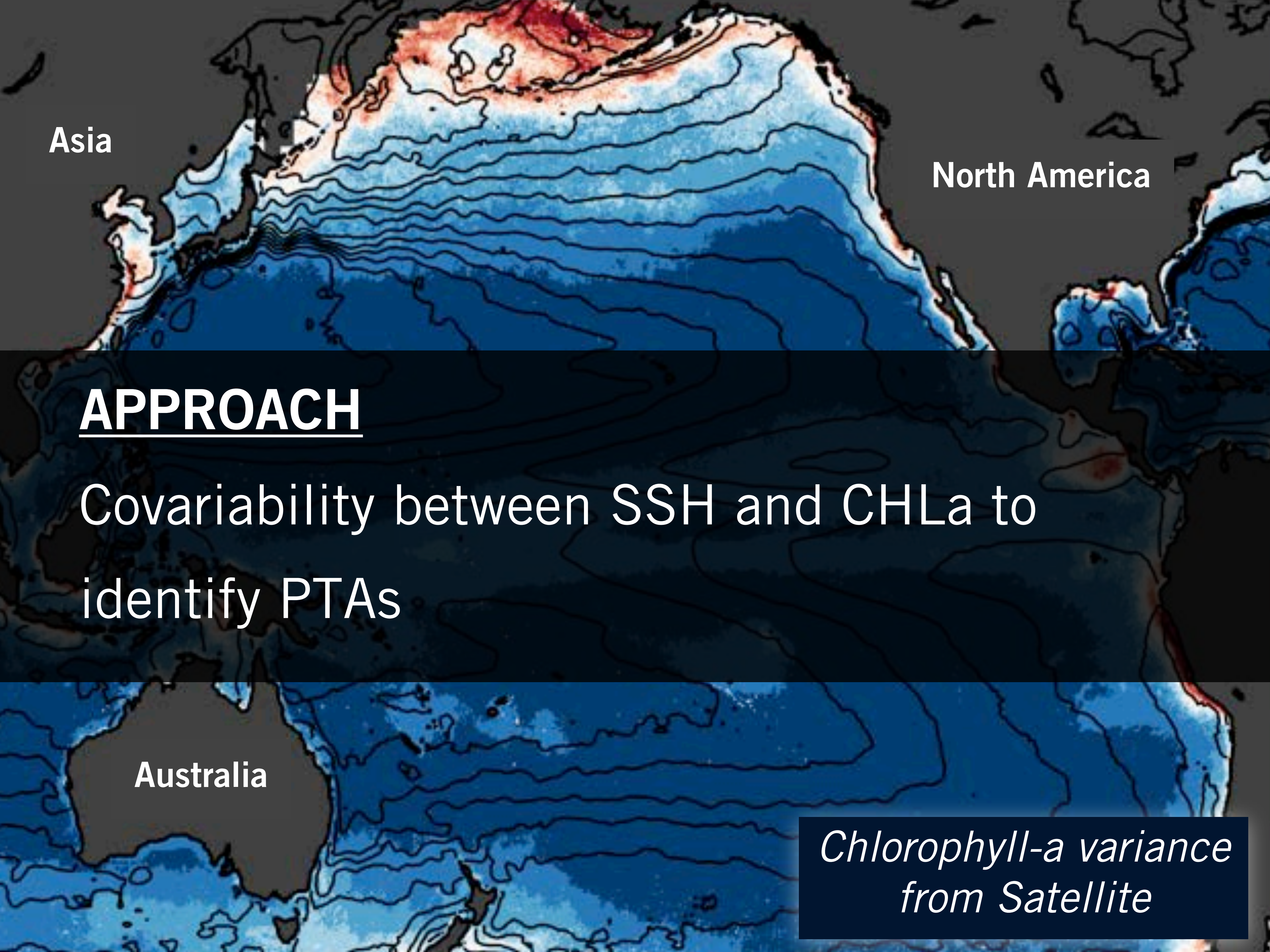


Asia
North America
Australia
Eddy Kinetic Energy from Satellite

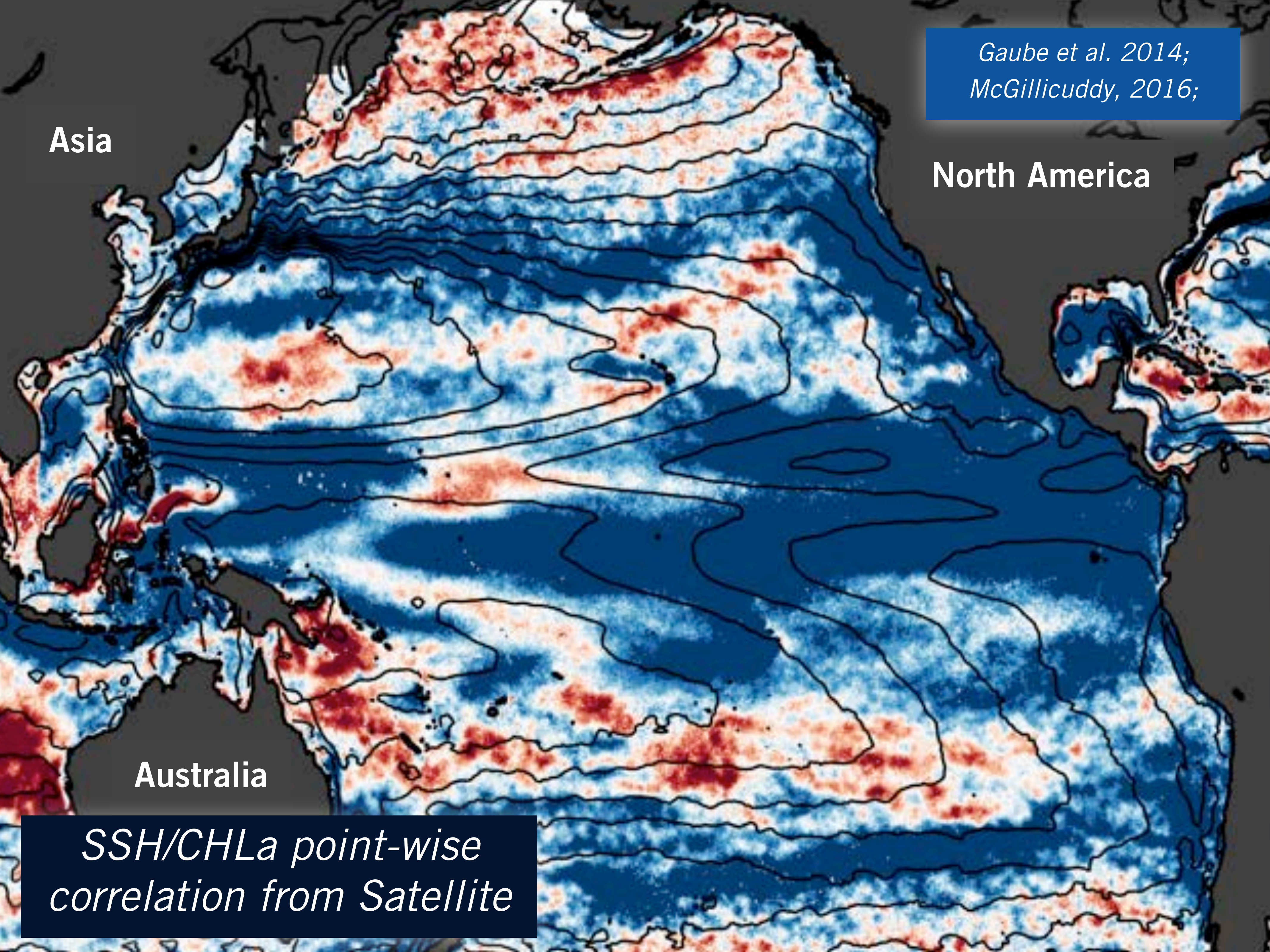

Asia
North America
Australia
Chlorophyll-a variance
from Satellite

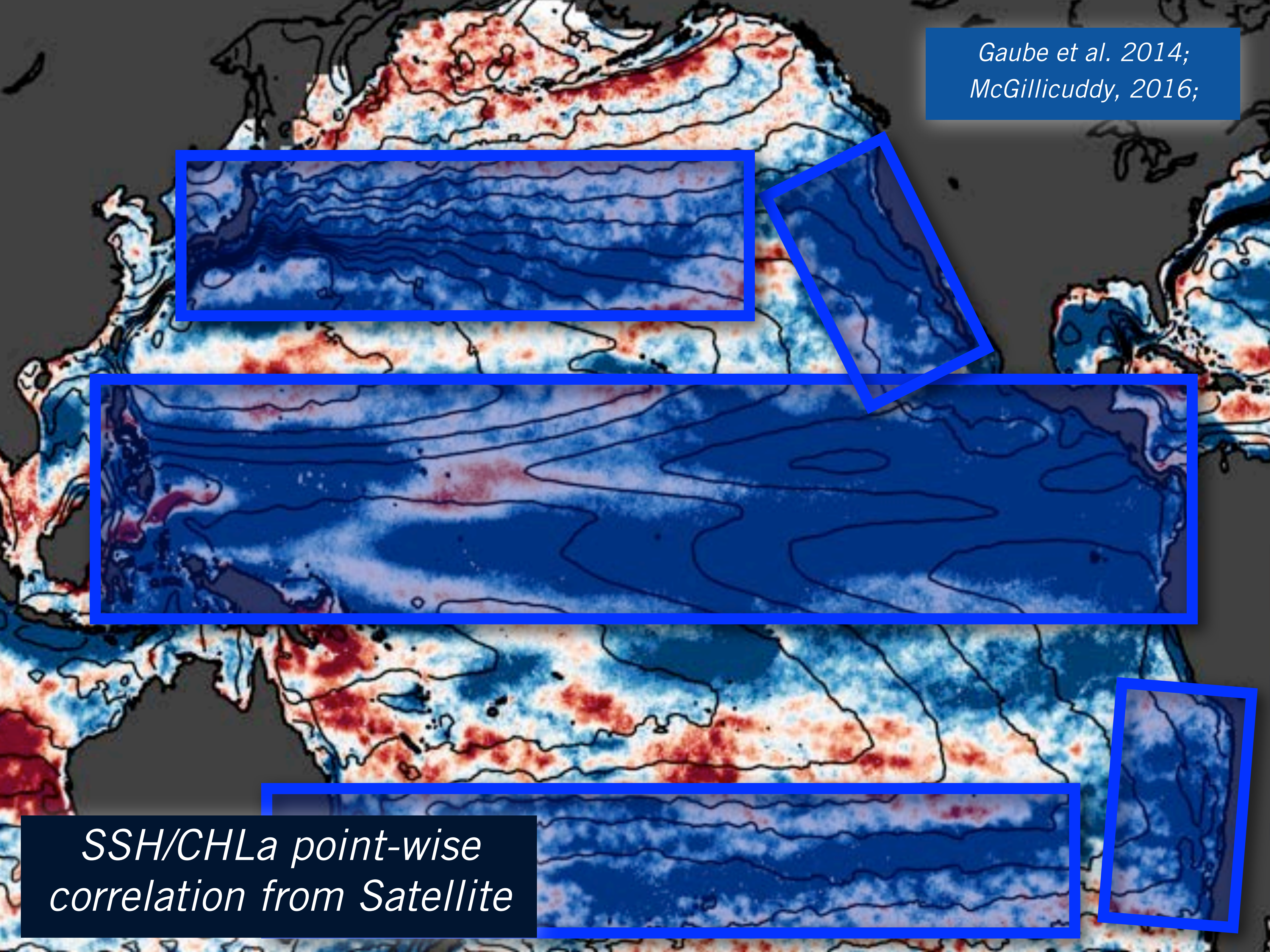
APPROACH

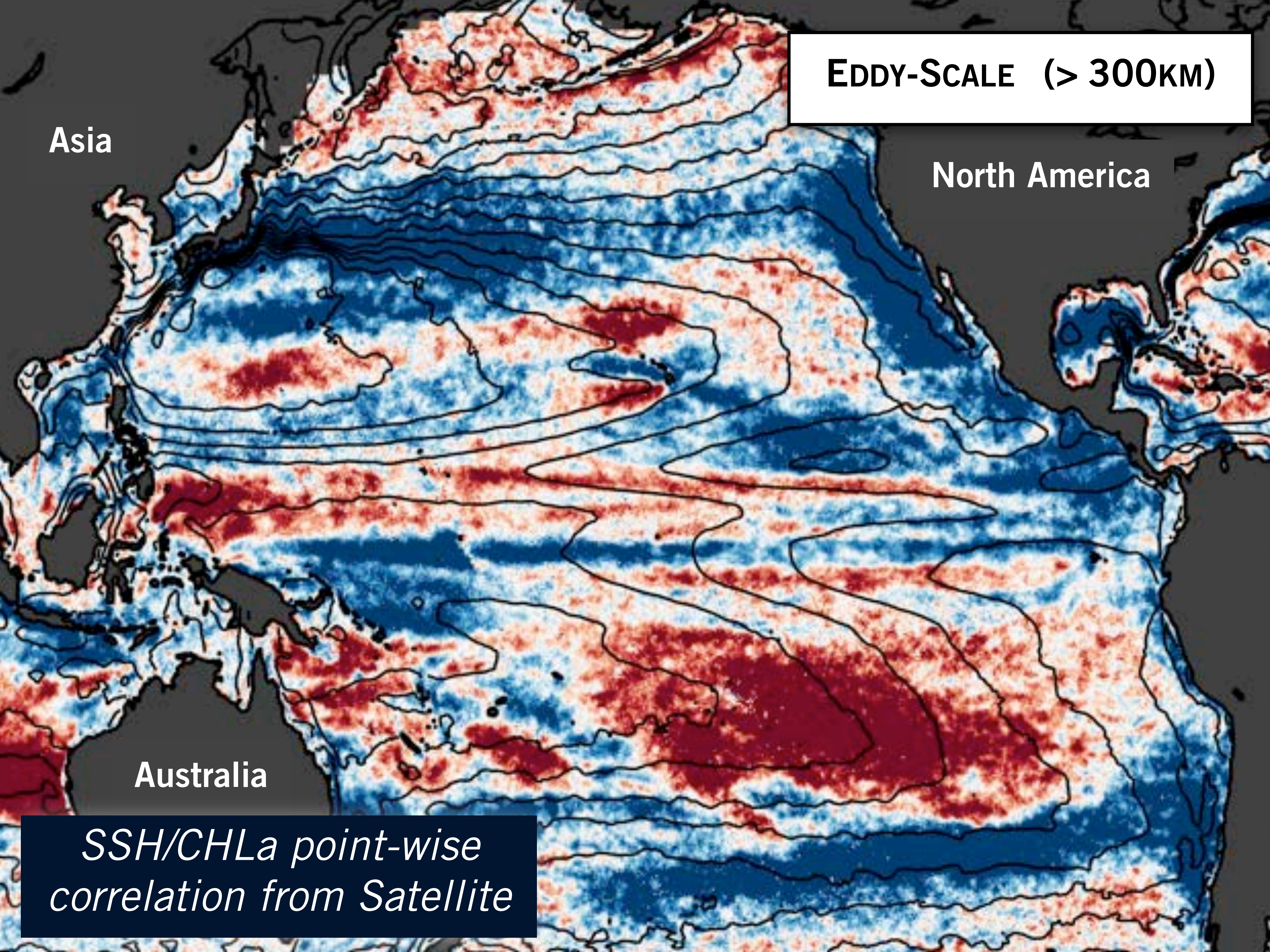
Covariability between SSH and CHLa to identify PTAs



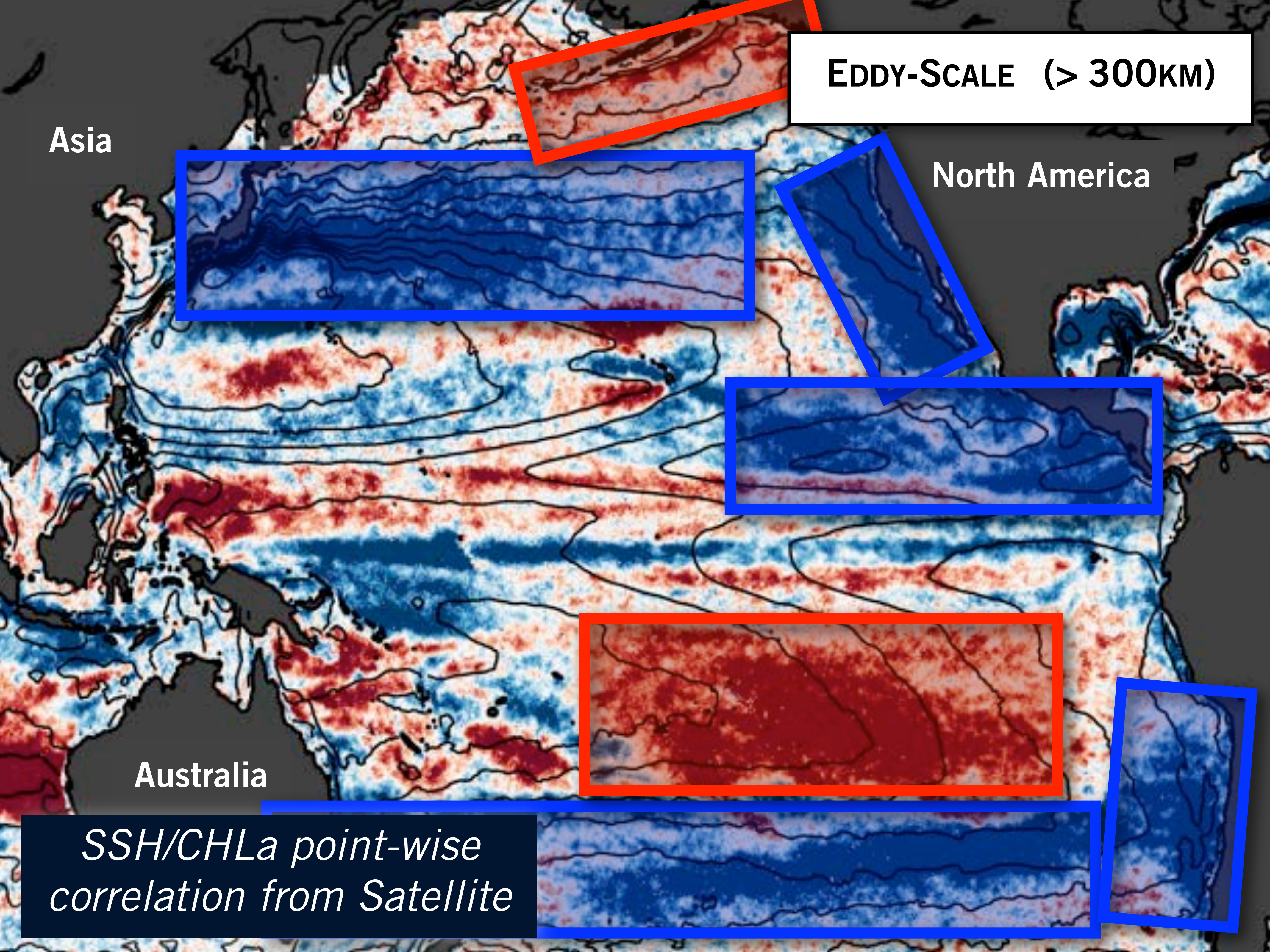
Chlorophyll-a variance from Satellite

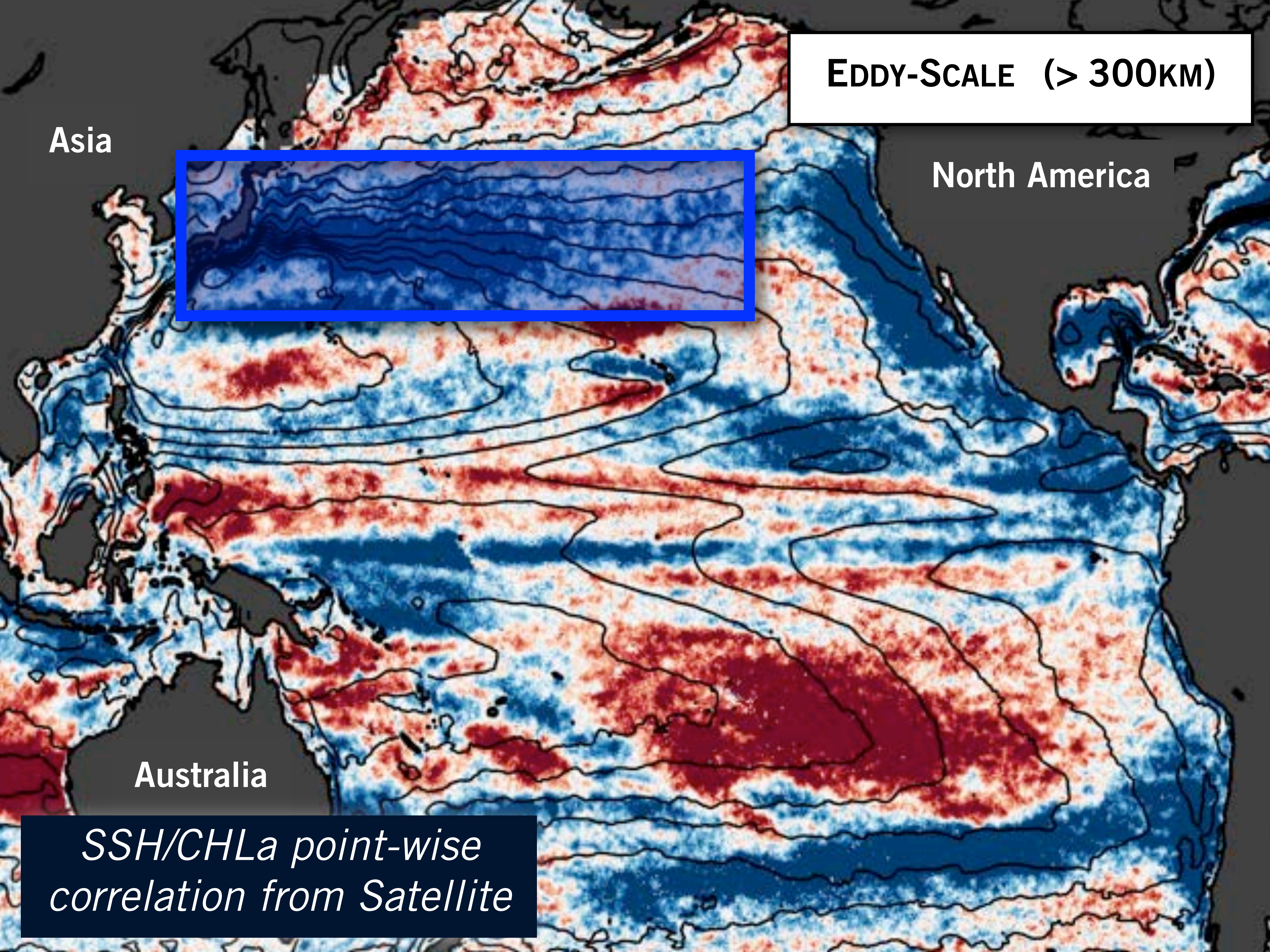

Gaube et al. 2014;
McGillicuddy, 2016;
Asia
North America
Australia
SSH/CHLa point-wise
correlation from Satellite

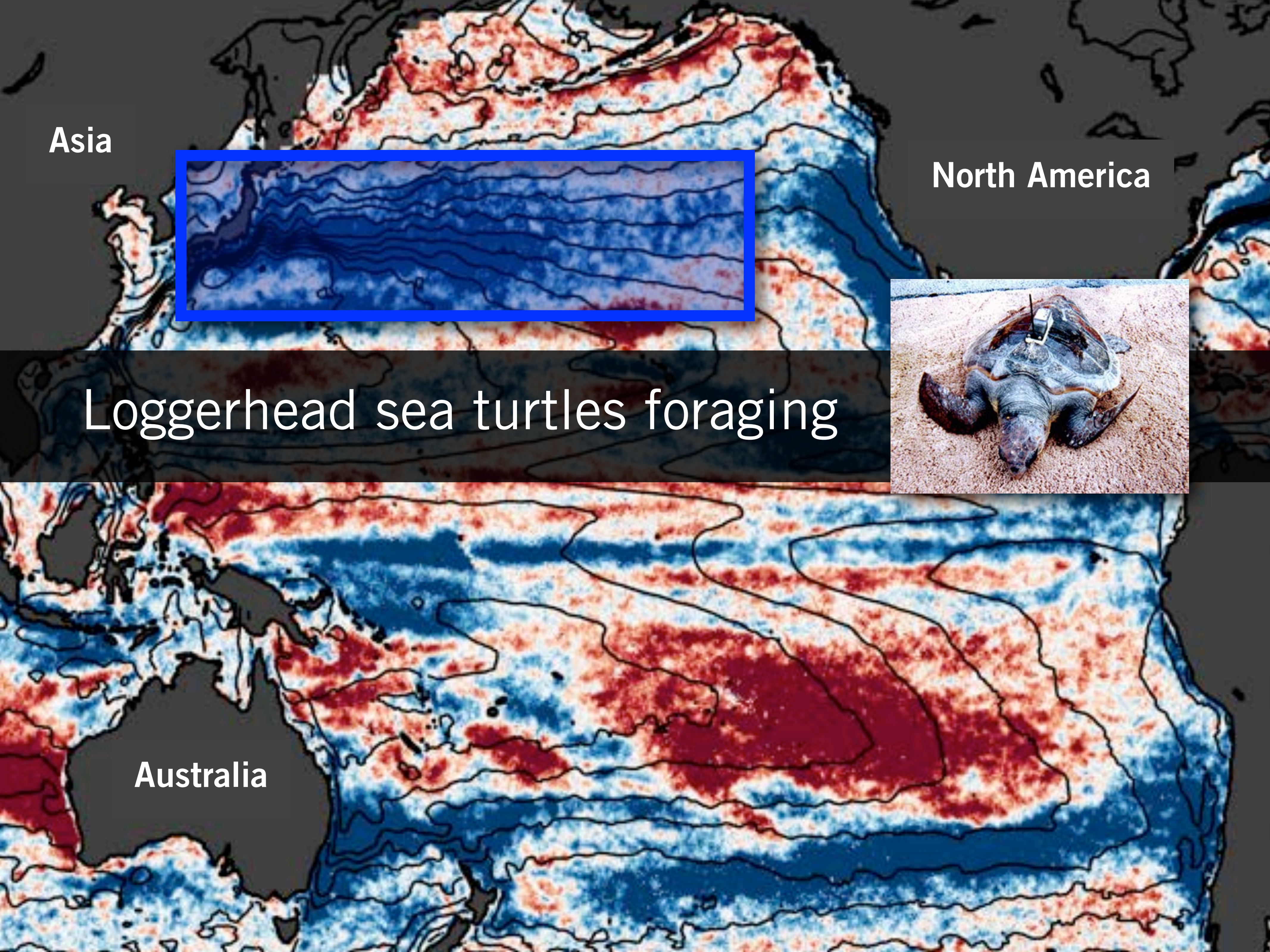

Gaube et al. 2014;
McGillicuddy, 2016;
SSH/CHLa point-wise
correlation from Satellite



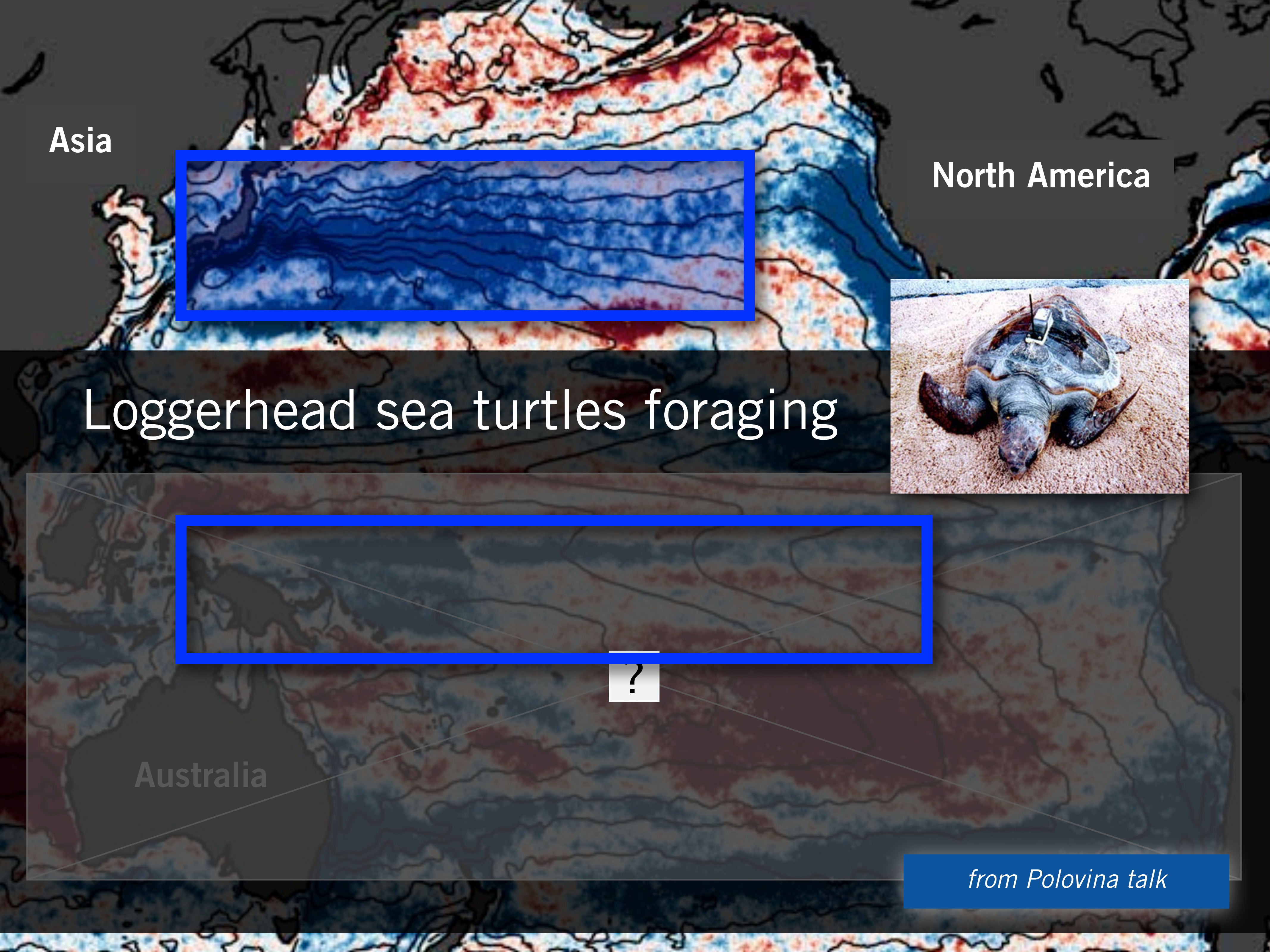
EDDY-SCALE (> 300KM)
Asia
North America
Australia
SSH/CHLa point-wise correlation from Satellite


EDDY-SCALE (> 300KM)
Asia
North America
Australia
SSH/CHLa point-wise
correlation from Satellite

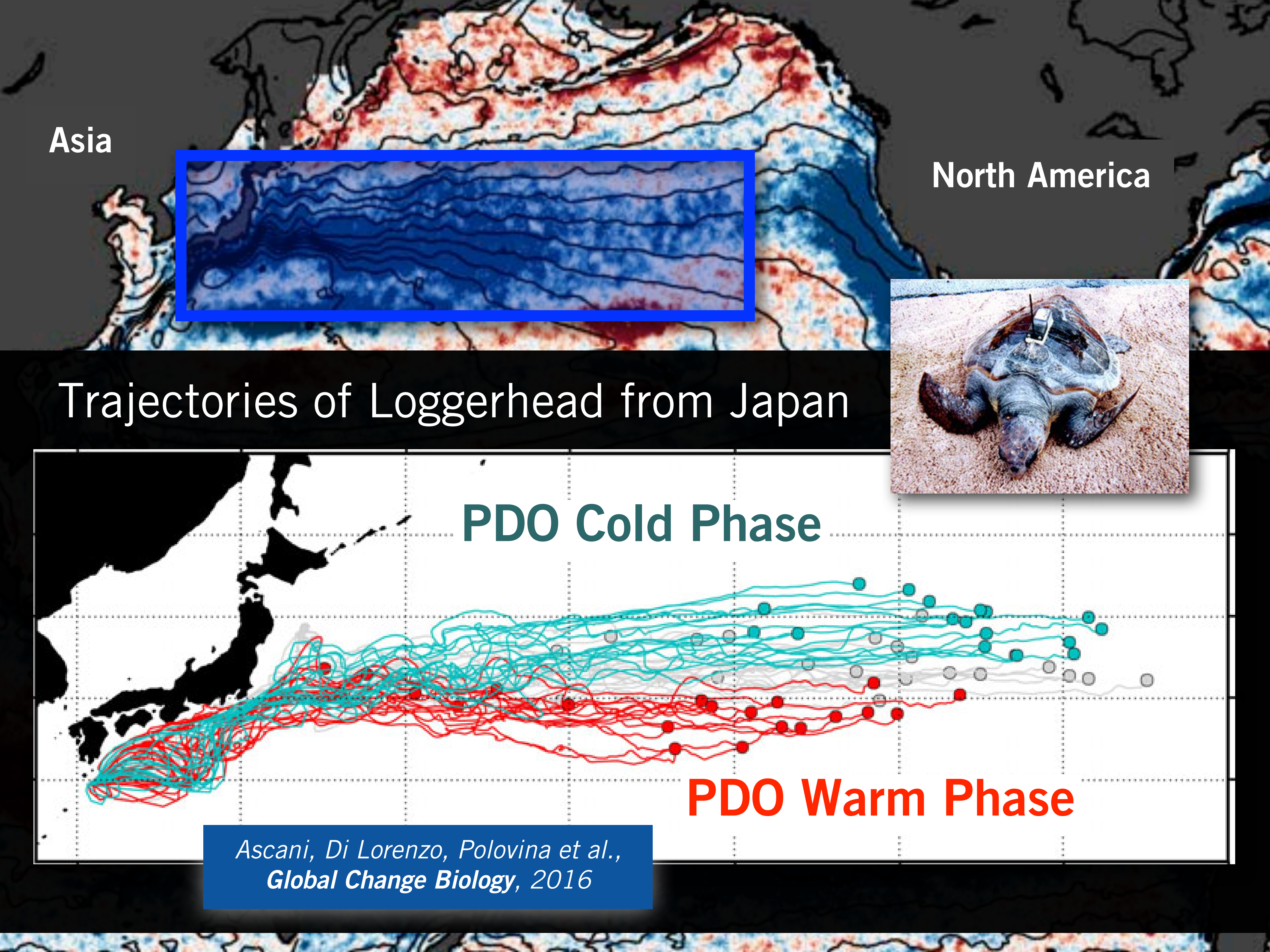

EDDY-SCALE (> 300KM)
Asia
North America
Australia
SSH/CHLa point-wise correlation from Satellite

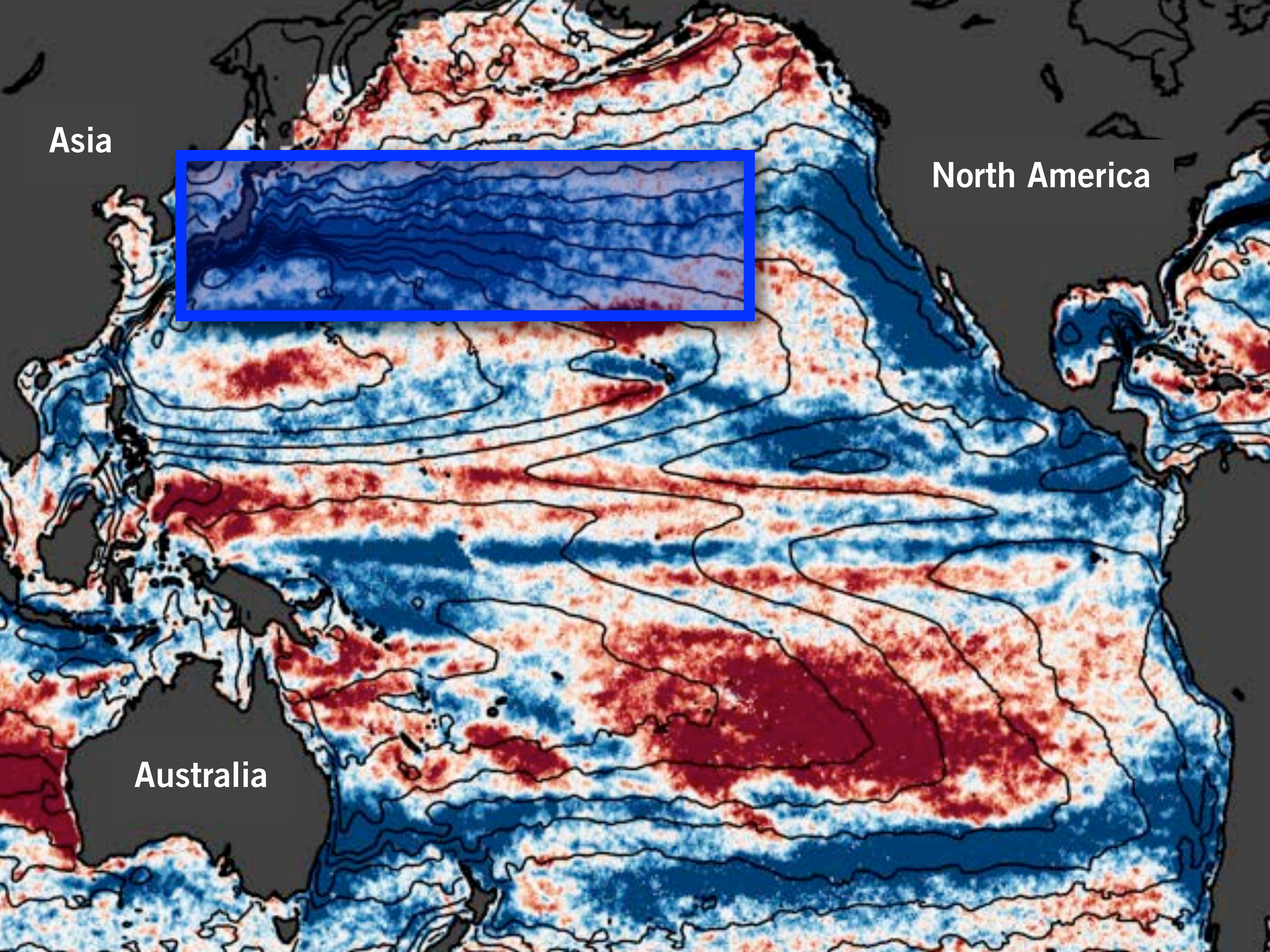

Asia
North America
Loggerhead sea turtles foraging
Australia

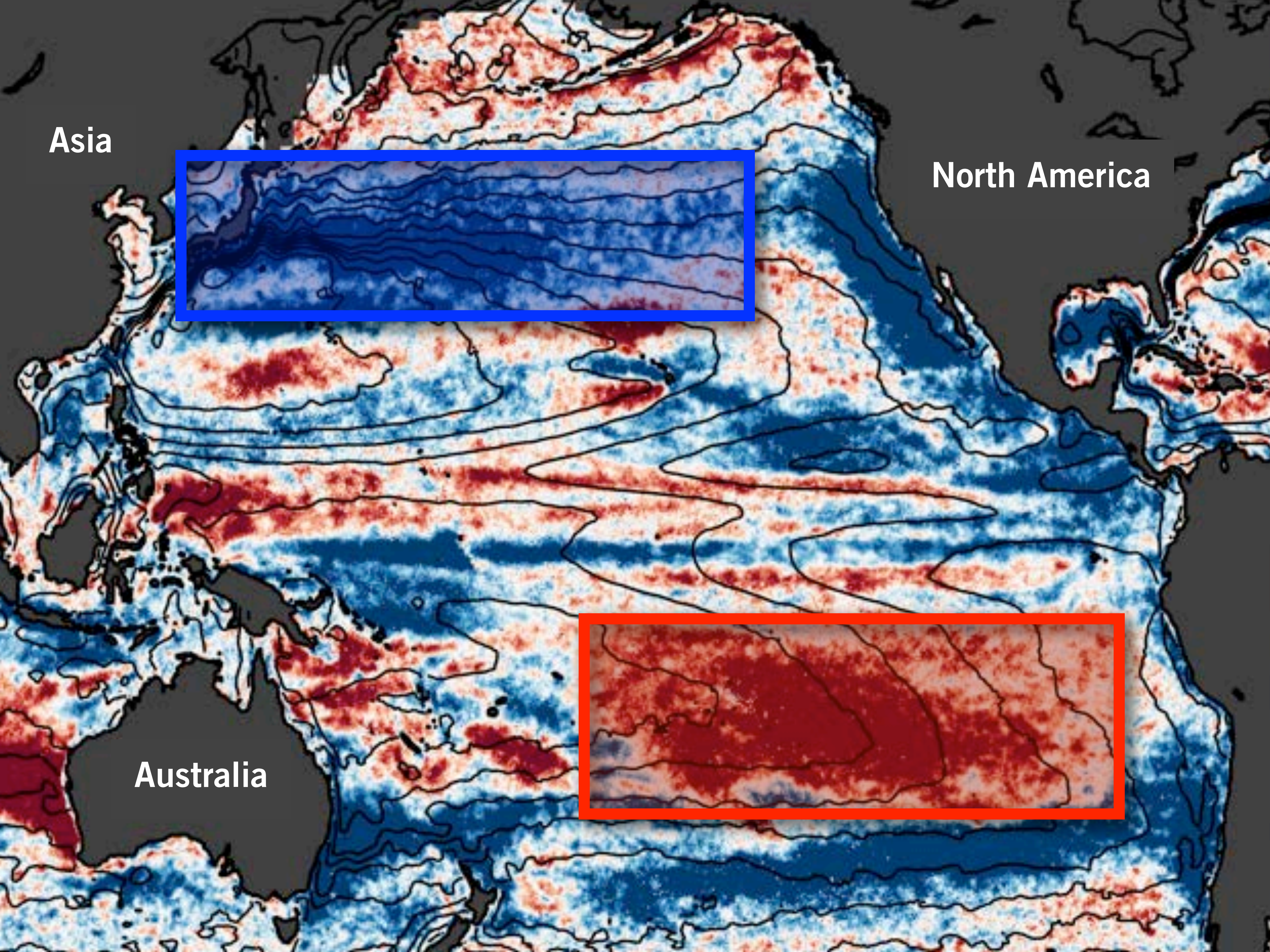
Loggerhead sea turtles foraging



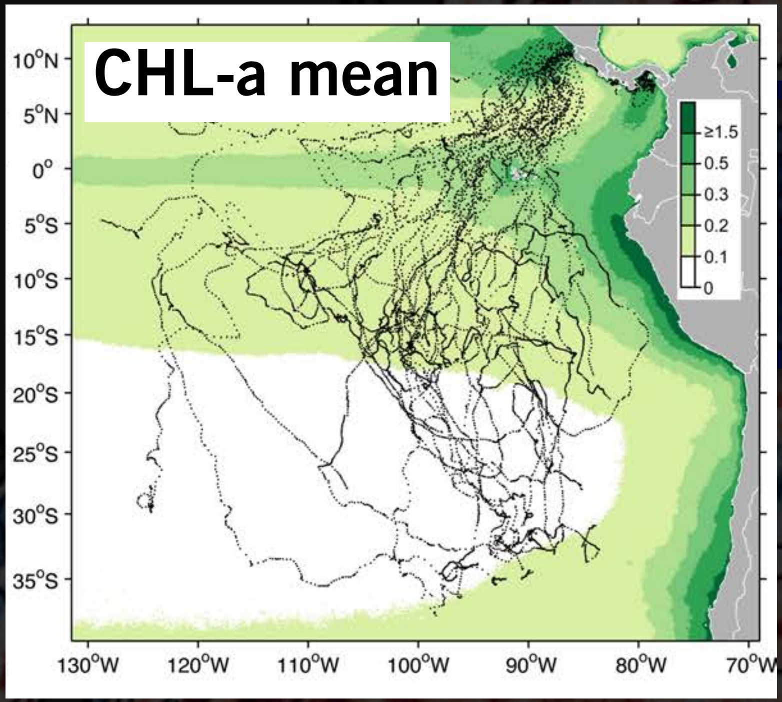
from Polovina talk

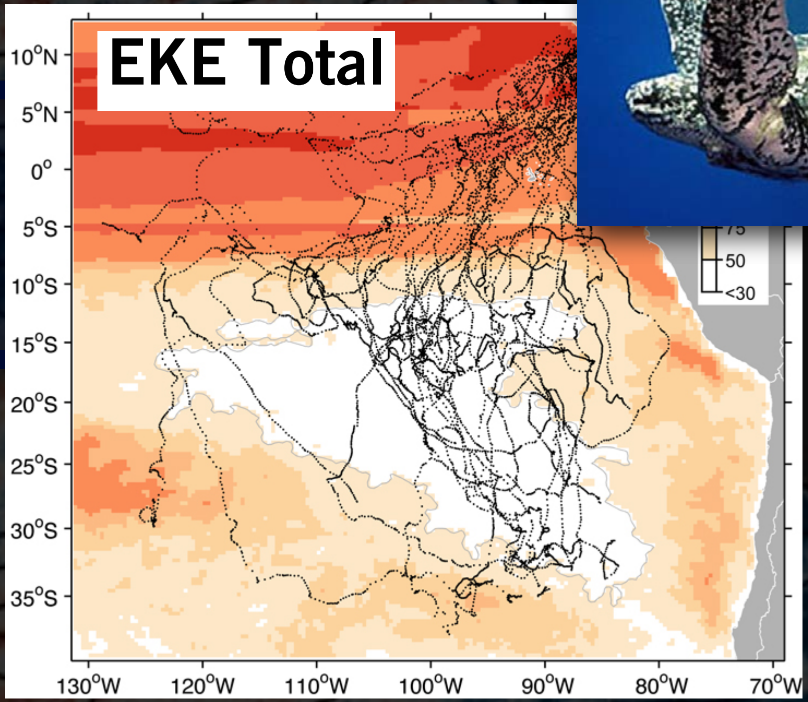

Asia
North America
Trajectories of Loggerhead from Japan
PDO Cold Phase
PDO Warm Phase
Ascani, Di Lorenzo, Polovina et al.,
Global Change Biology, 2016

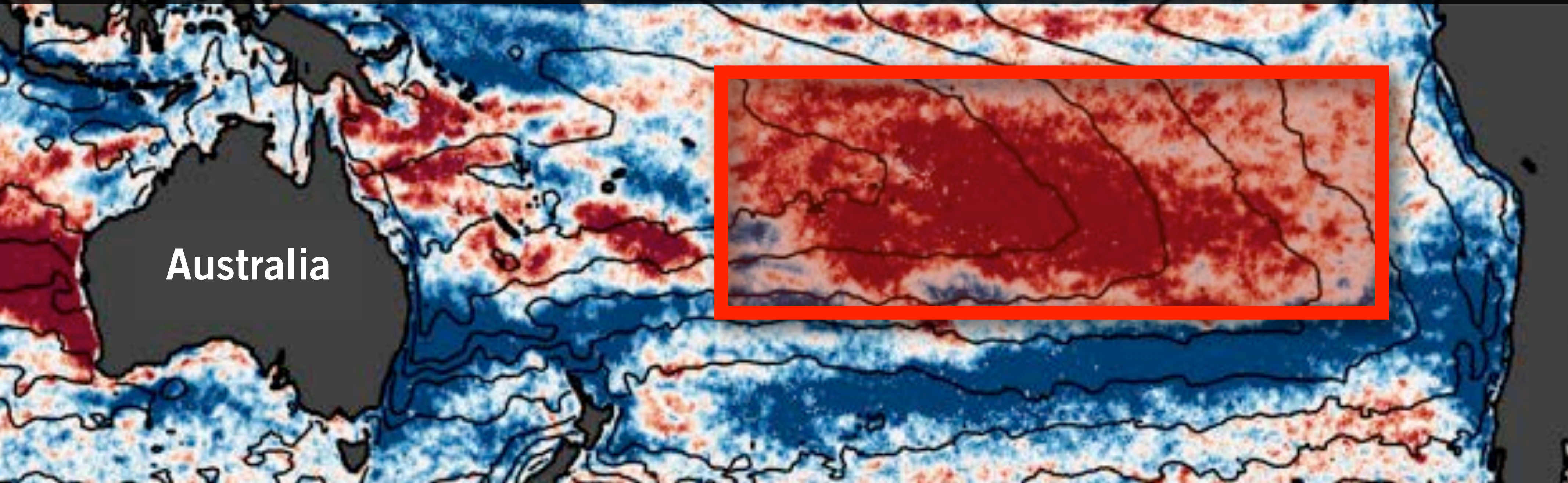

Asia
North America
Australia


Asia
North America
Australia

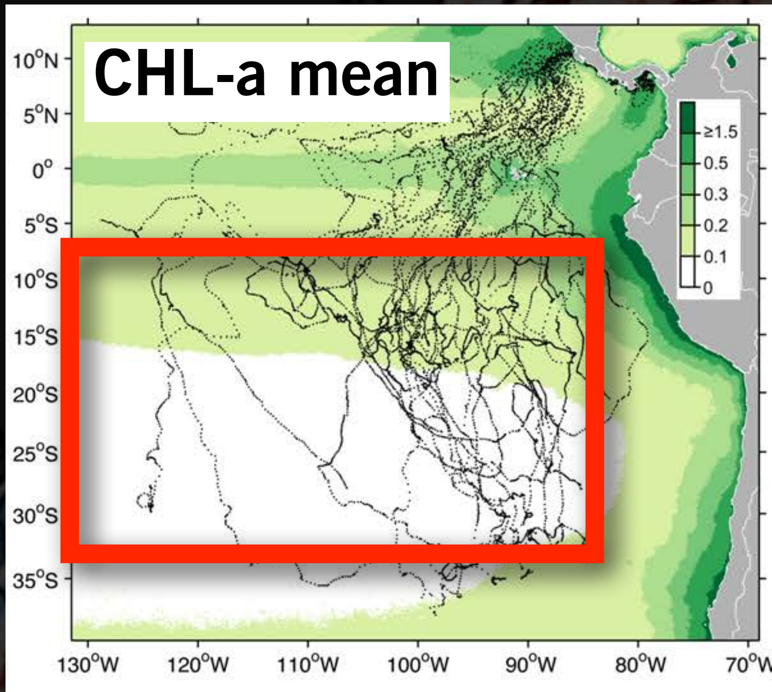
Trajectories of Leatherback Turtle

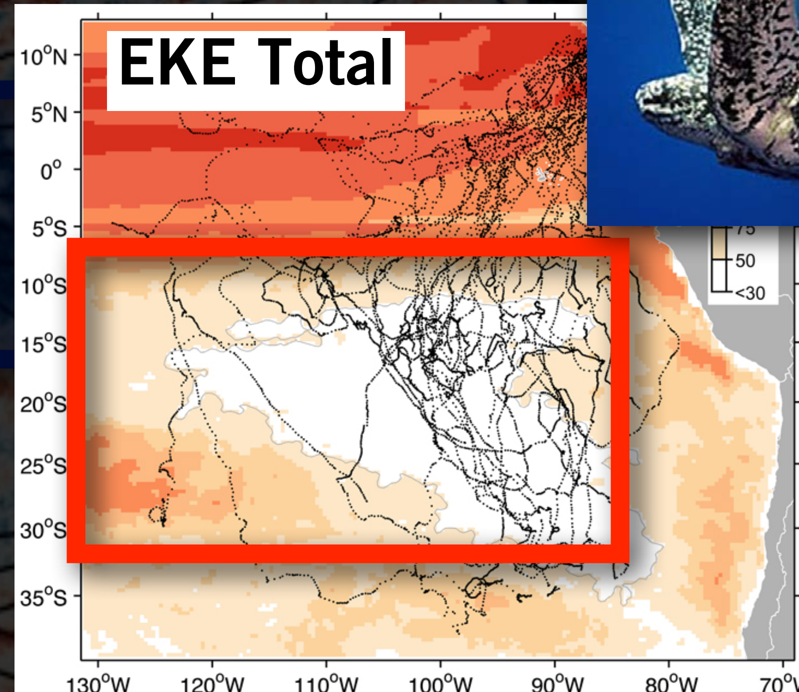


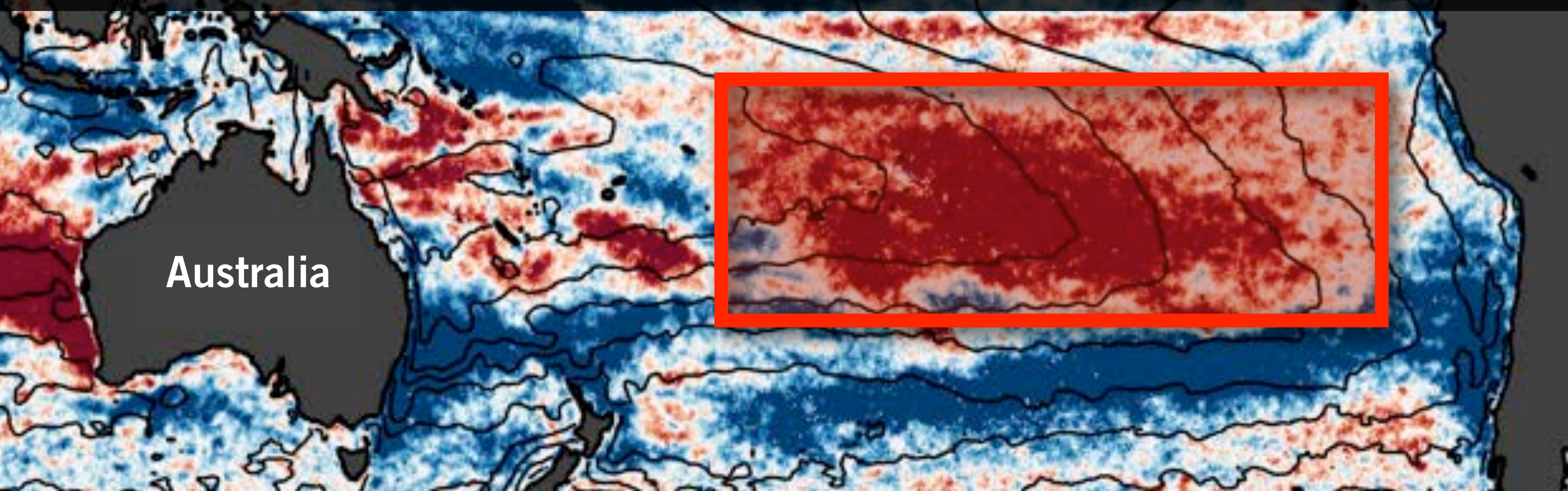


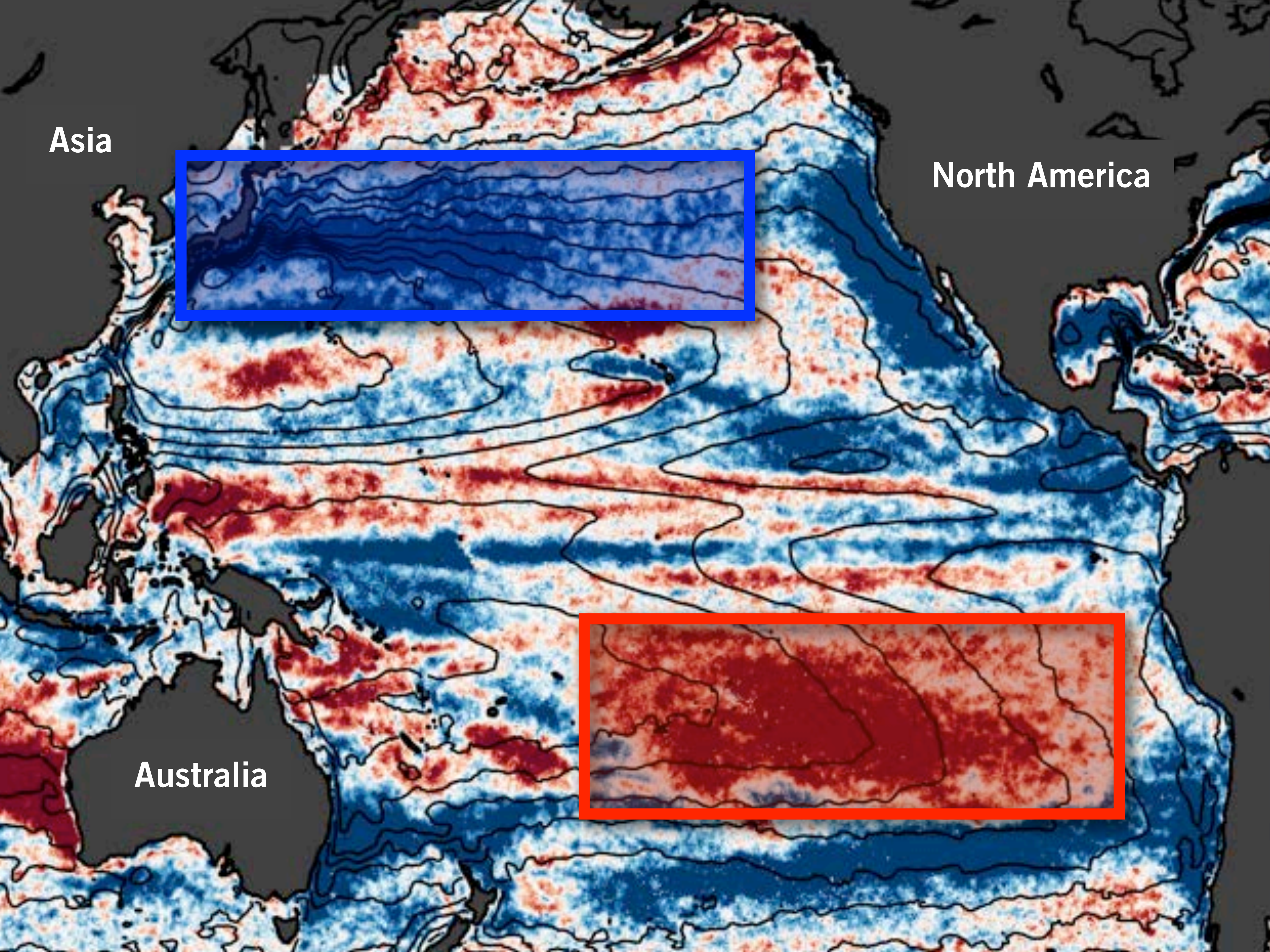


Trajectories of Leatherback Turtle

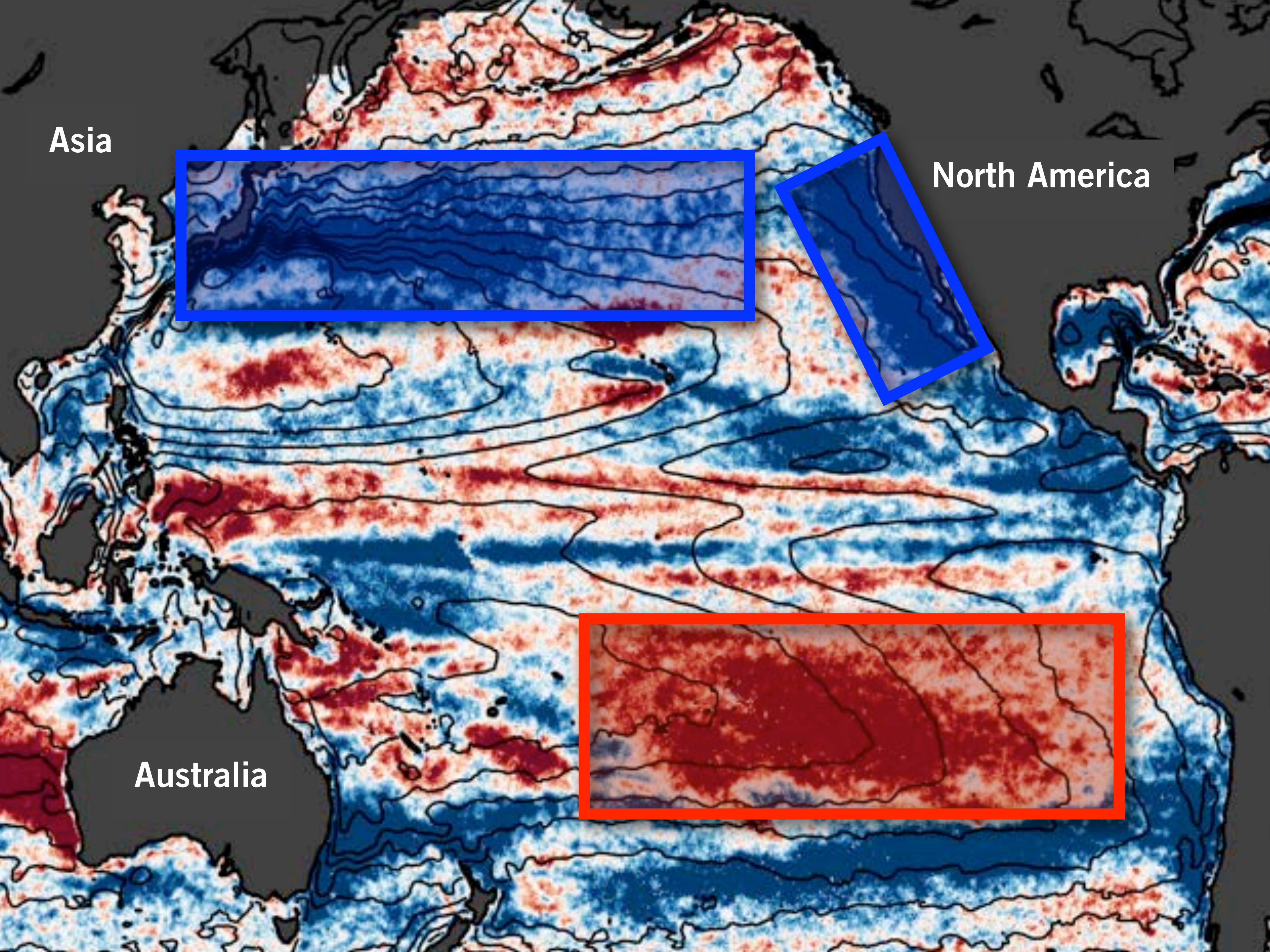


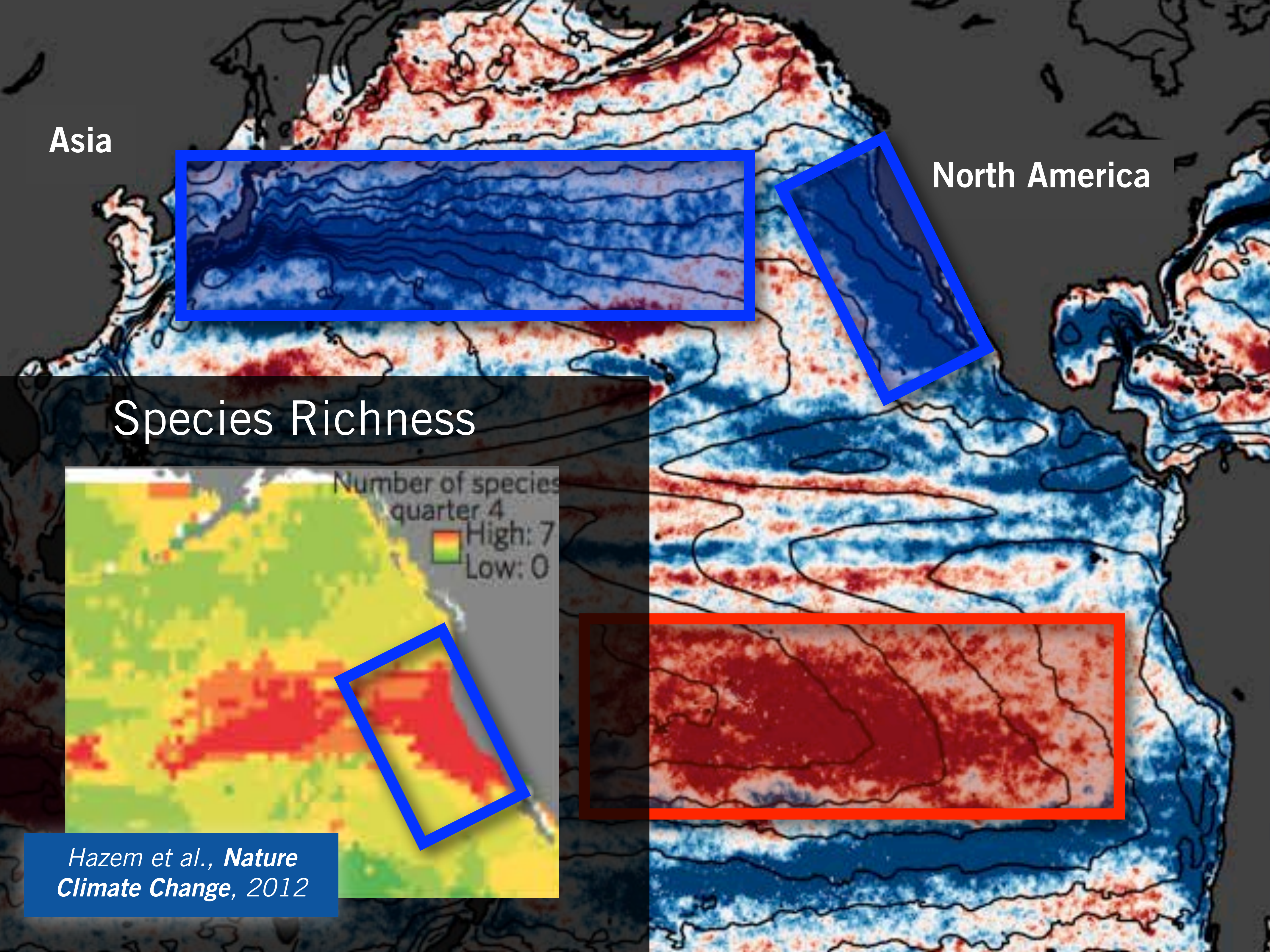




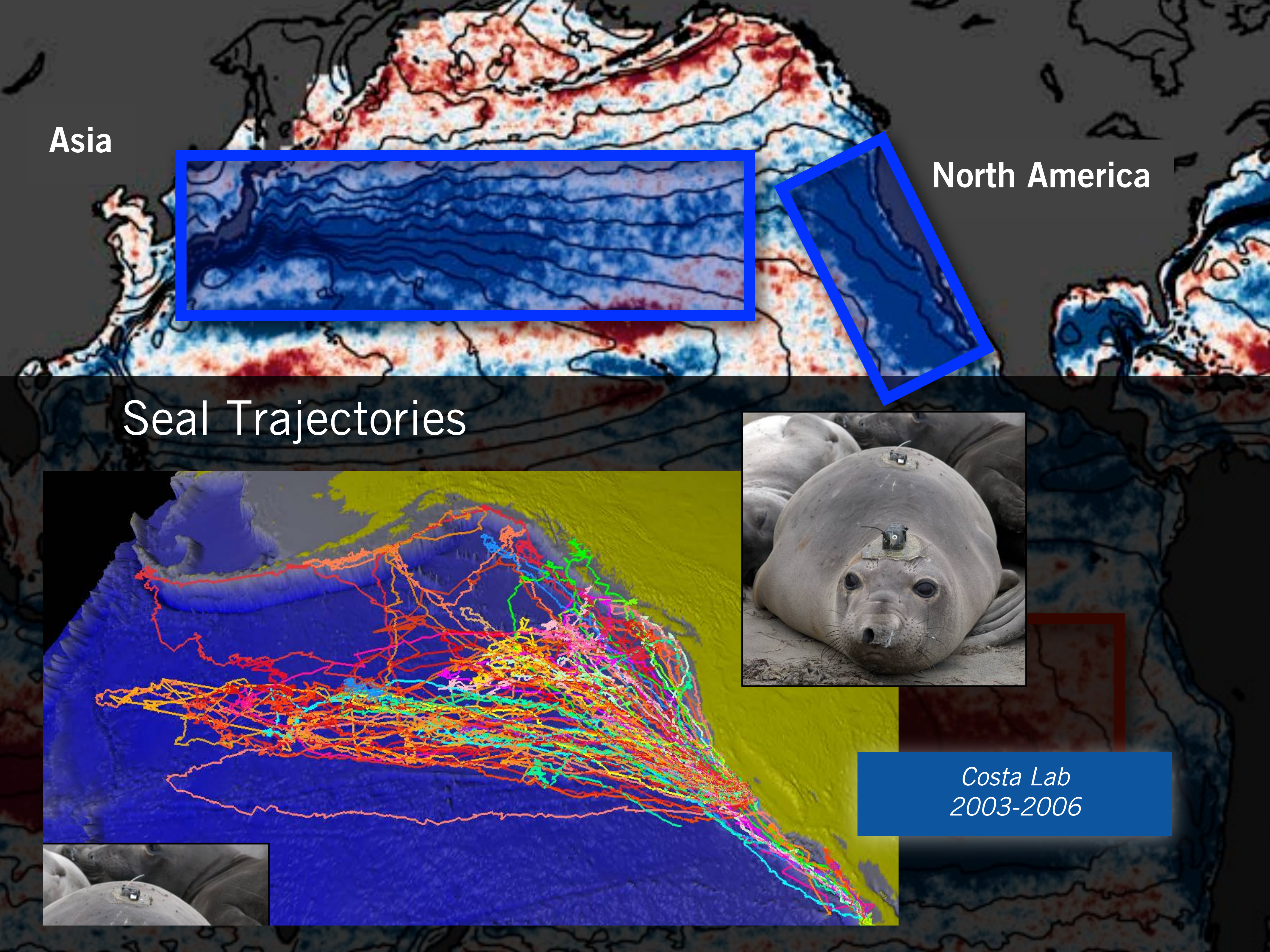


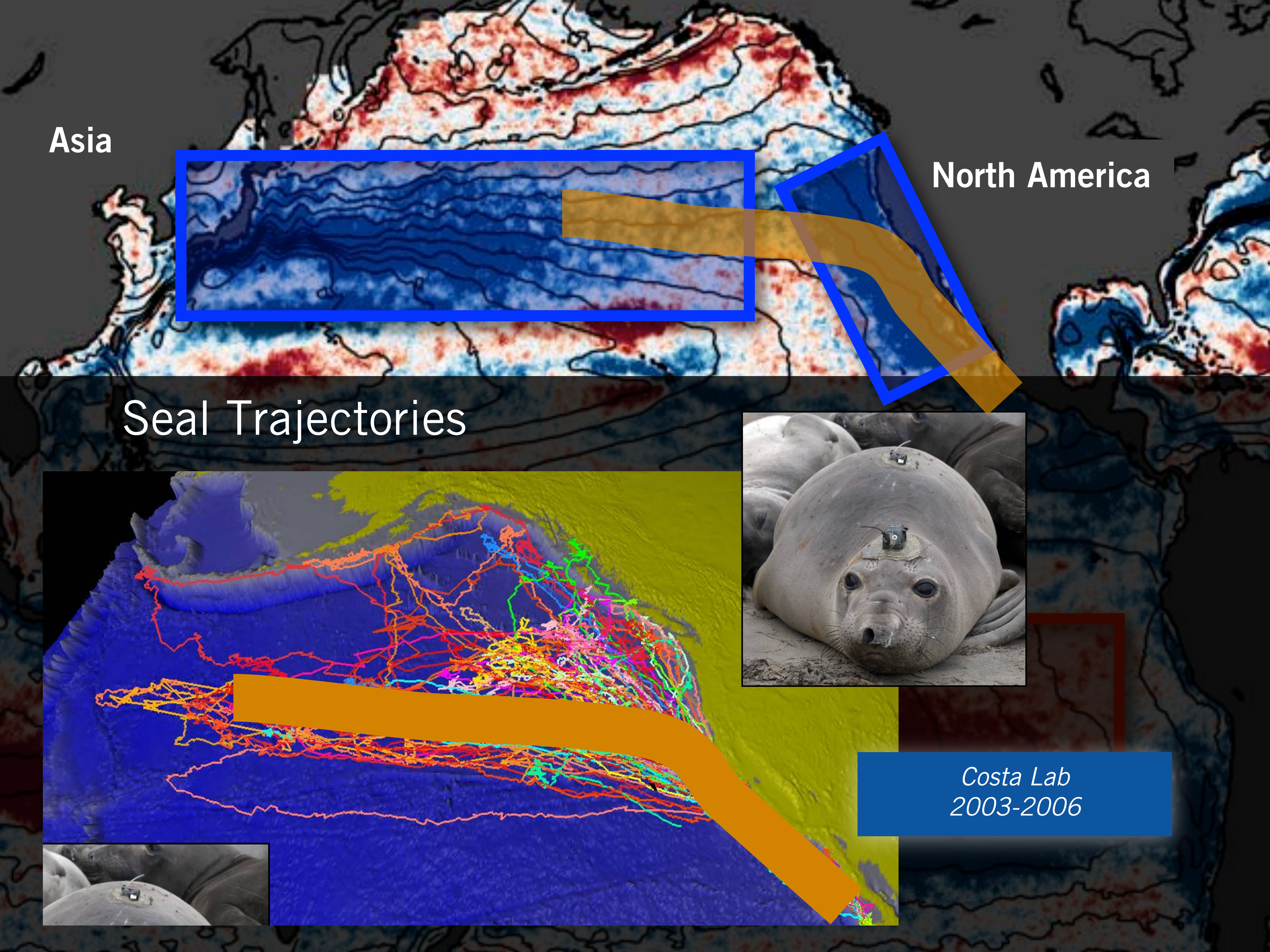
Asia
North America
Australia

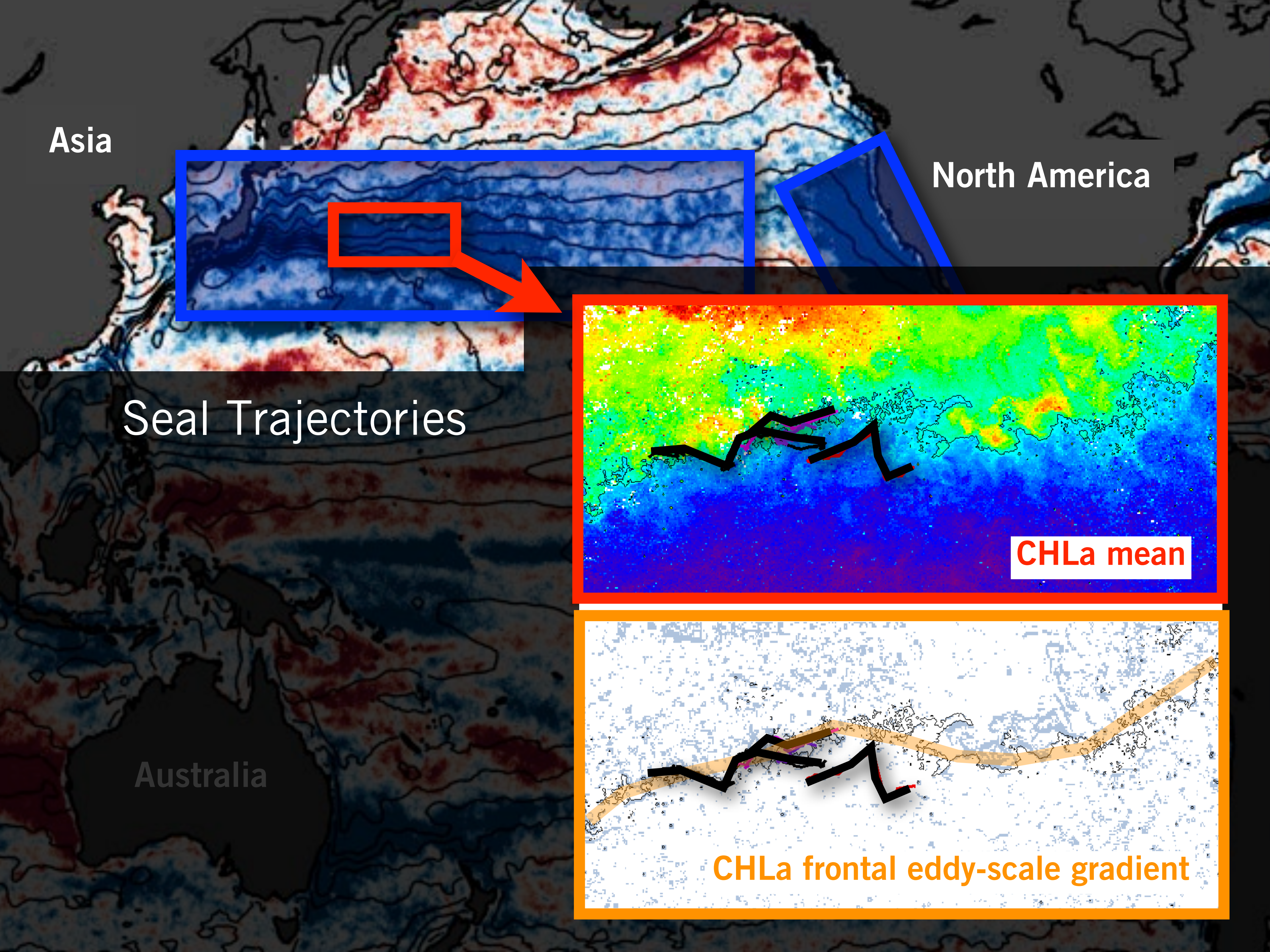

Asia
North America
Australia

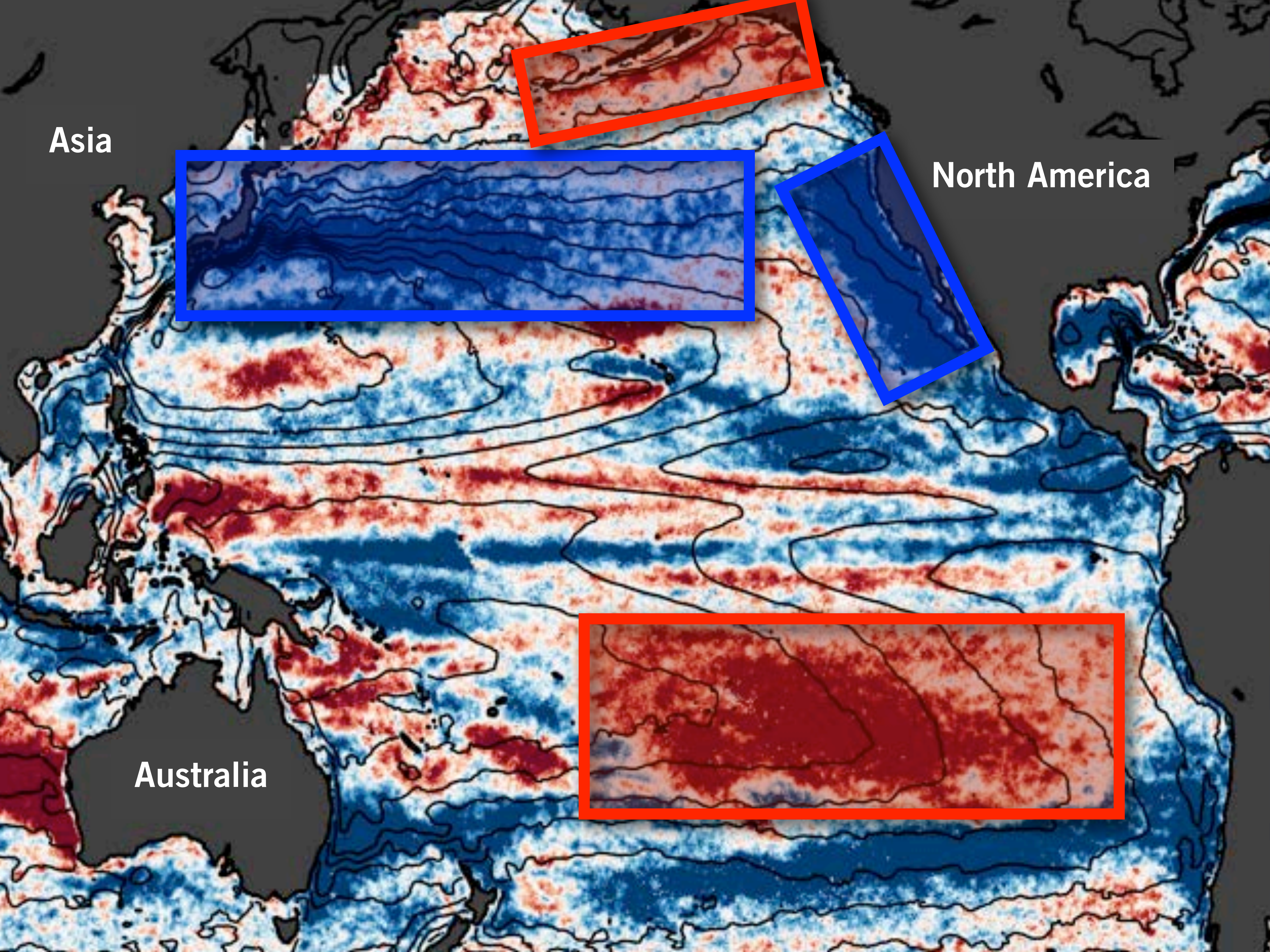


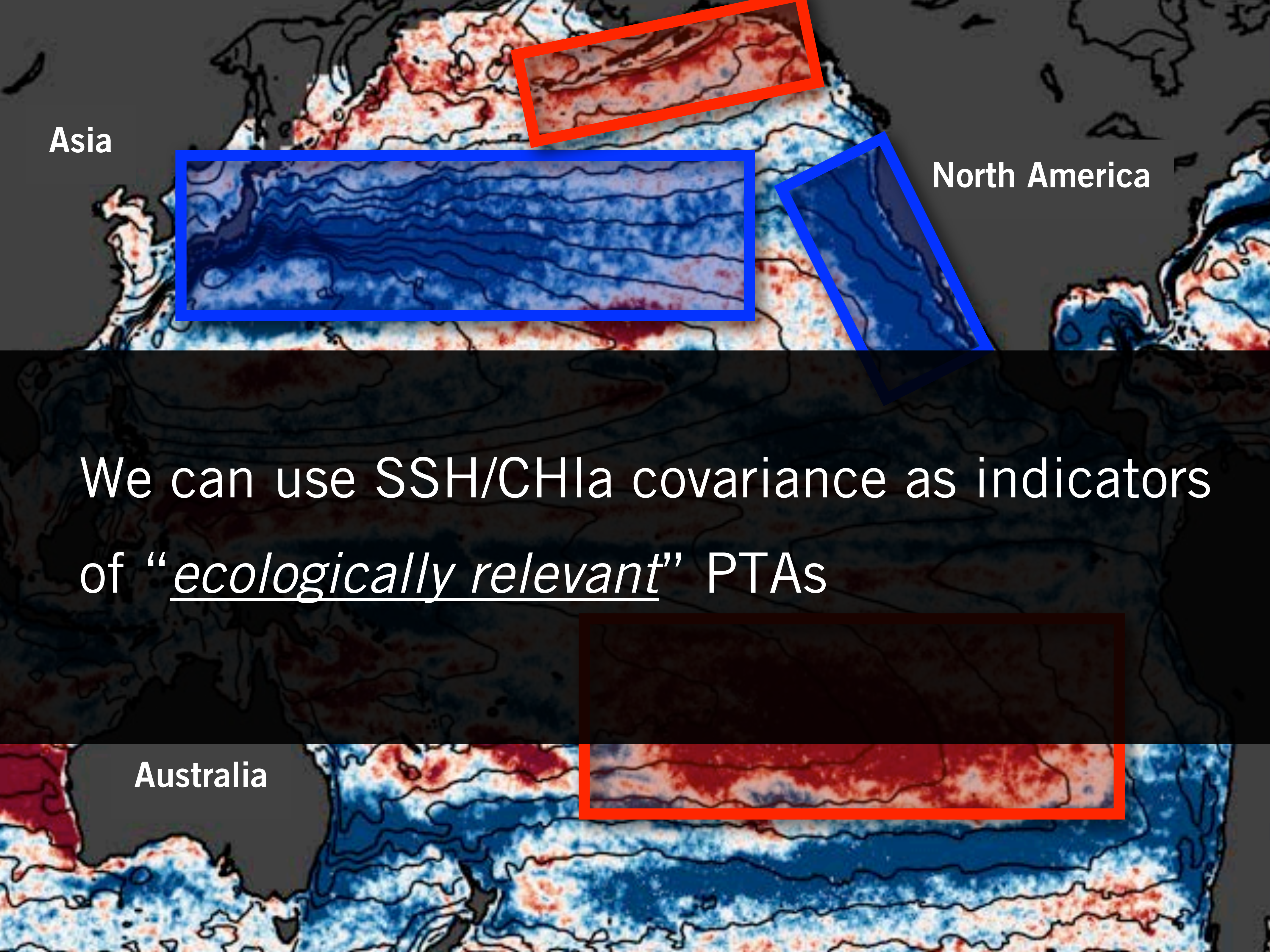
Asia
North America
Species Richness
Number of species
quarter 4
High: 7
Low: 0
Hazem et al., ***Nature Climate Change***, *2012*


Asia
North America
Seal Trajectories
Costa Lab
2003-2006


Asia
North America
Seal Trajectories
Costa Lab
2003-2006

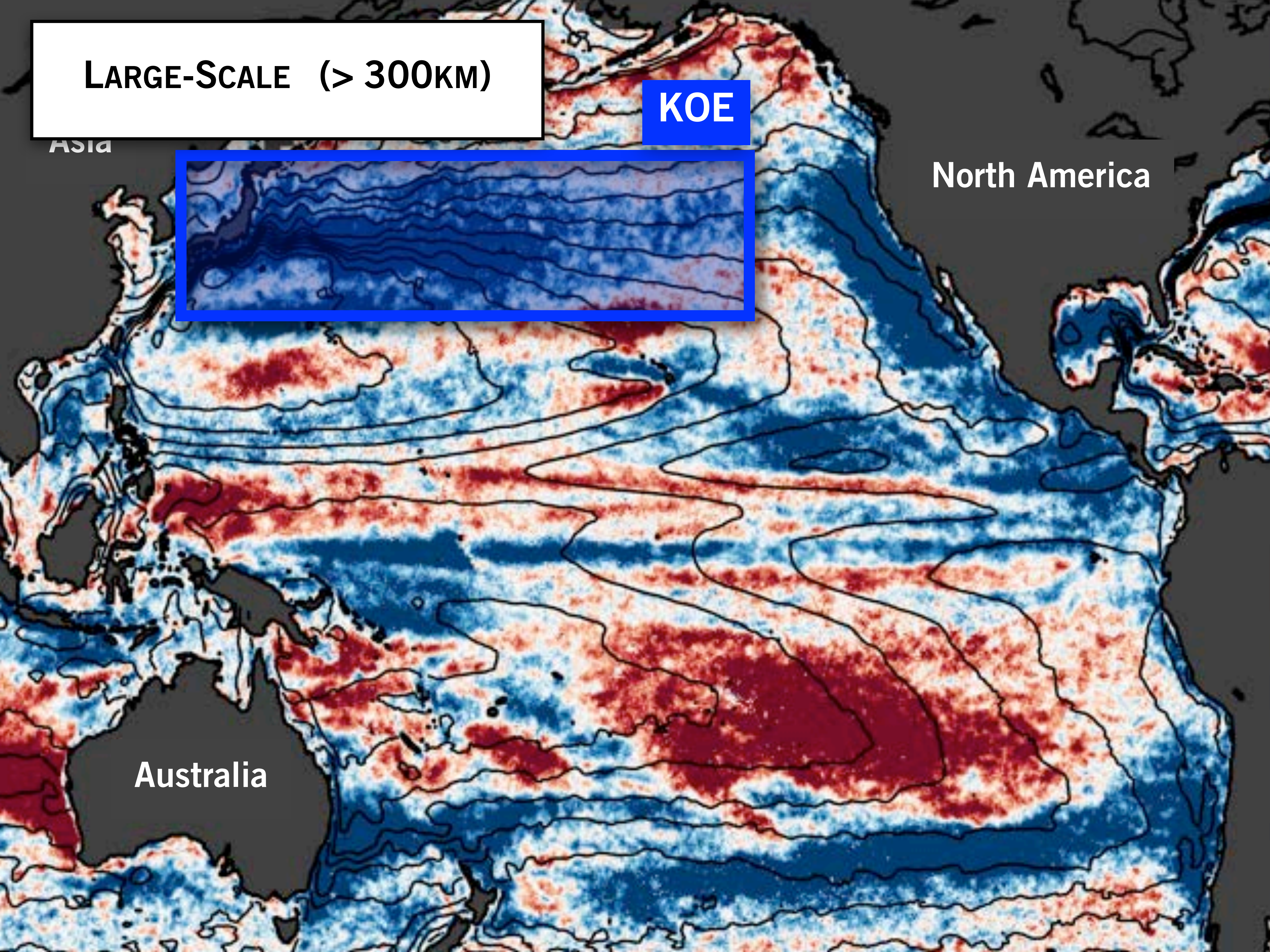

Asia
North America
Seal Trajectories
Australia
CHLa mean
CHLa frontal eddy-scale gradient

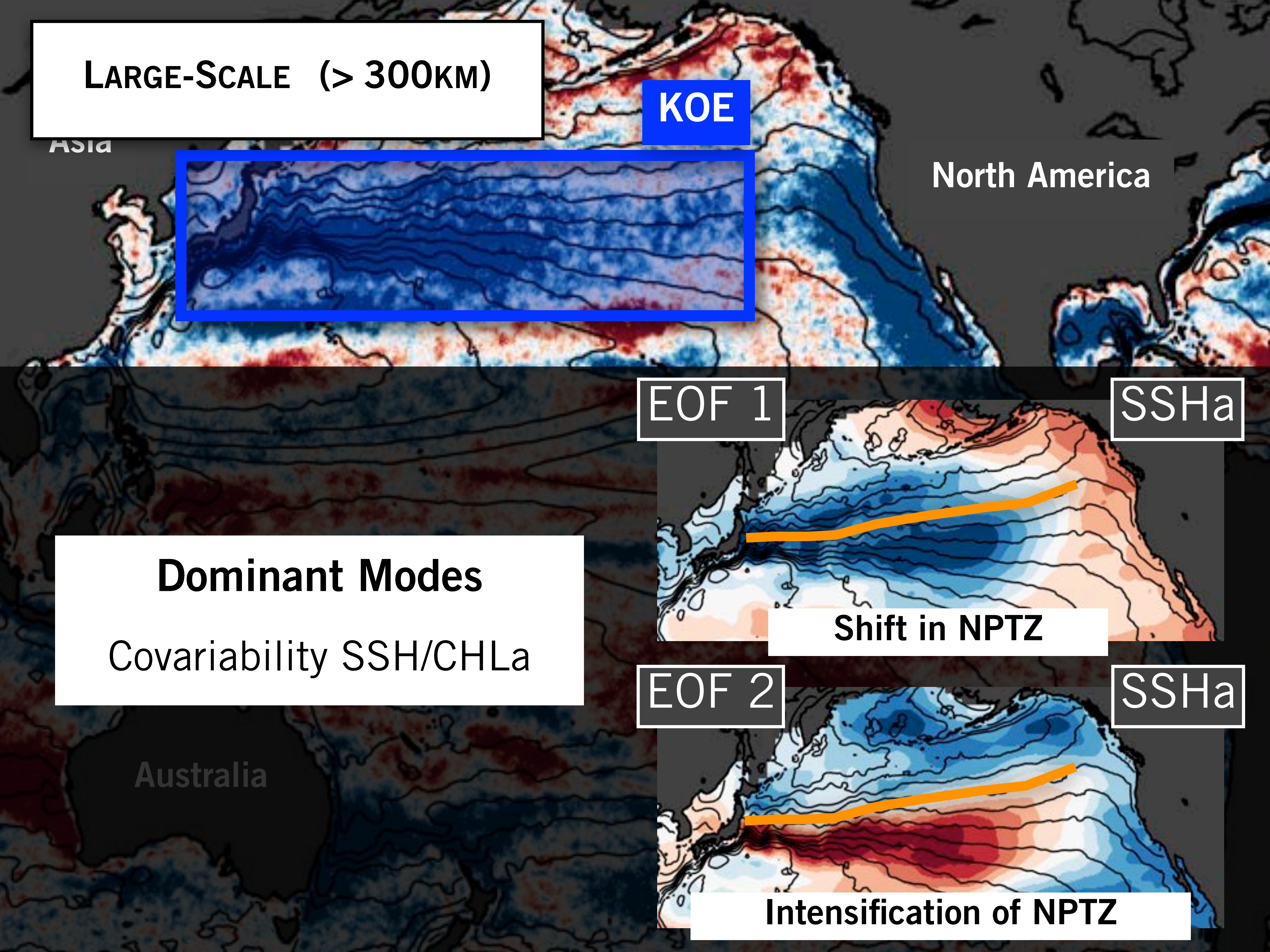

Asia
North America
Australia



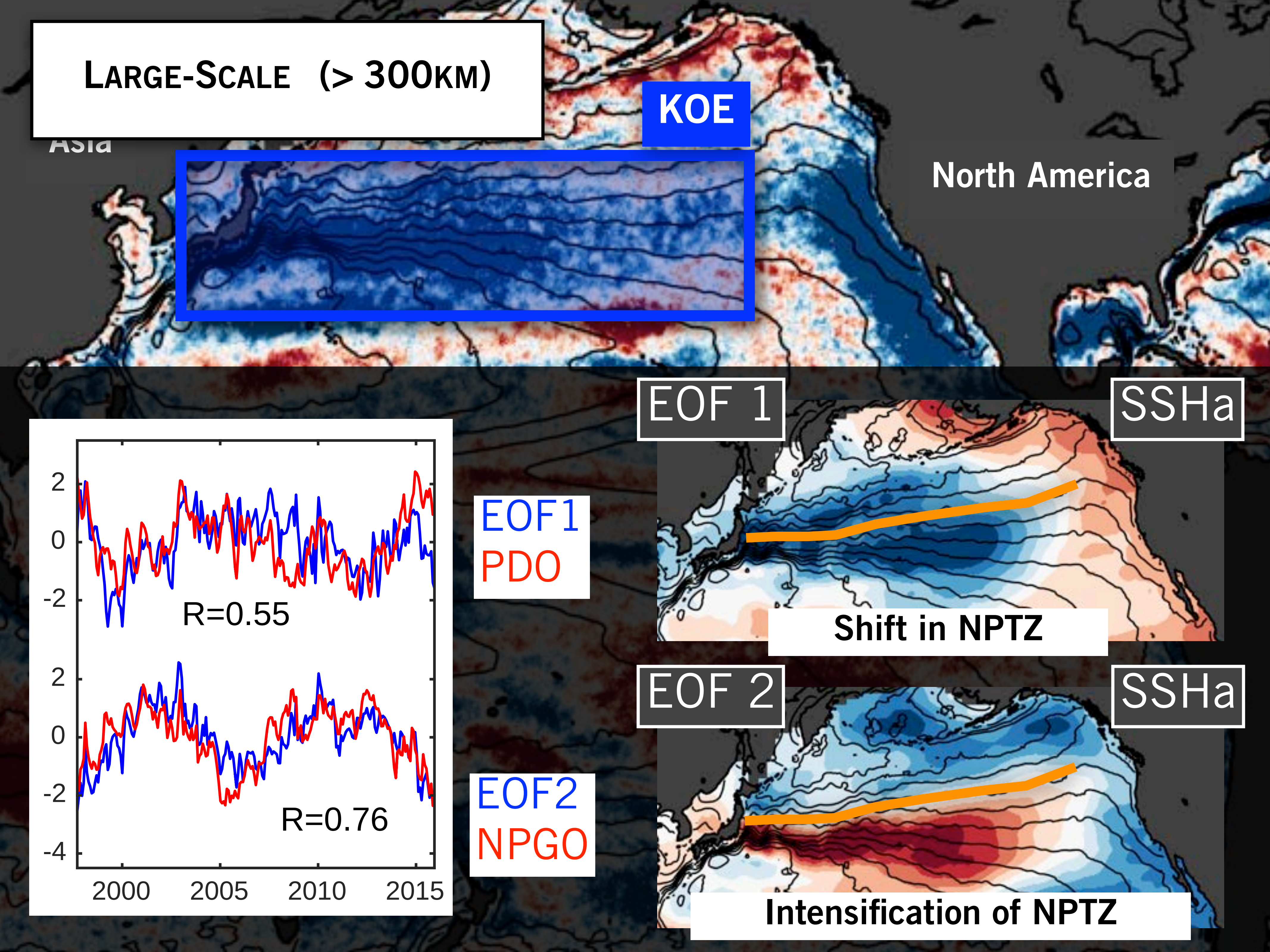
We can use SSH/CHla covariance as indicators of "*ecologically relevant*" PTAs

LARGE-SCALE (> 300KM)

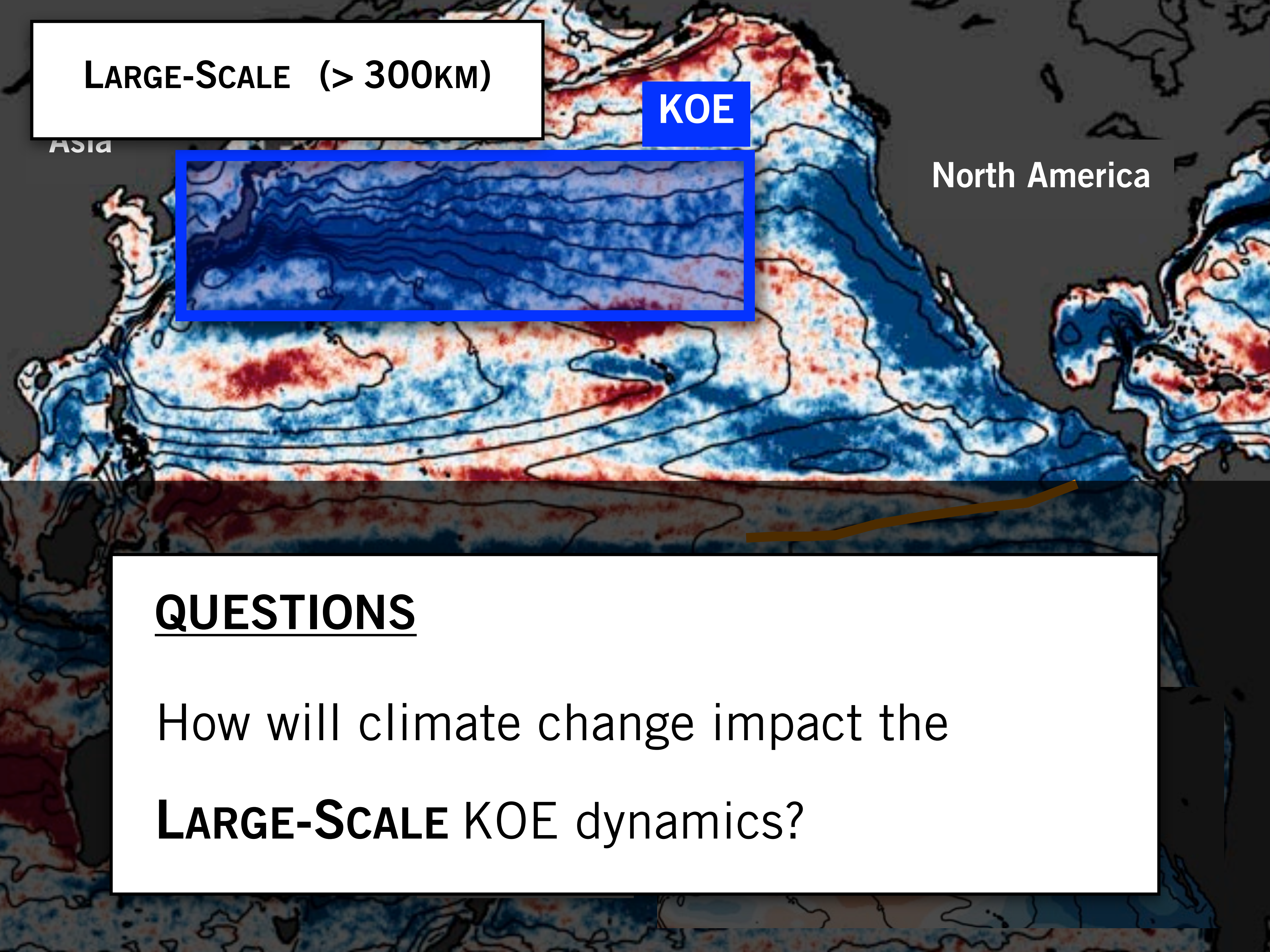




Large-Scale (> 300km)
KOE
Asia
North America
EOF 1
SSHa
Shift in NPTZ
Dominant Modes
Covariability SSH/CHLa
EOF 2
SSHa
Australia
Intensification of NPTZ


LARGE-SCALE (> 300KM)
Asia
KOE
North America
EOF 1
SSHa
Shift in NPTZ
EOF 2
SSHa
Intensification of NPTZ
2
0
-2
R=0.55
2
0
-2
-4
R=0.76
2000
2005
2010
2015
EOF1
PDO
EOF2
NPGO

Large-Scale (> 300km)



QUESTIONS

How will climate change impact the **Large-Scale** KOE dynamics?

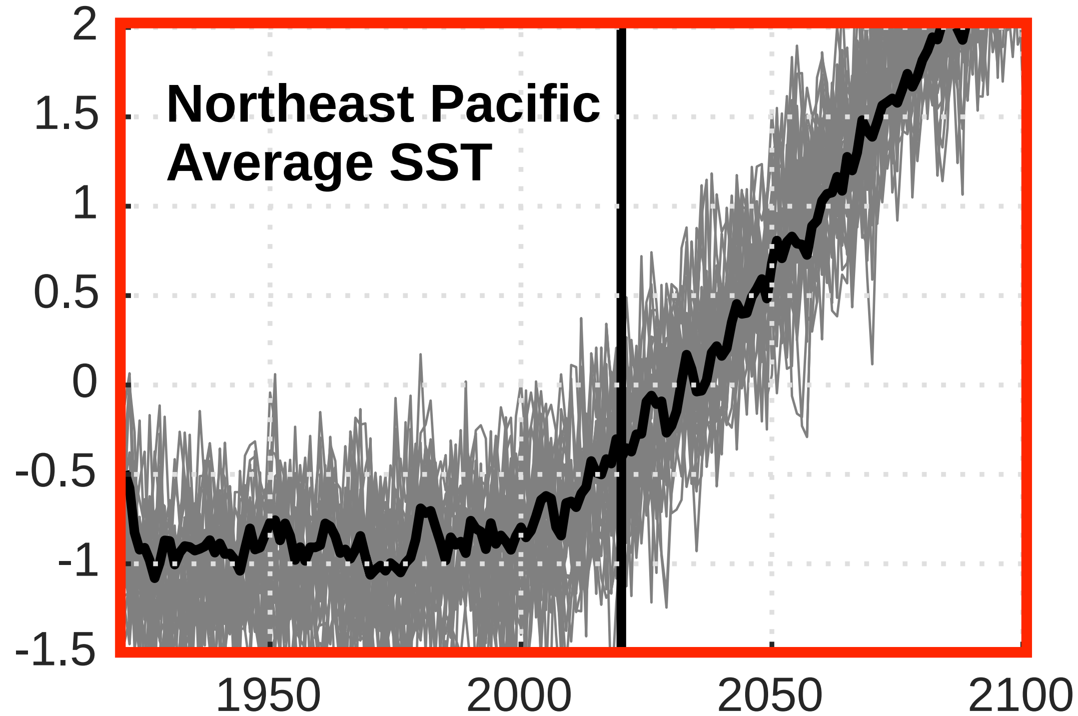
LARGE-SCALE (> 300KM)

Climate Model Projections

Community Earth System Model

CESM Large-Ensemble (n=30)

1920-2100 RCP8.5



QUESTIONS

How will climate change impact the

LARGE-SCALE KOE dynamics?

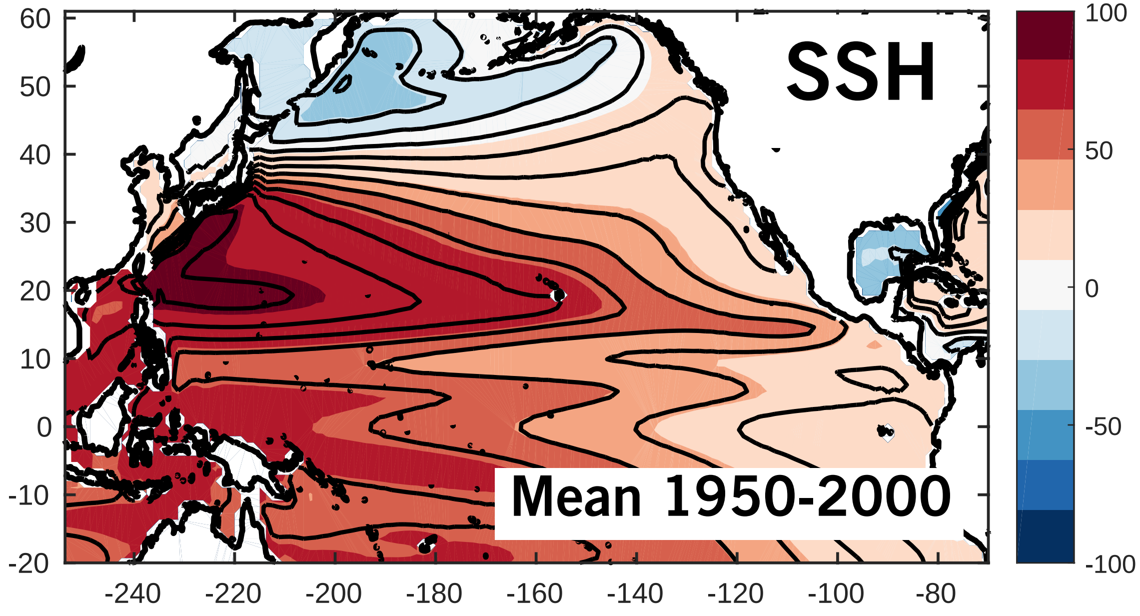
LARGE-SCALE (> 300KM)

Climate Model Projections

Community Earth System Model

CESM Large-Ensemble (n=30)

1920-2100 RCP8.5



QUESTIONS

How will climate change impact the **LARGE-SCALE** KOE dynamics?

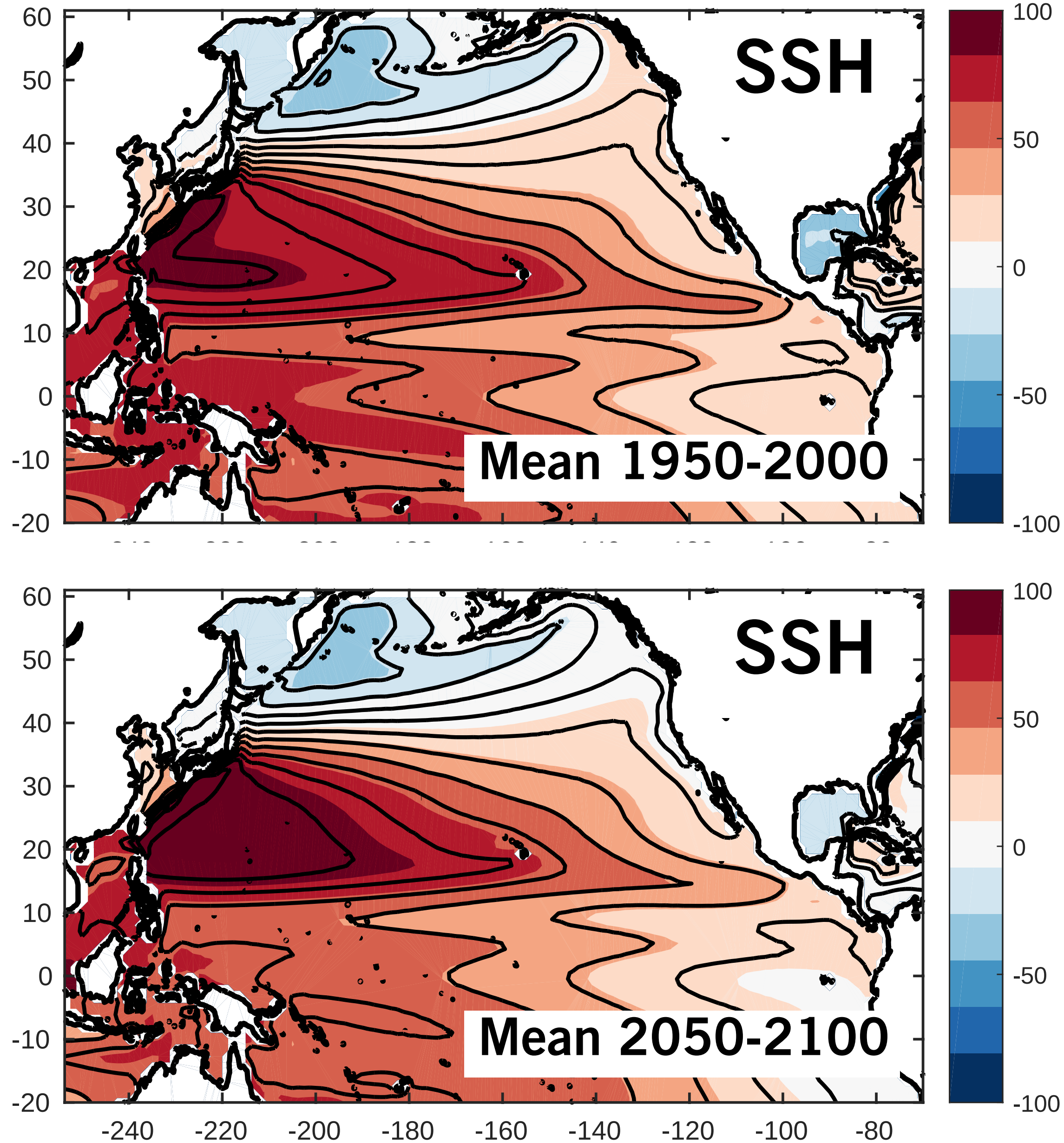
Large-Scale (> 300km)

Climate Model Projections

Community Earth System Model

CESM Large-Ensemble (n=30)

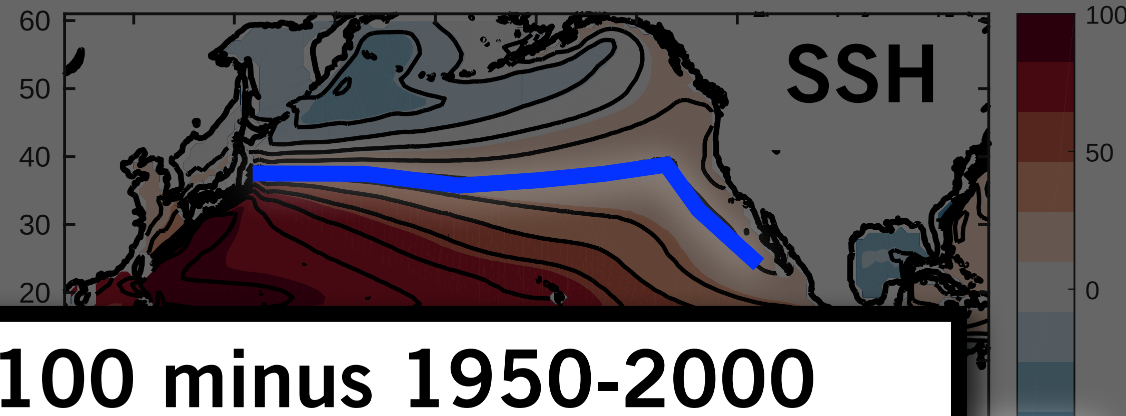
1920-2100 RCP8.5



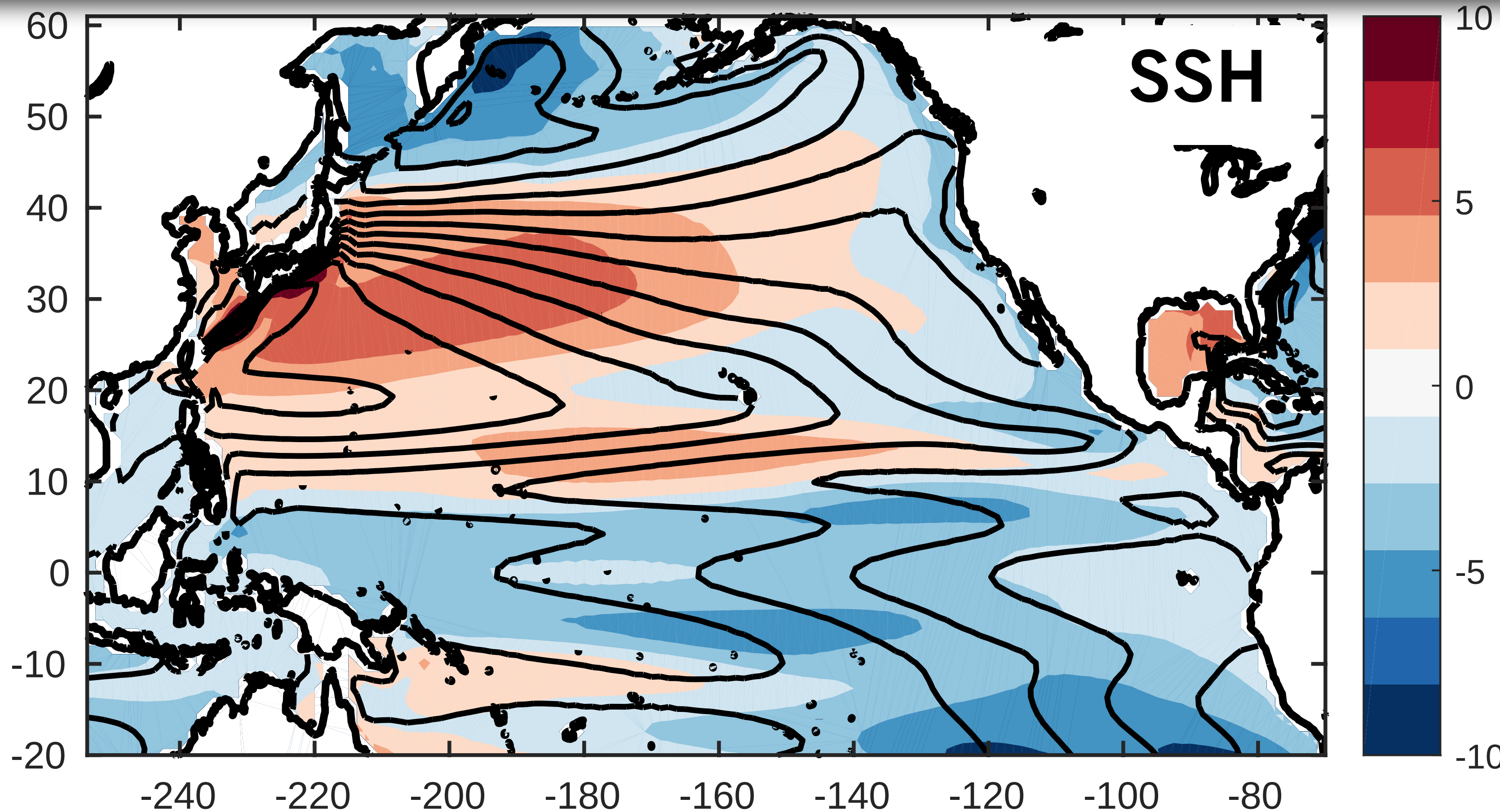
Community Earth System Model

CESM Large-Ensemble (n=30)

1920-2100 RCP8.5



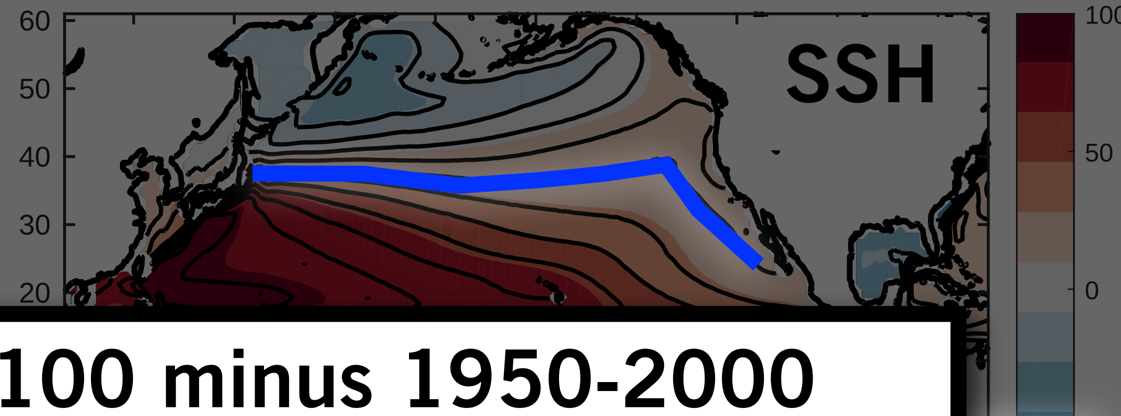
difference 2050-2100 minus 1950-2000



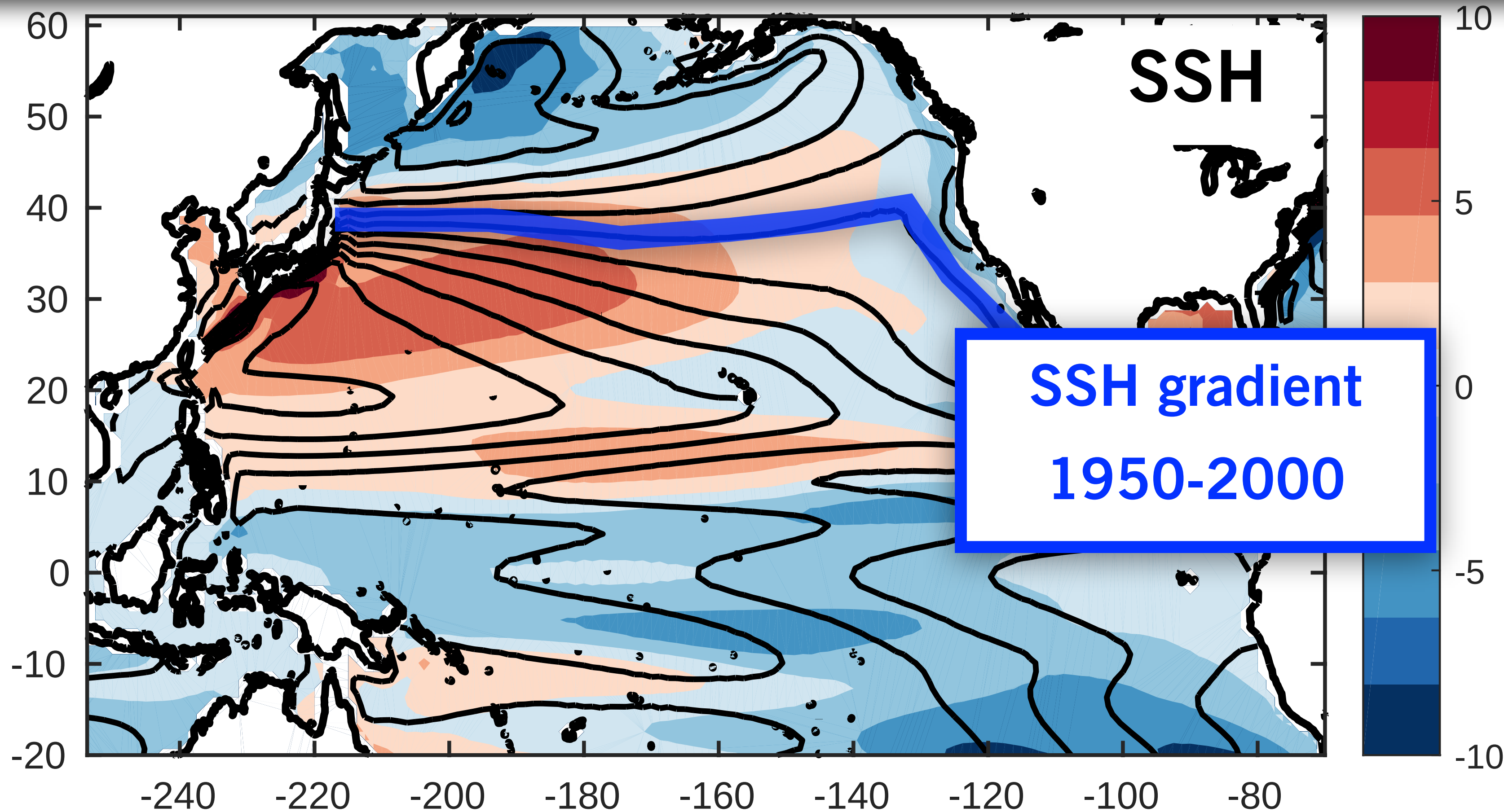
Community Earth System Model

CESM Large-Ensemble (n=30)

1920-2100 RCP8.5



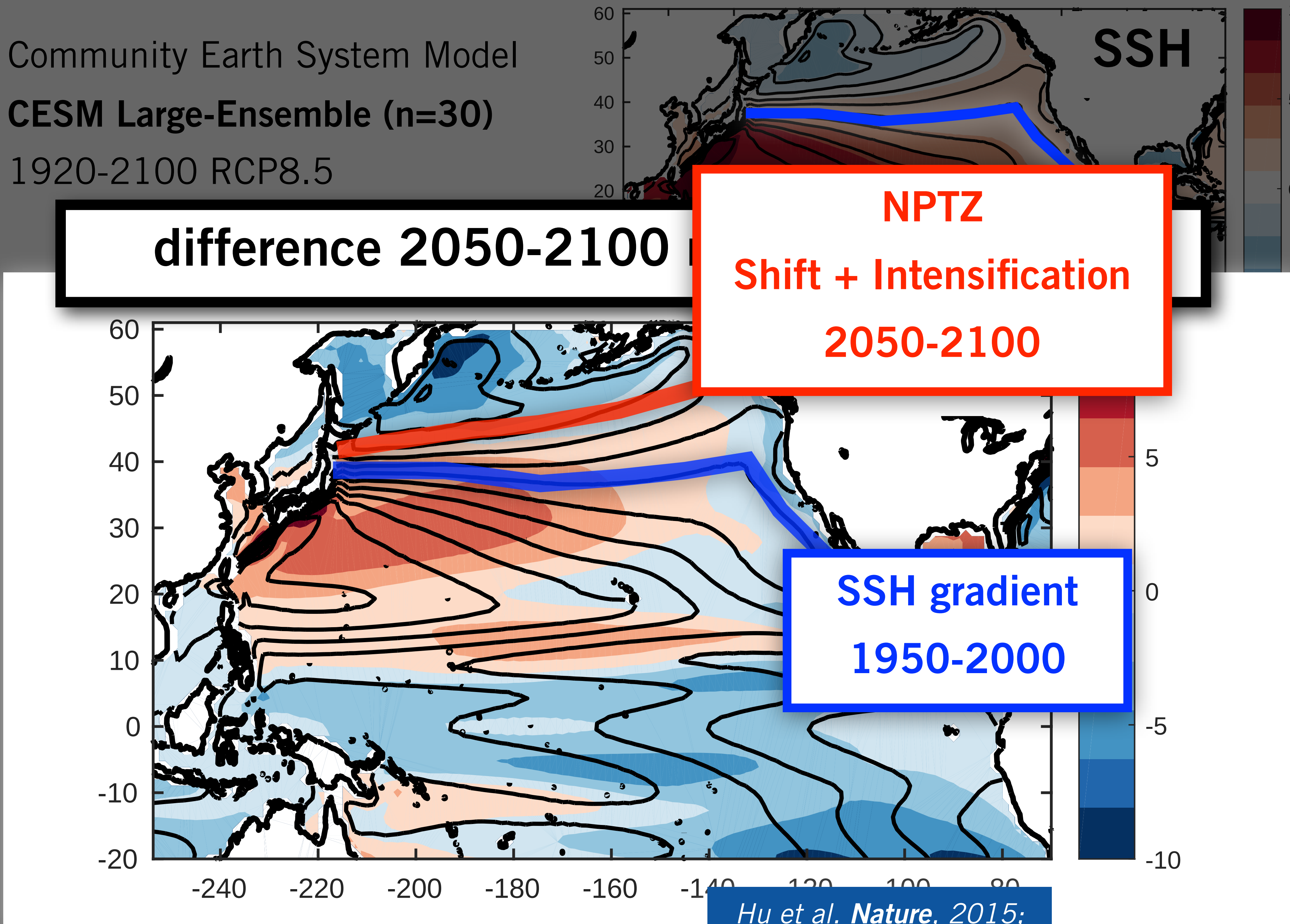
difference 2050-2100 minus 1950-2000



Community Earth System Model

CESM Large-Ensemble (n=30)

1920-2100 RCP8.5

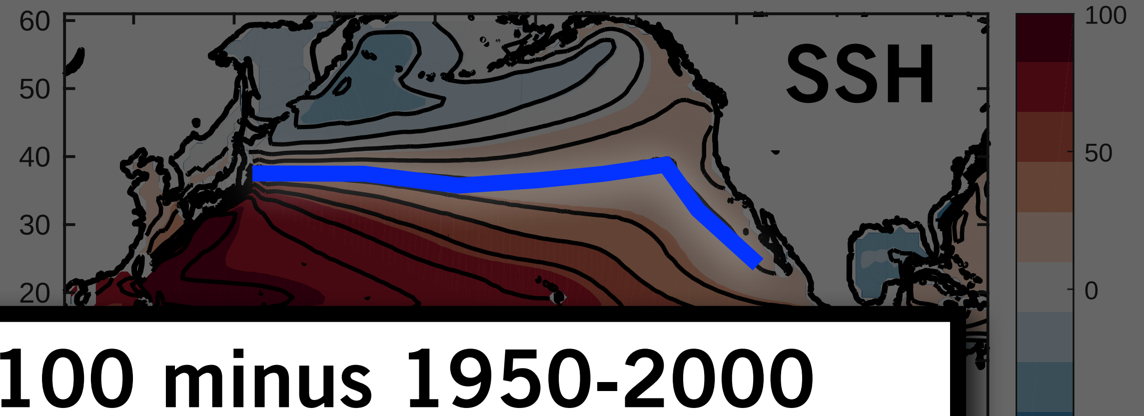


Hu et al. ***Nature****, 2015;*
Hu et al. ***JGR****, 2017*

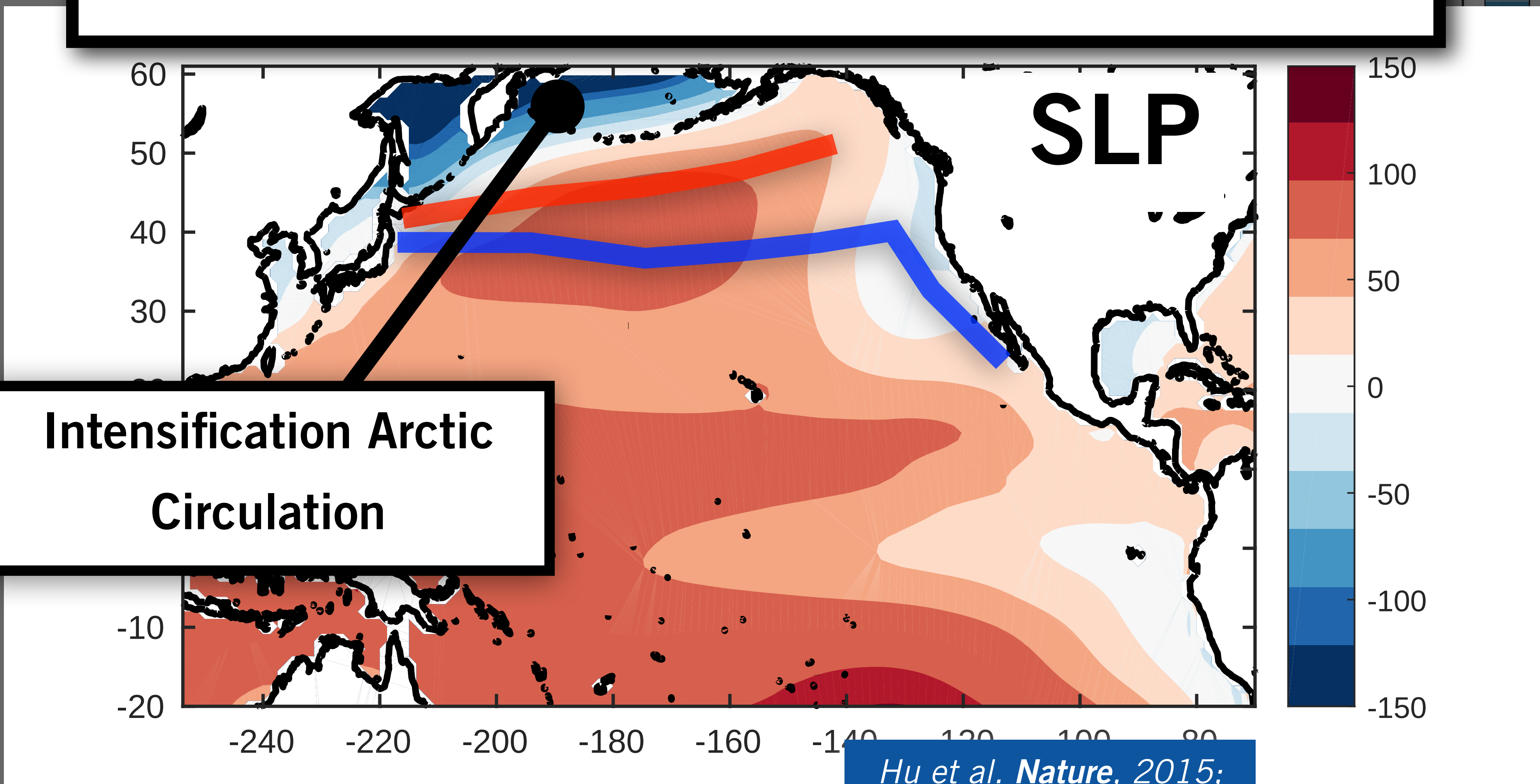
Community Earth System Model

CESM Large-Ensemble (n=30)

1920-2100 RCP8.5



difference 2050-2100 minus 1950-2000

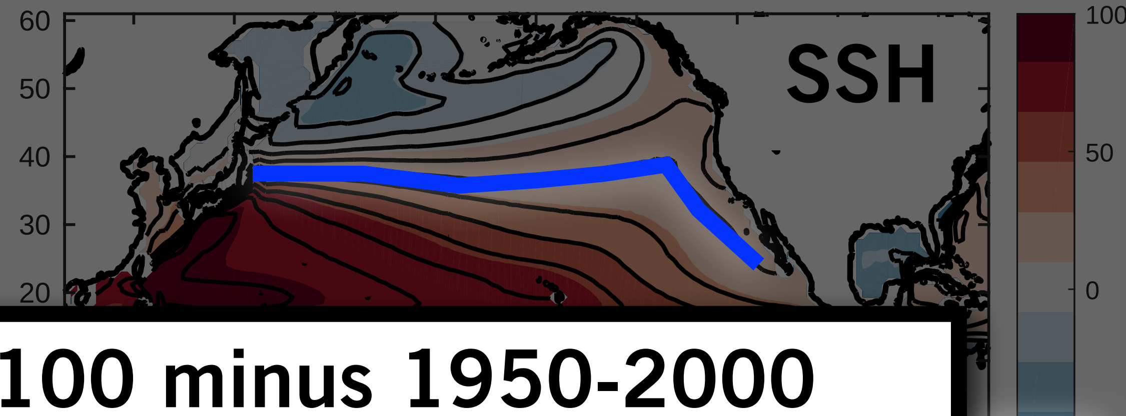


Hu et al. ***Nature****, 2015;*
Hu et al. ***JGR****, 2017*

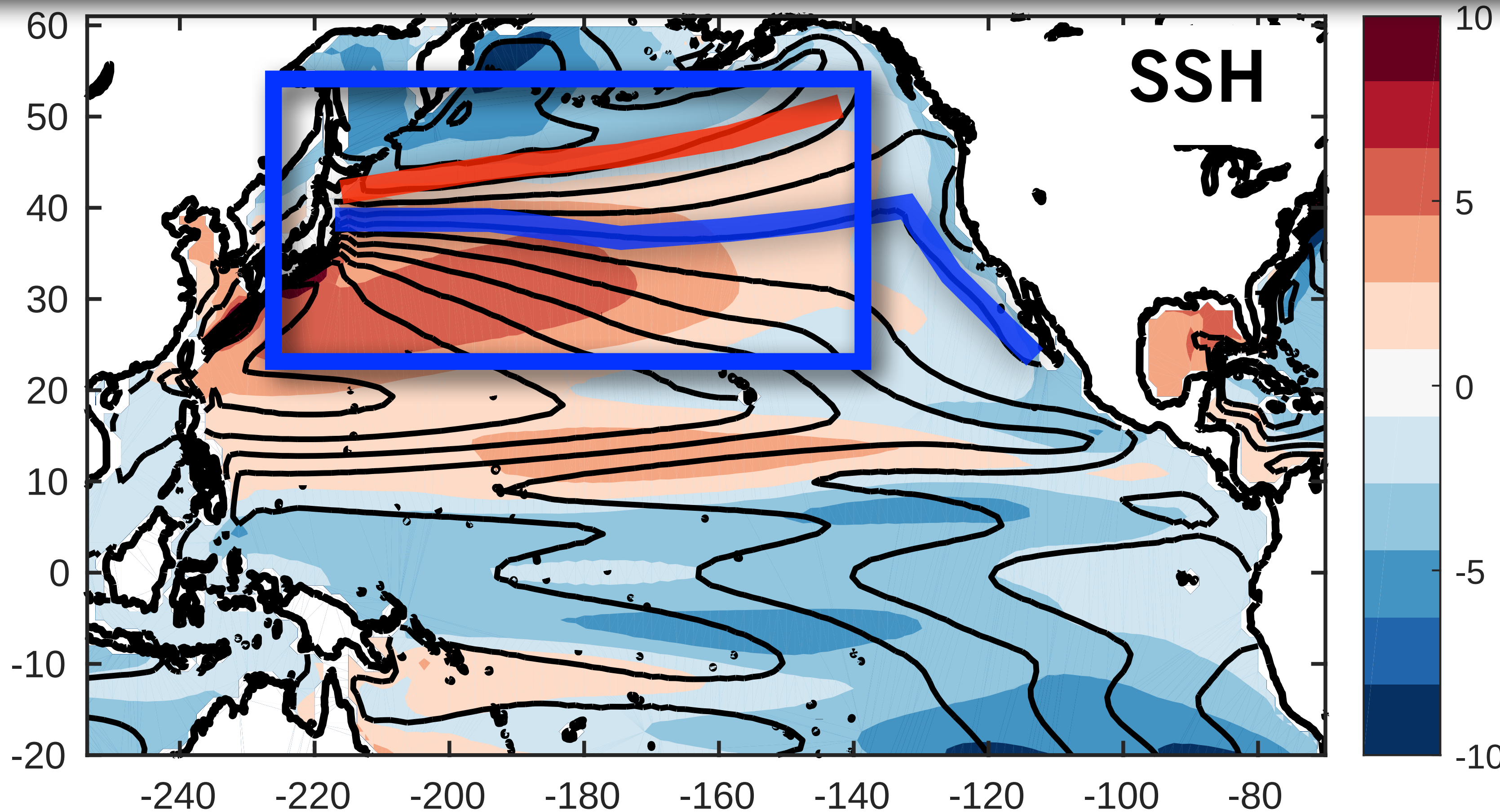
Community Earth System Model

CESM Large-Ensemble (n=30)

1920-2100 RCP8.5



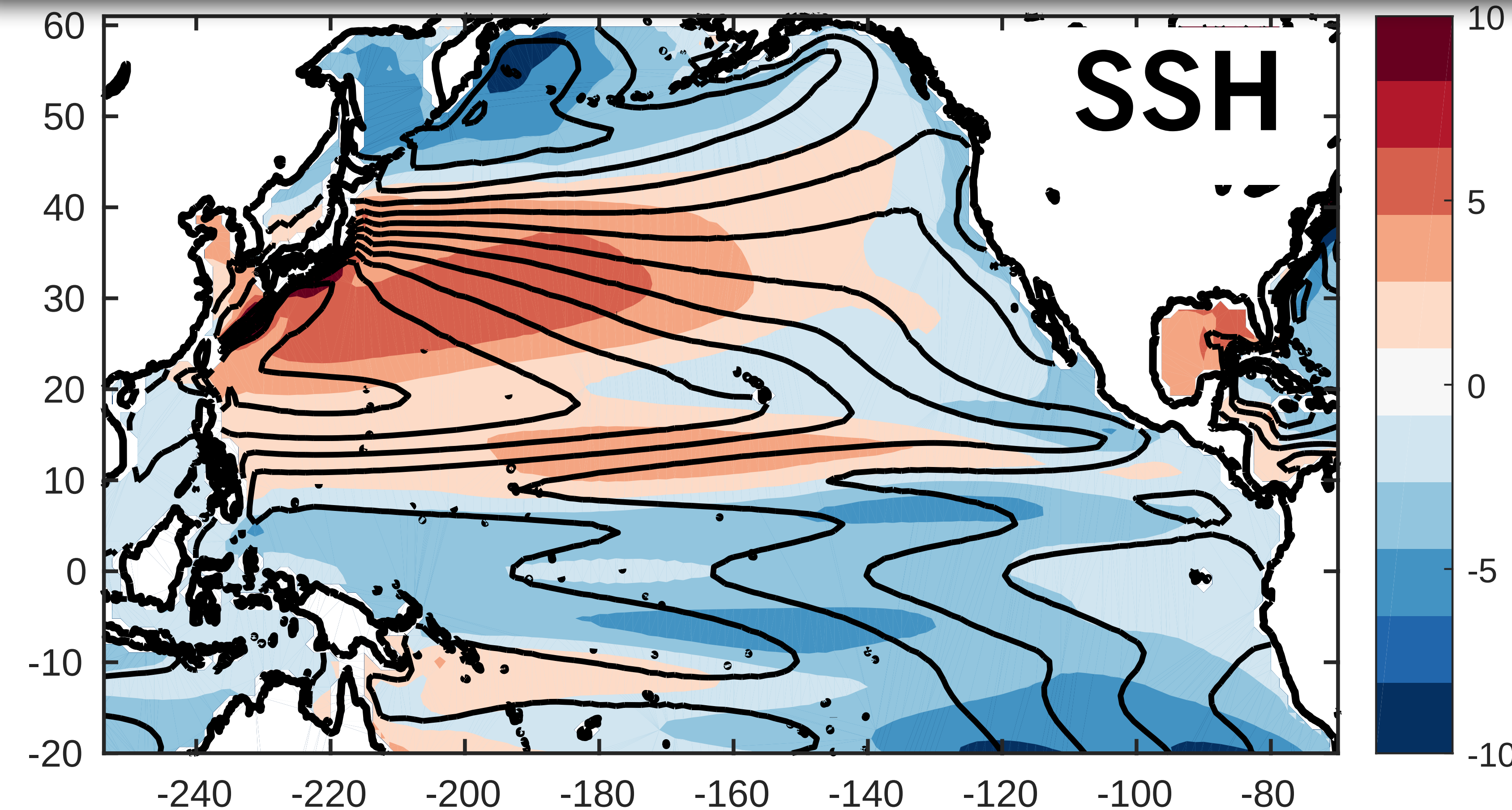
difference 2050-2100 minus 1950-2000



QUESTIONS

How about changes in **LARGE-SCALE** variance in KOE?

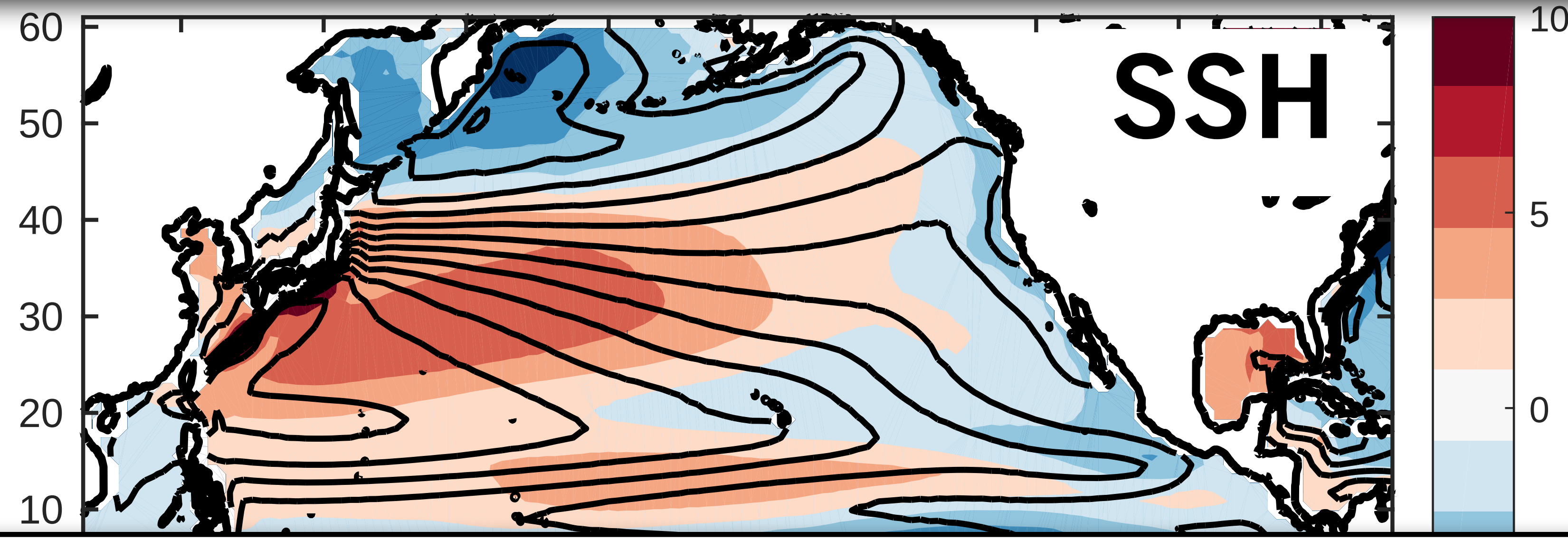
difference 2050-2100 minus 1950-2000



QUESTIONS

How about changes in **LARGE-SCALE** variance in KOE?

difference 2050-2100 minus 1950-2000



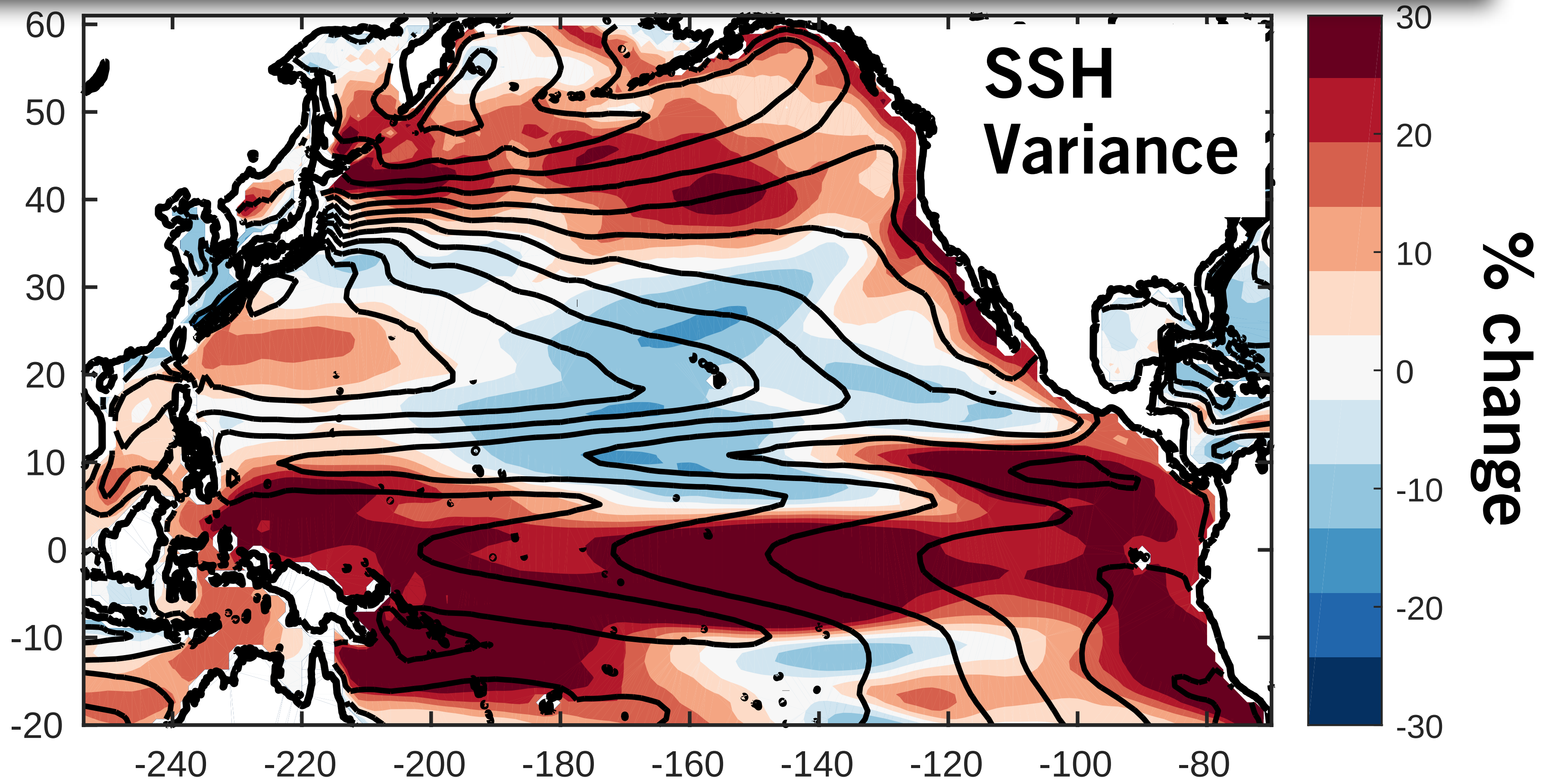
NOTE

We remove the anthropogenic signal first be removing the ensemble mean trajectory at each point.

QUESTIONS

How about changes in **LARGE-SCALE** variance in KOE?

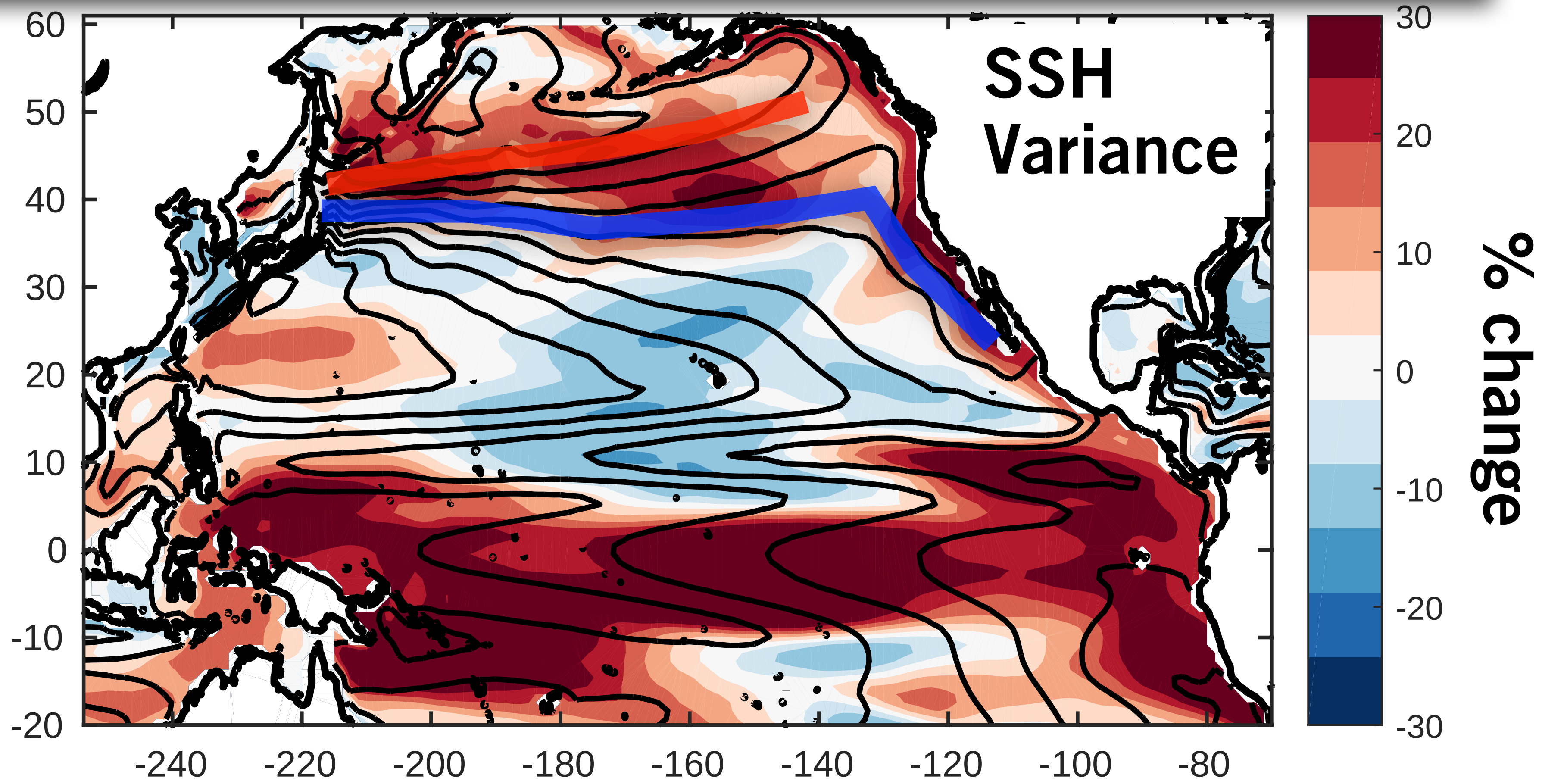
difference 2050-2100 minus 1950-2000



QUESTIONS

How about changes in **LARGE-SCALE** variance in KOE?

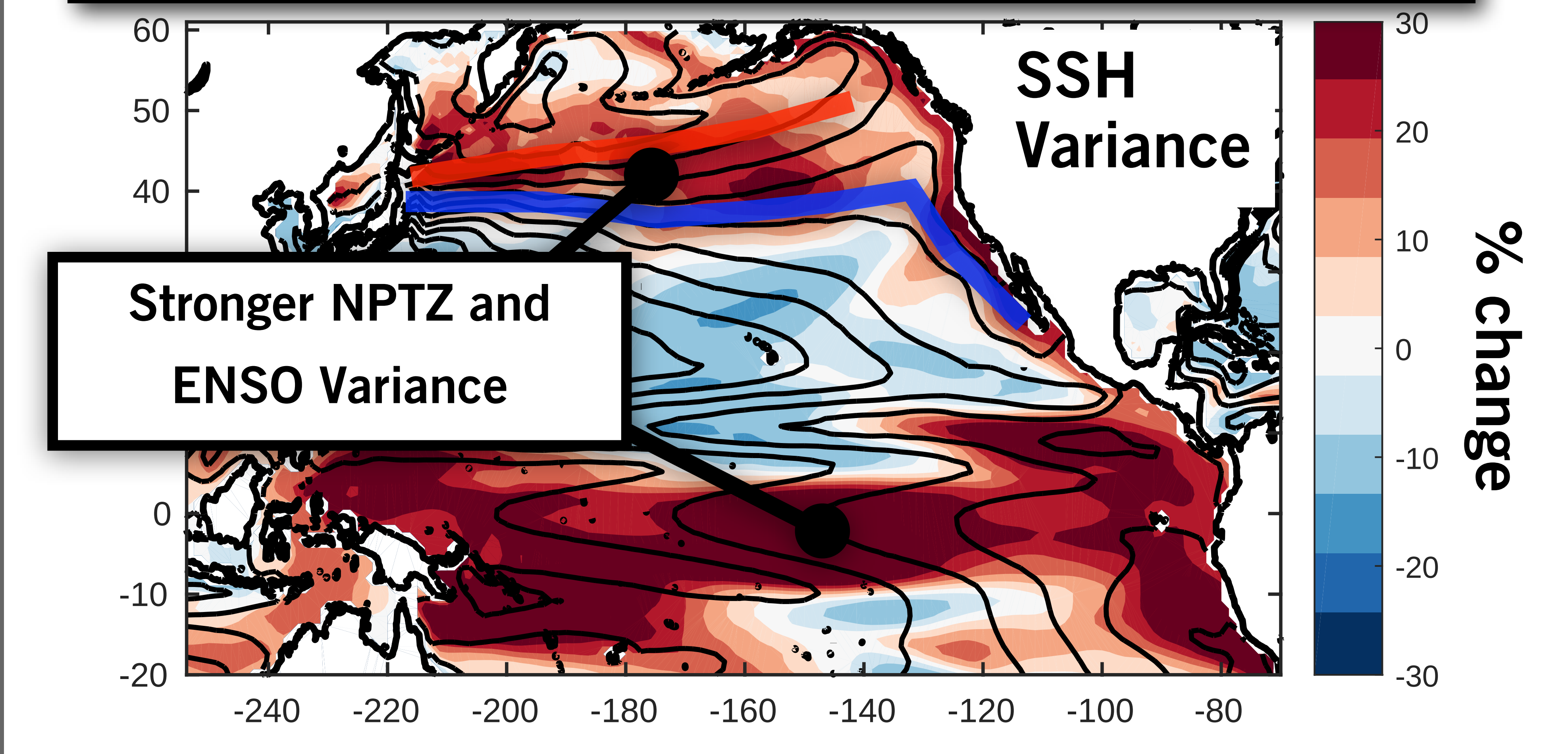
difference 2050-2100 minus 1950-2000



QUESTIONS

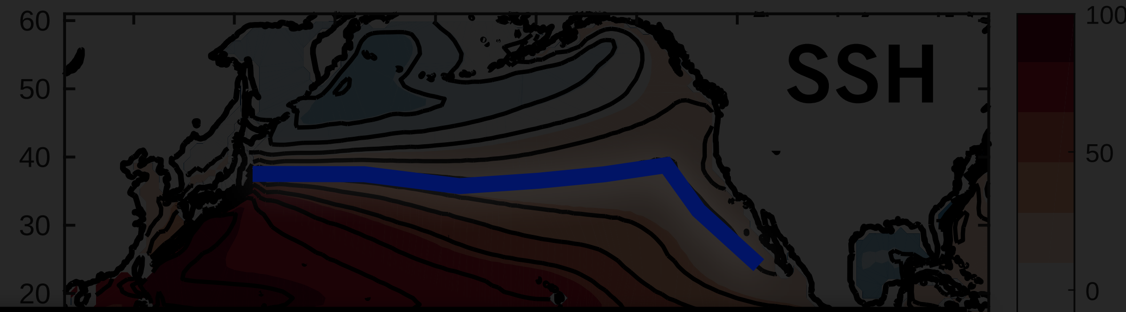
How about changes in **LARGE-SCALE** variance in KOE?

difference 2050-2100 minus 1950-2000

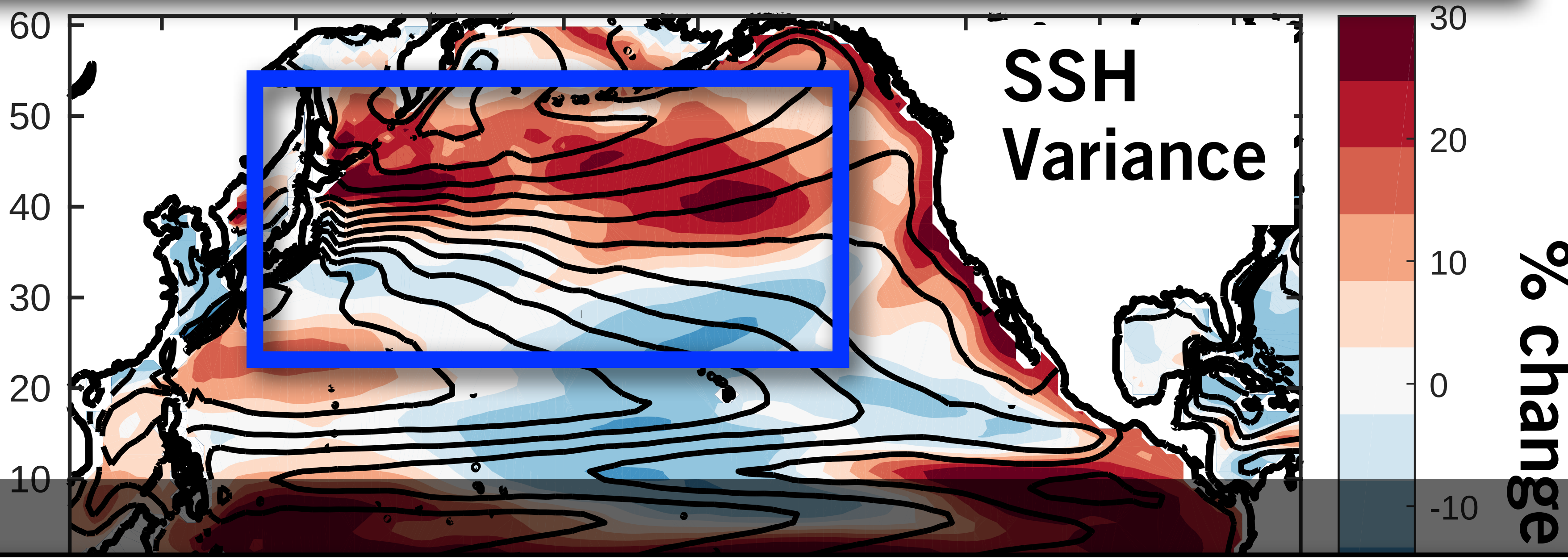


LARGE-SCALE (> 300KM)

1920-2100 RCP8.5



difference 2050-2100 minus 1950-2000

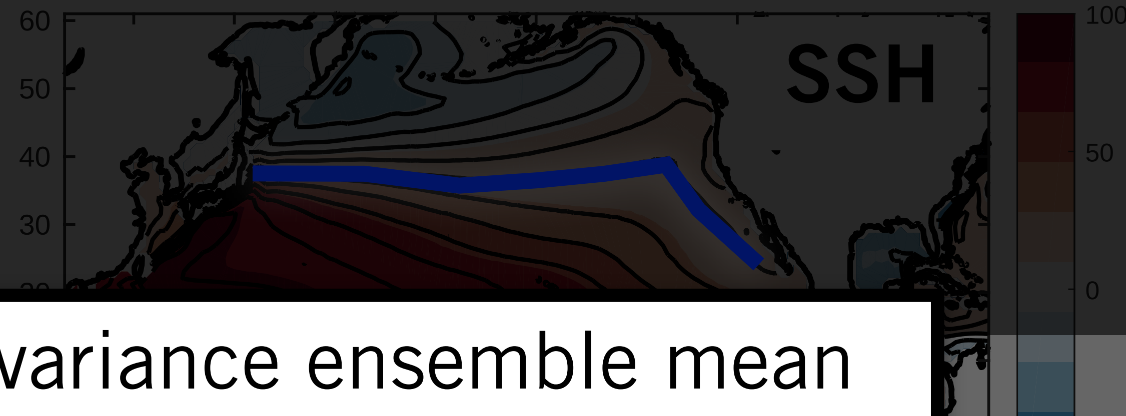


APPROACH

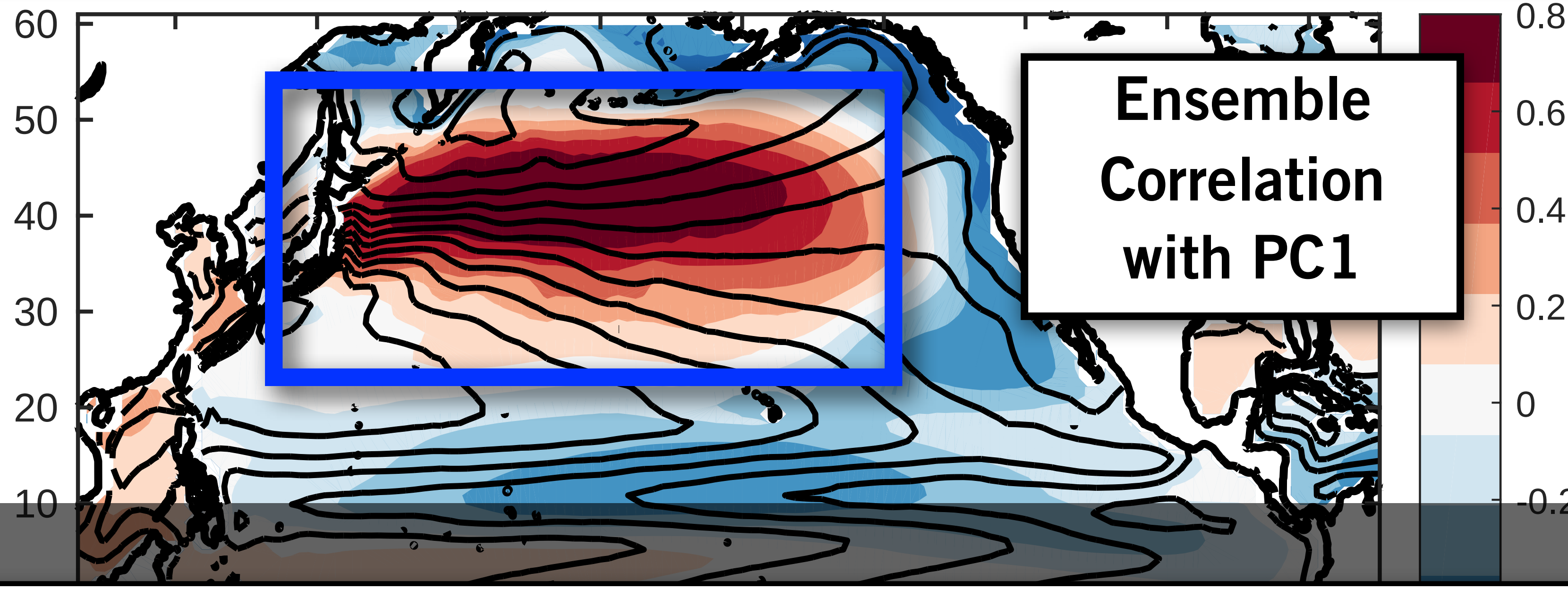
Decompose the KOE variance using EOFs/PCA analysis

Large-Scale (> 300km)

1920-2100 RCP8.5

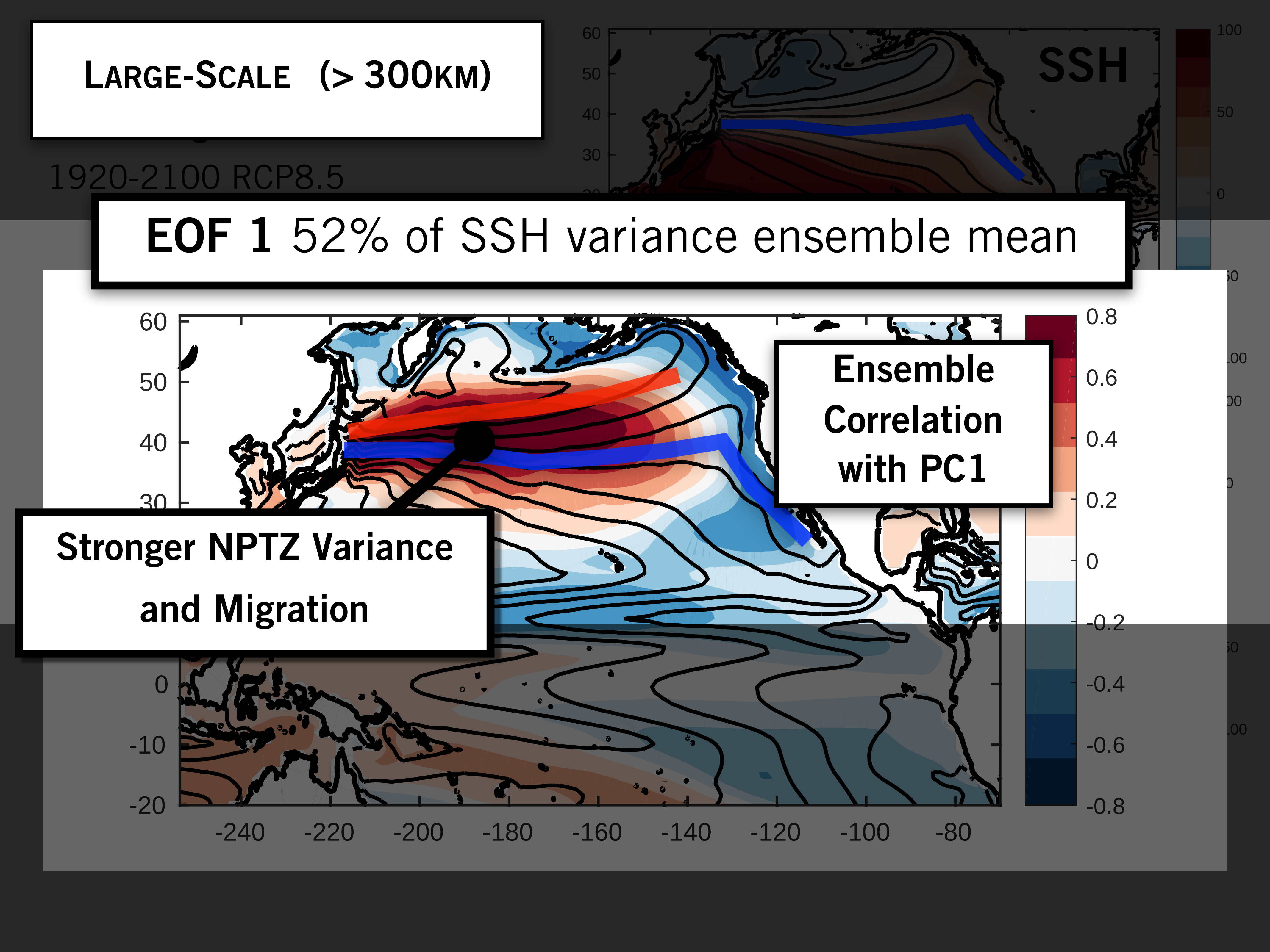


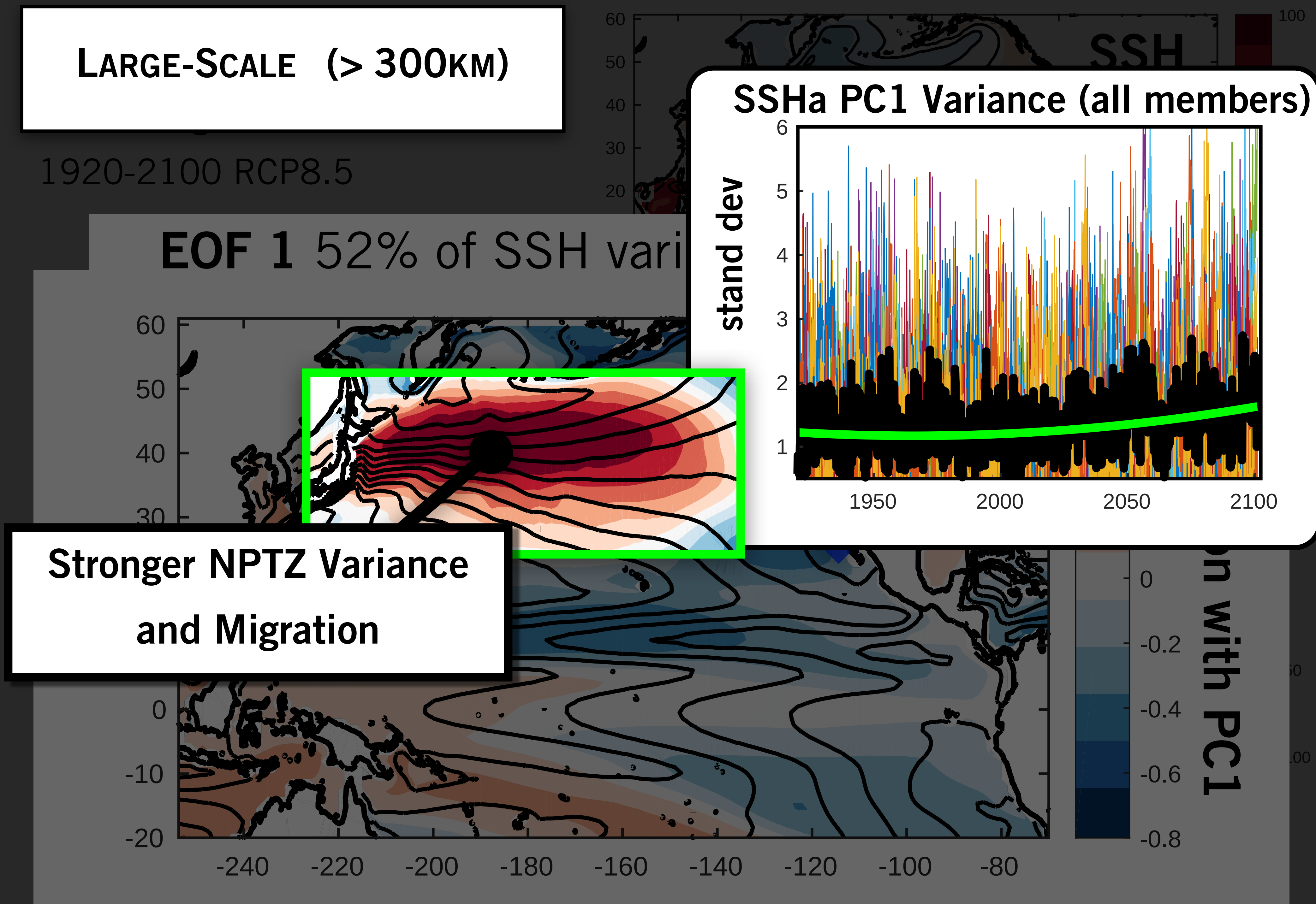
EOF 1 52% of SSH variance ensemble mean



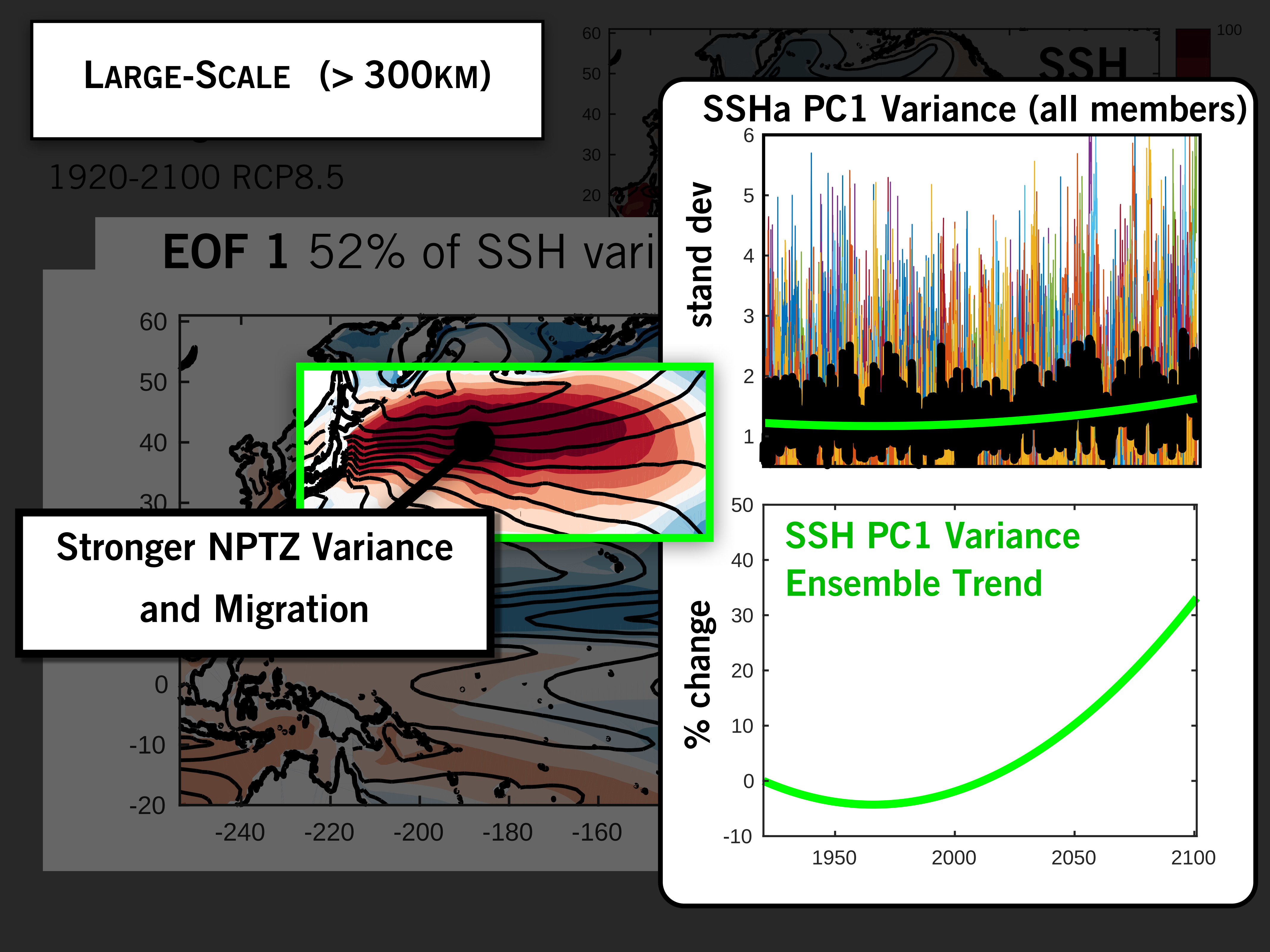
APPROACH

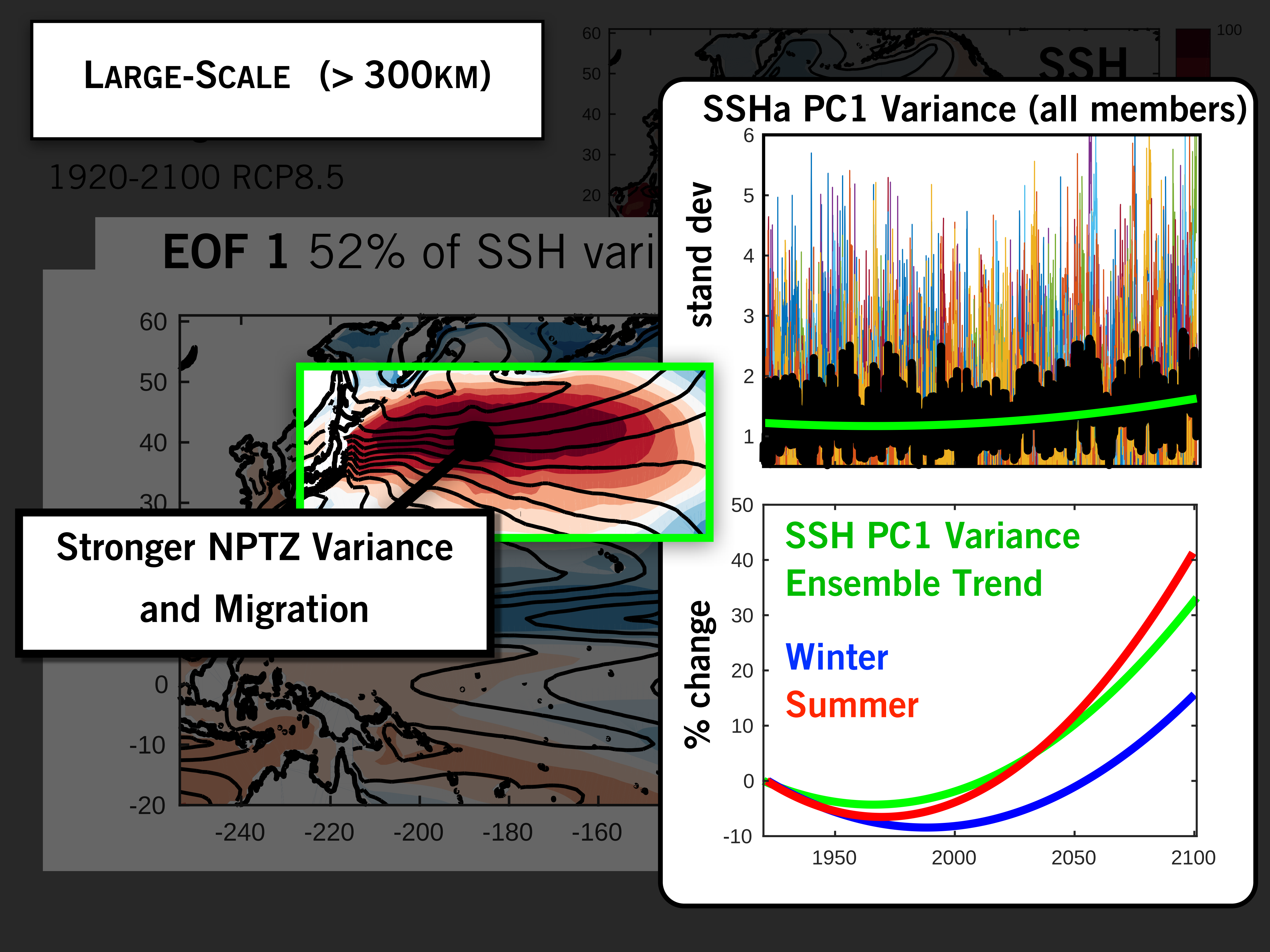
Decompose the KOE variance using EOFs/PCA analysis


LARGE-SCALE (> 300KM)
1920-2100 RCP8.5
SSH
EOF 1 52% of SSH variance ensemble mean
Ensemble Correlation with PC1
Stronger NPTZ Variance and Migration
60
50
40
30
0
-10
-20
-240
-220
-200
-180
-160
-140
-120
-100
-80
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8



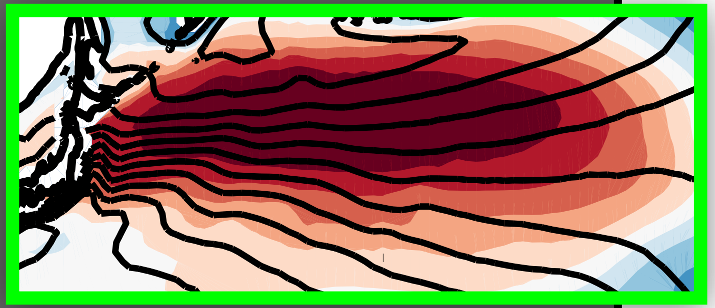
LARGE-SCALE (> 300KM)
1920-2100 RCP8.5
EOF 1 52% of SSH vari
SSH
SSHa PC1 Variance (all members)
stand dev
1950
2000
2050
2100
Stronger NPTZ Variance
and Migration
with PC1


LARGE-SCALE (> 300KM)
1920-2100 RCP8.5
EOF 1 52% of SSH vari
SSH
100
60
50
40
30
20
0
-10
-20
-240
-220
-200
-180
-160
Stronger NPTZ Variance
and Migration
SSHa PC1 Variance (all members)
stand dev
6
5
4
3
2
1
SSH PC1 Variance
Ensemble Trend
% change
50
40
30
20
10
0
-10
1950
2000
2050
2100



LARGE-SCALE (> 300KM)
1920-2100 RCP8.5
EOF 1 52% of SSH vari
SSH
Stronger NPTZ Variance
and Migration
SSHa PC1 Variance (all members)
stand dev
% change
SSH PC1 Variance
Ensemble Trend
Winter
Summer
60
50
40
30
0
-10
-20
-240
-220
-200
-180
-160
1950
2000
2050
2100

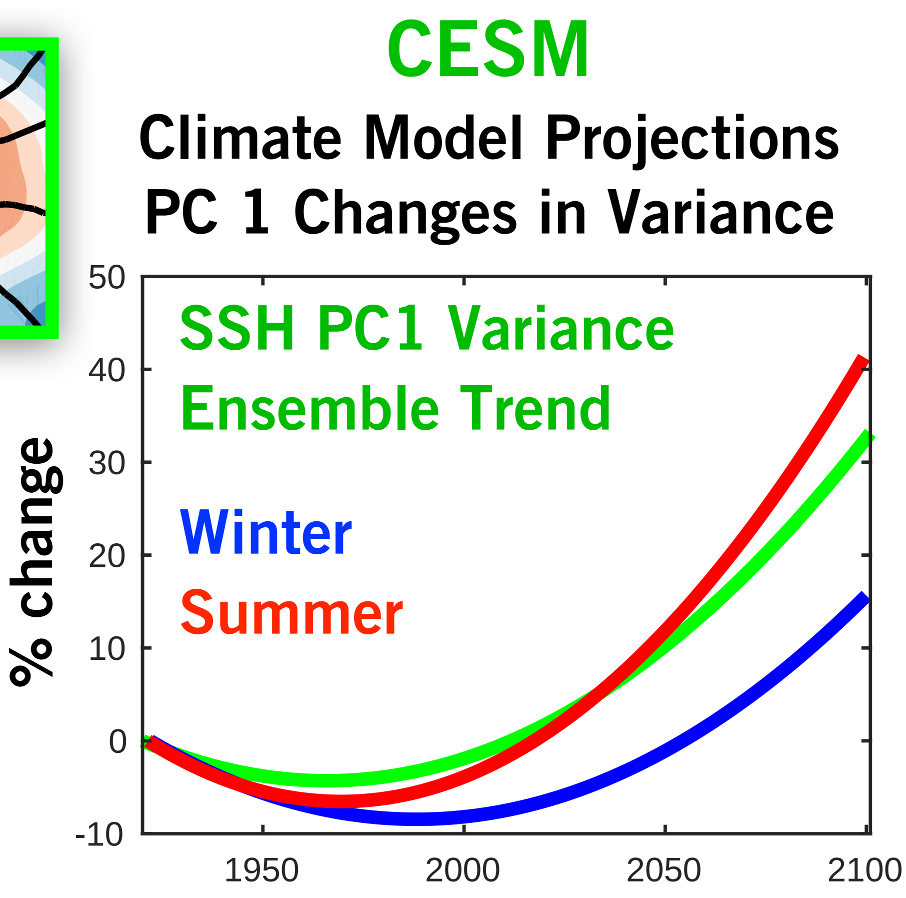
LARGE-SCALE (> 300KM)

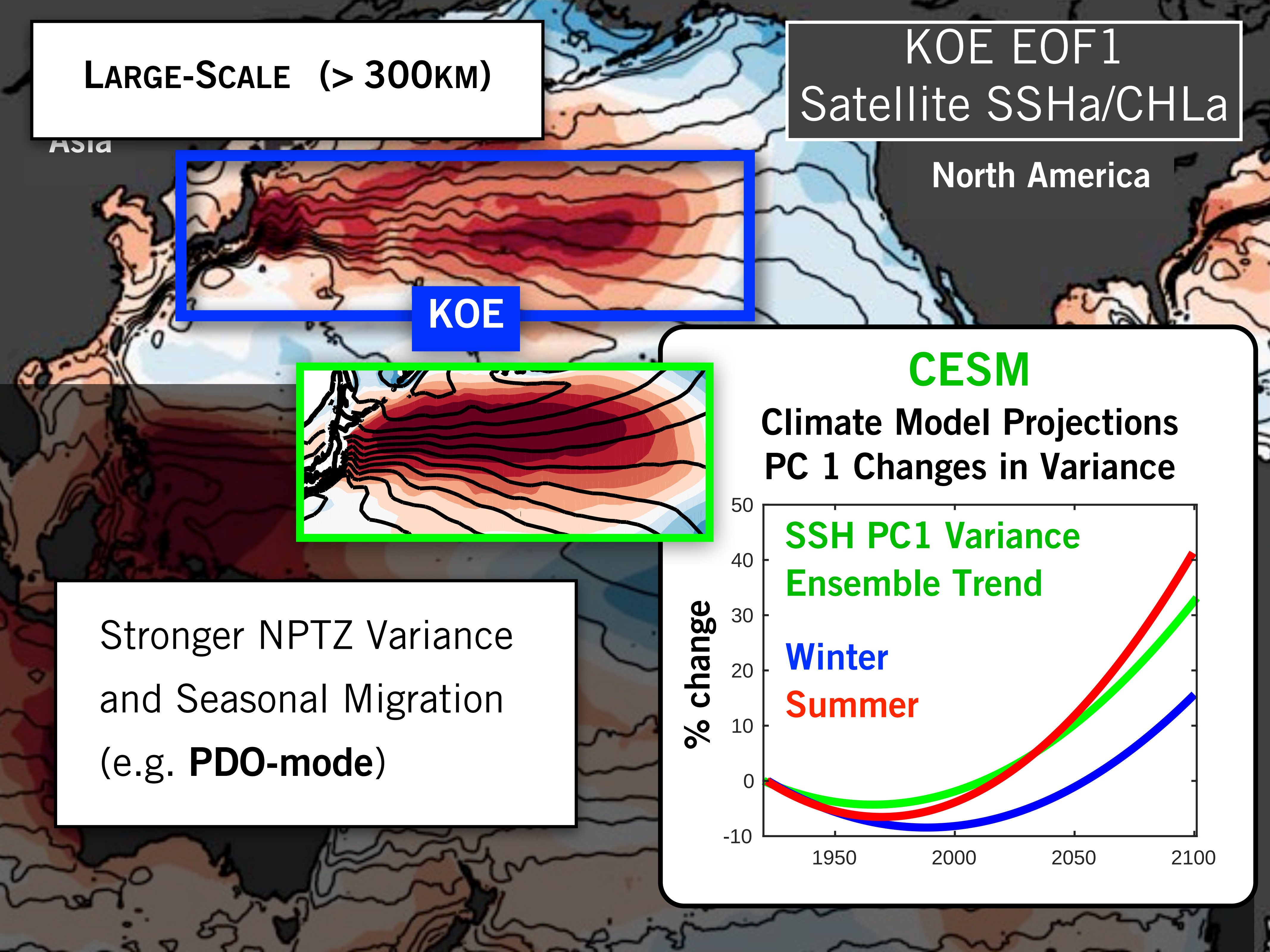


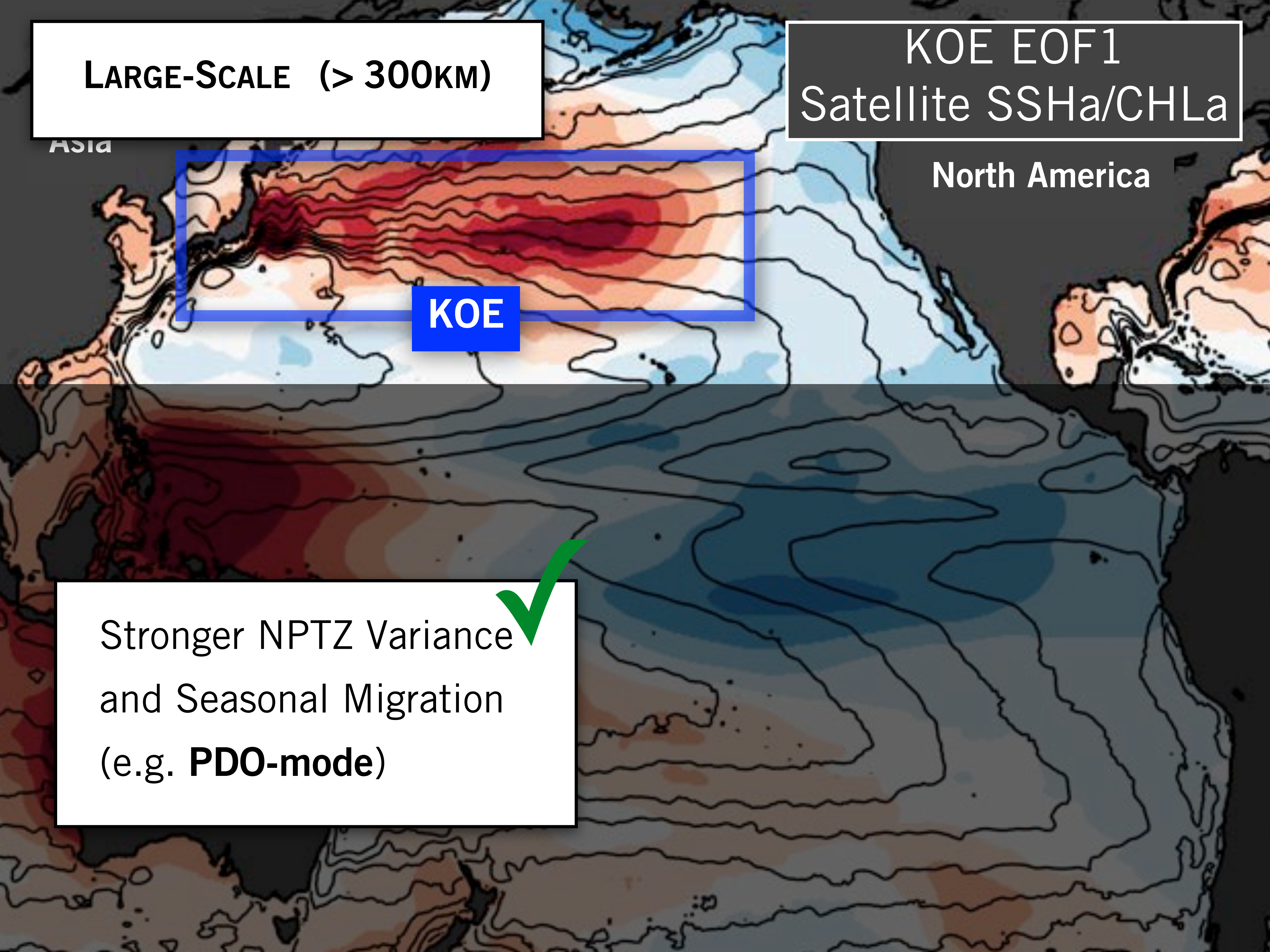
Stronger NPTZ Variance

and Seasonal Migration

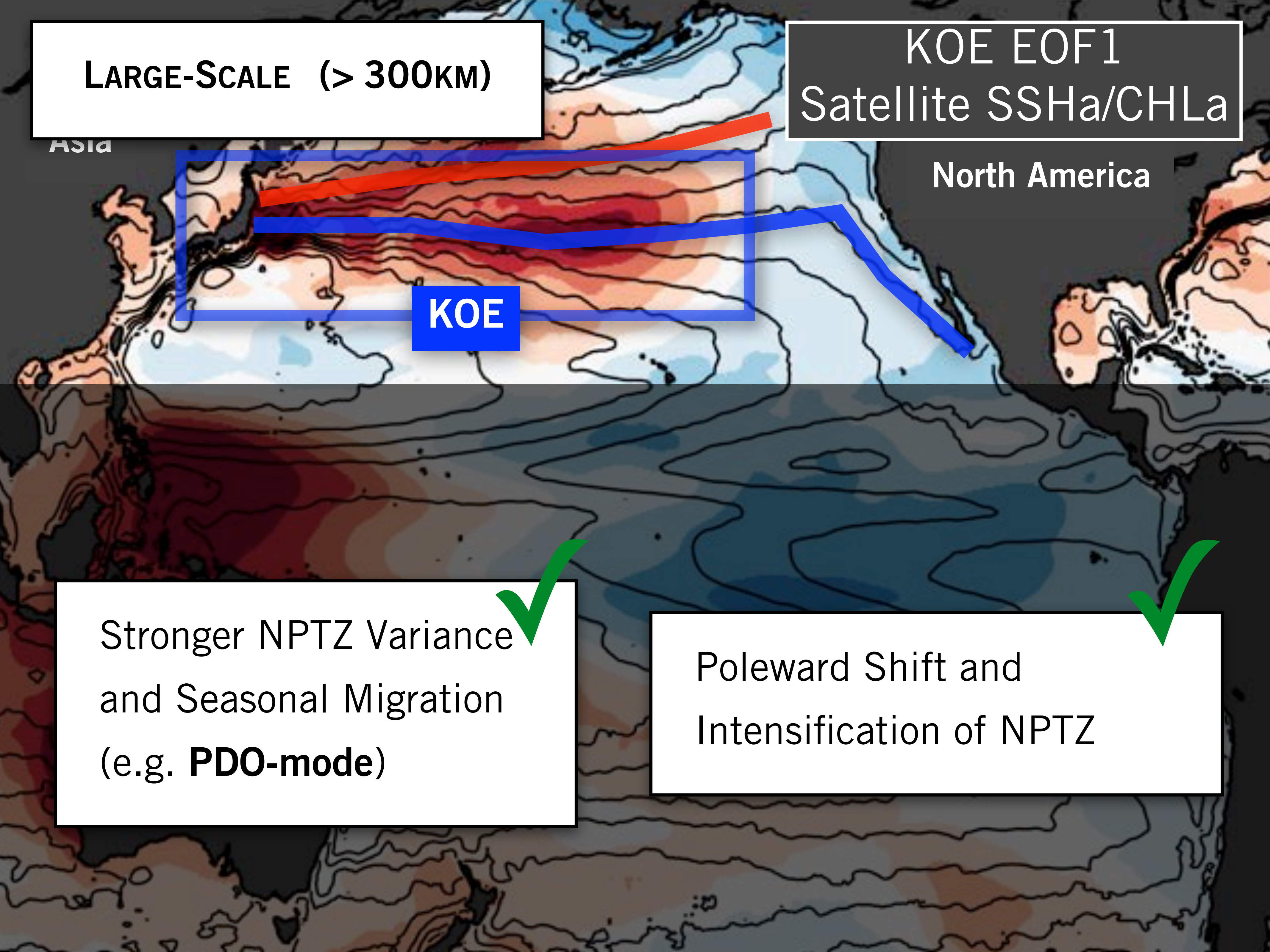
(e.g. **PDO-mode**)



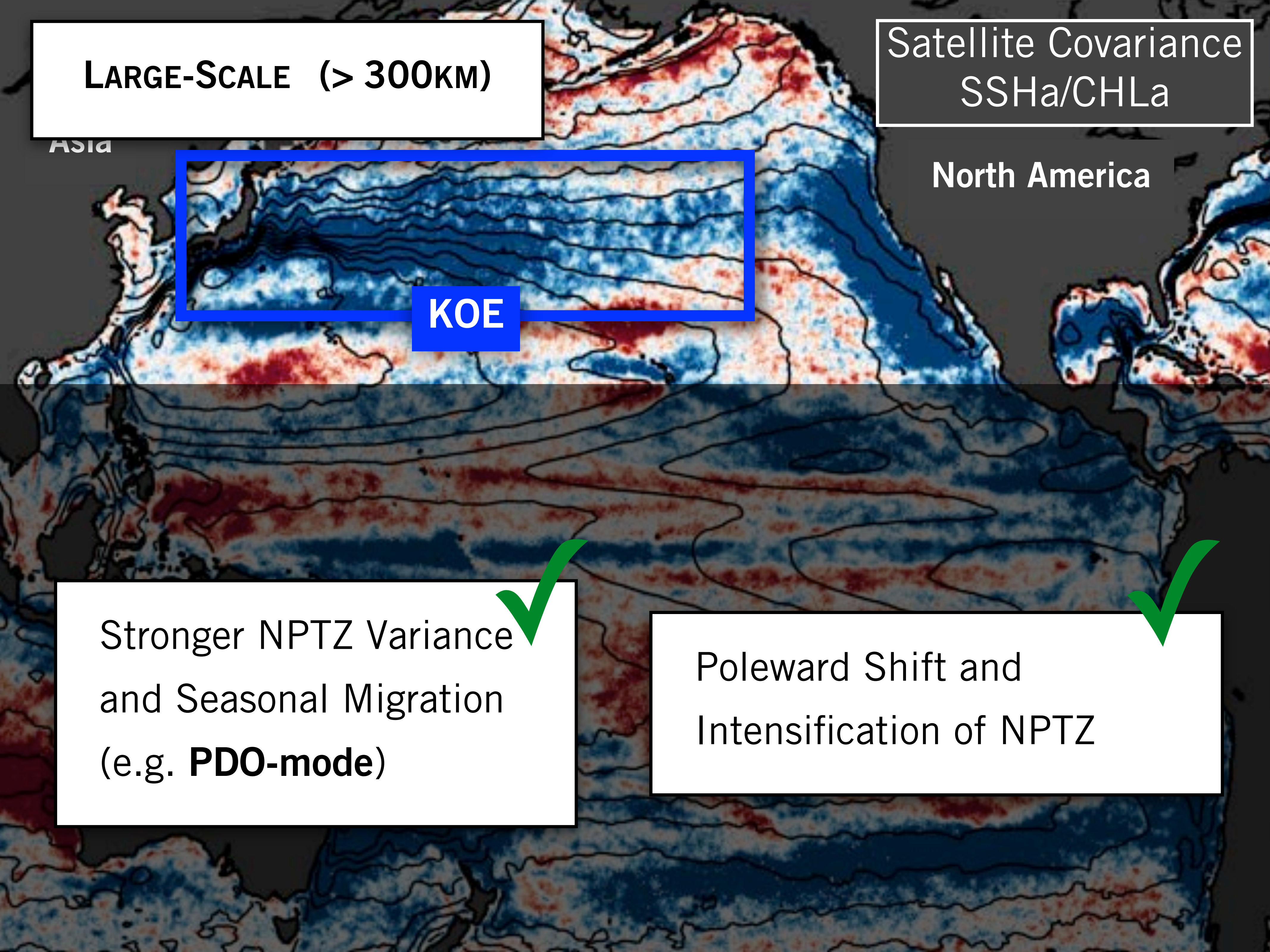

LARGE-SCALE (> 300KM)
Asia
KOE EOF1
Satellite SSHa/CHLa
North America
KOE
CESM
Climate Model Projections
PC 1 Changes in Variance
SSH PC1 Variance
Ensemble Trend
Winter
Summer
% change
50
40
30
20
10
0
-10
1950
2000
2050
2100
Stronger NPTZ Variance
and Seasonal Migration
(e.g. PDO-mode)



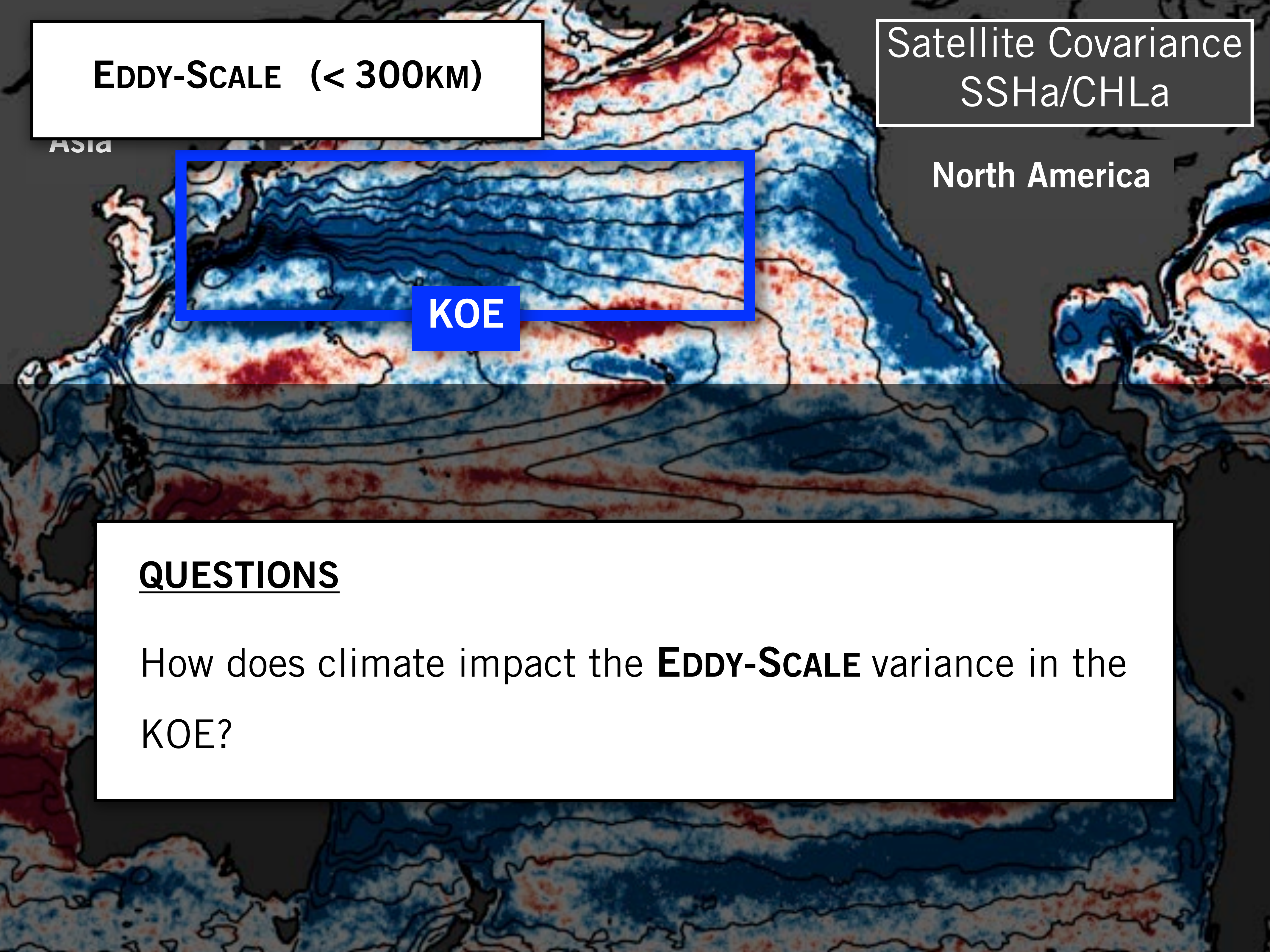
Large-Scale (> 300km)
KOE EOF1
Satellite SSHa/CHLa
Asia
North America
KOE
Stronger NPTZ Variance
and Seasonal Migration
(e.g. **PDO-mode**)



Large-Scale (> 300km)
KOE EOF1
Satellite SSHa/CHLa
North America
KOE
Stronger NPTZ Variance and Seasonal Migration (e.g. **PDO-mode**)
Poleward Shift and Intensification of NPTZ

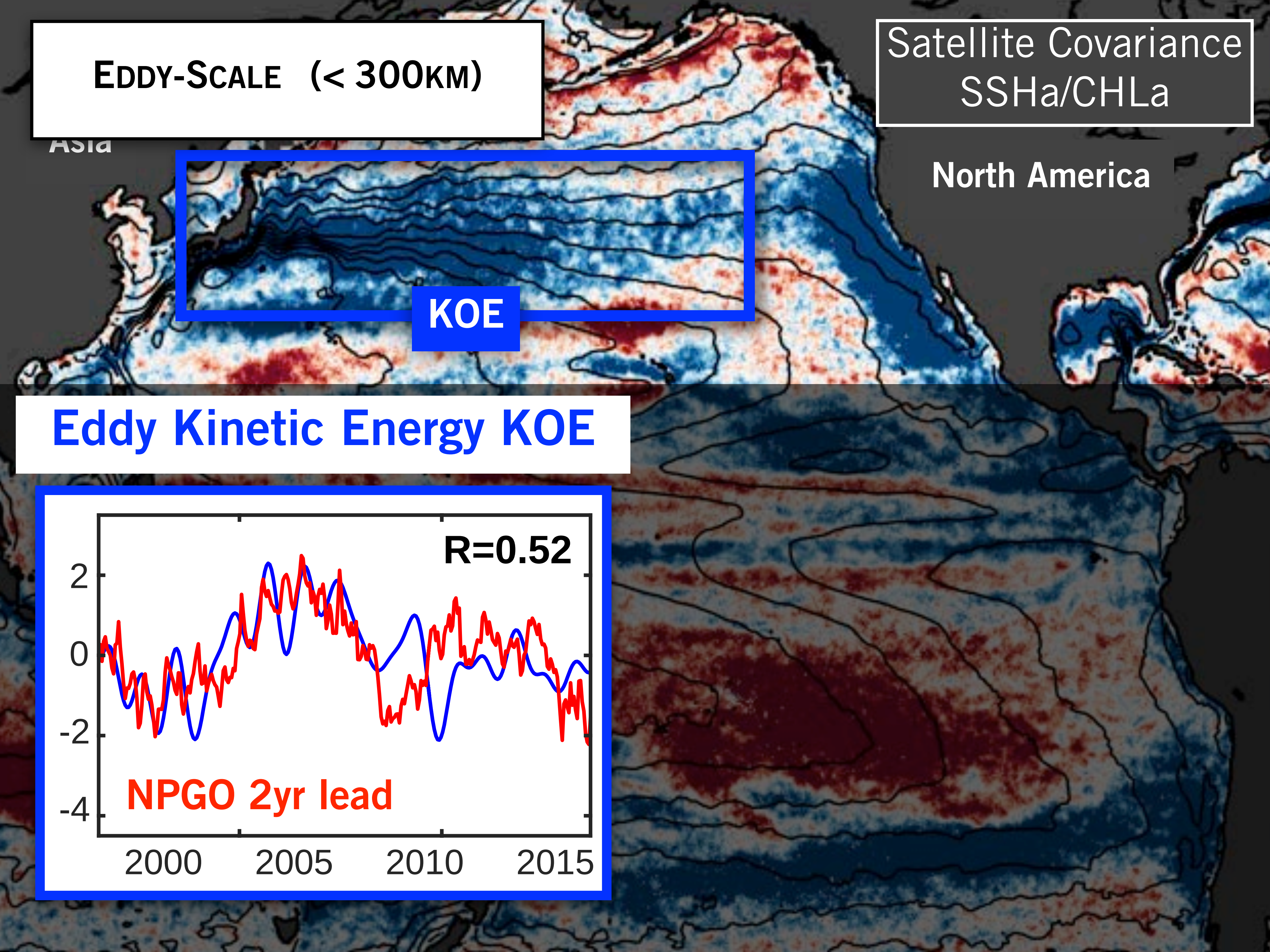

LARGE-SCALE (> 300KM)
Satellite Covariance
SSHa/CHLa
Asia
North America
KOE
Stronger NPTZ Variance and Seasonal Migration (e.g. **PDO-mode**)
Poleward Shift and Intensification of NPTZ

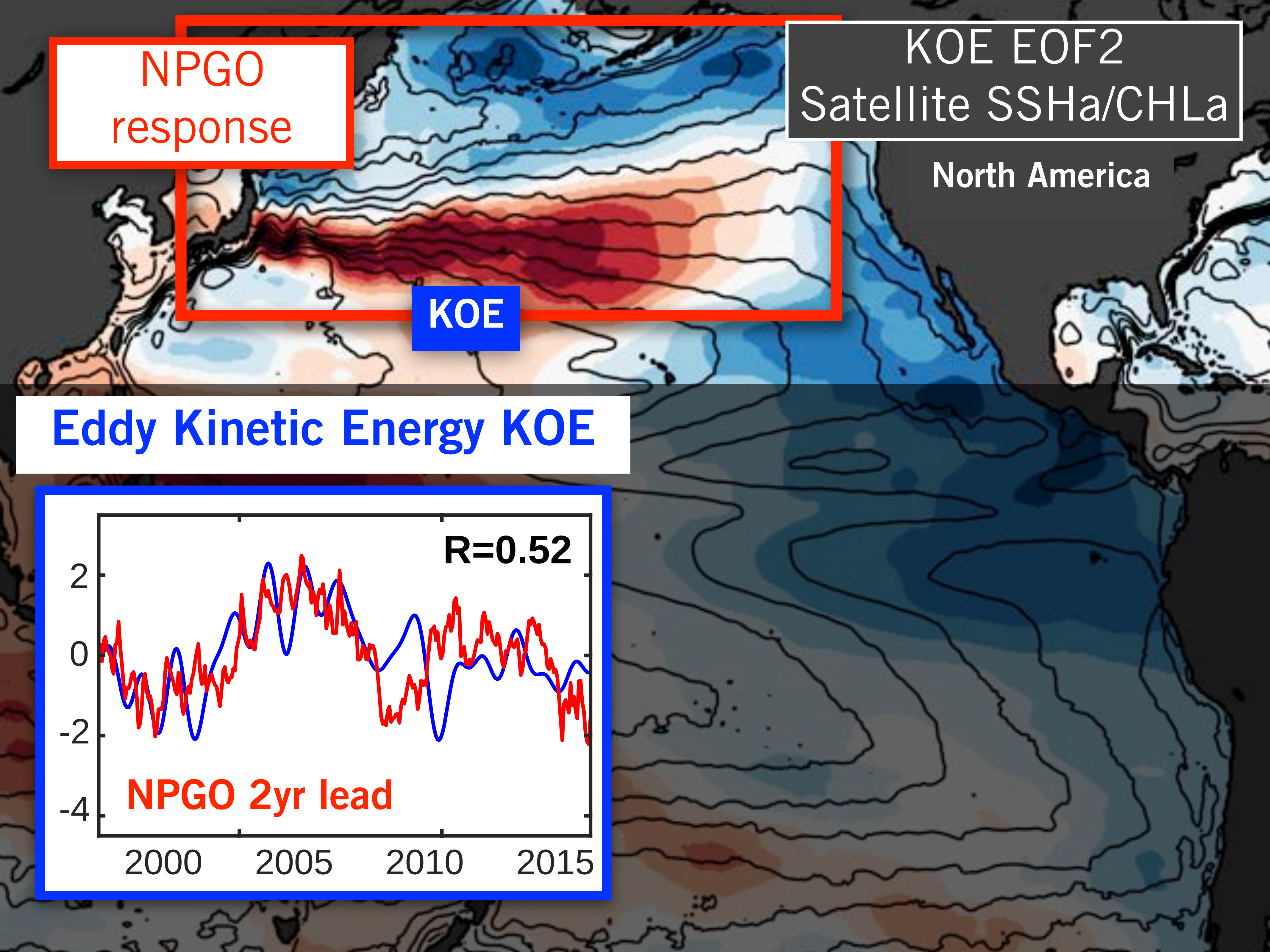
EDDY-SCALE (< 300KM)



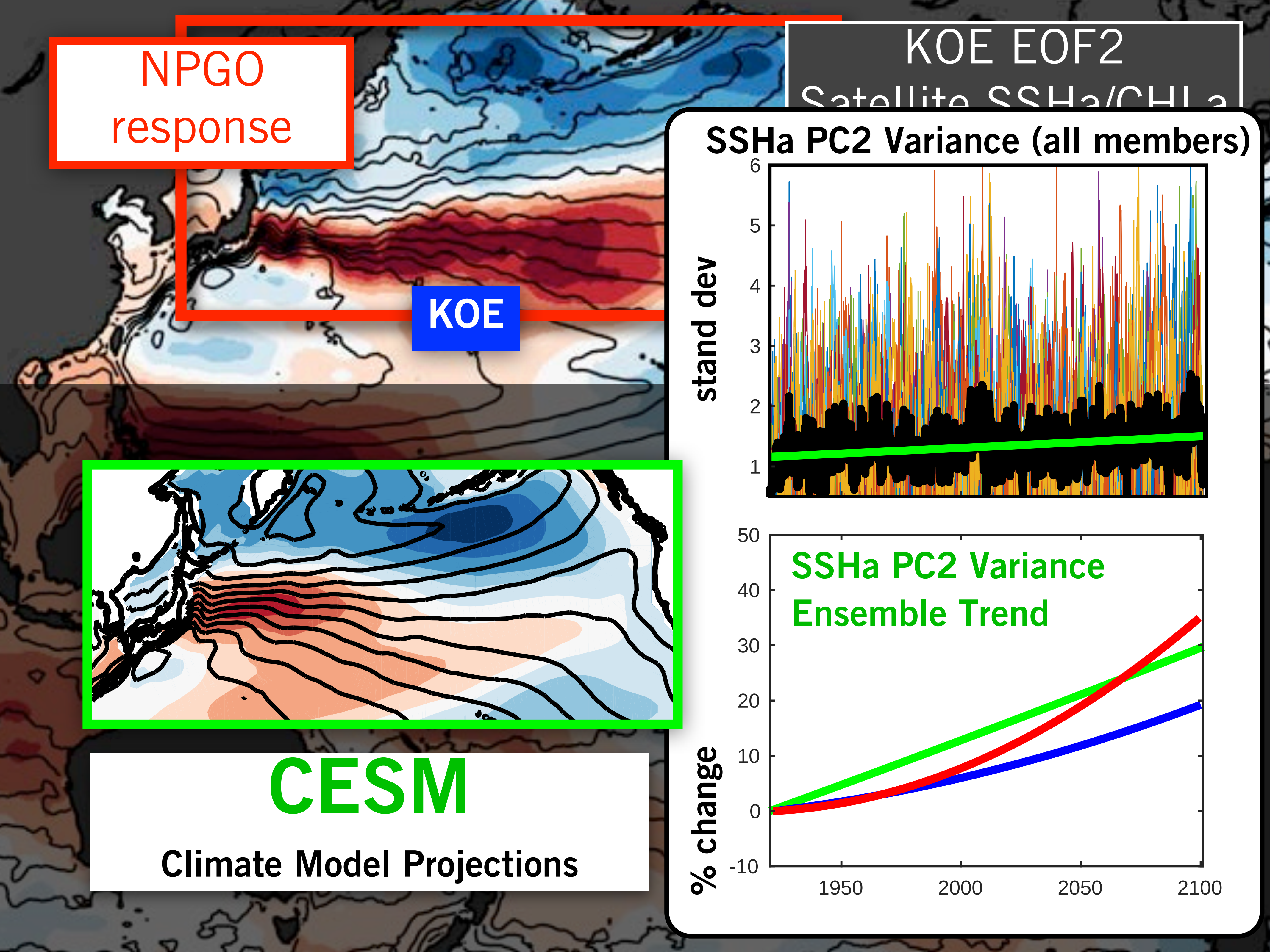
QUESTIONS

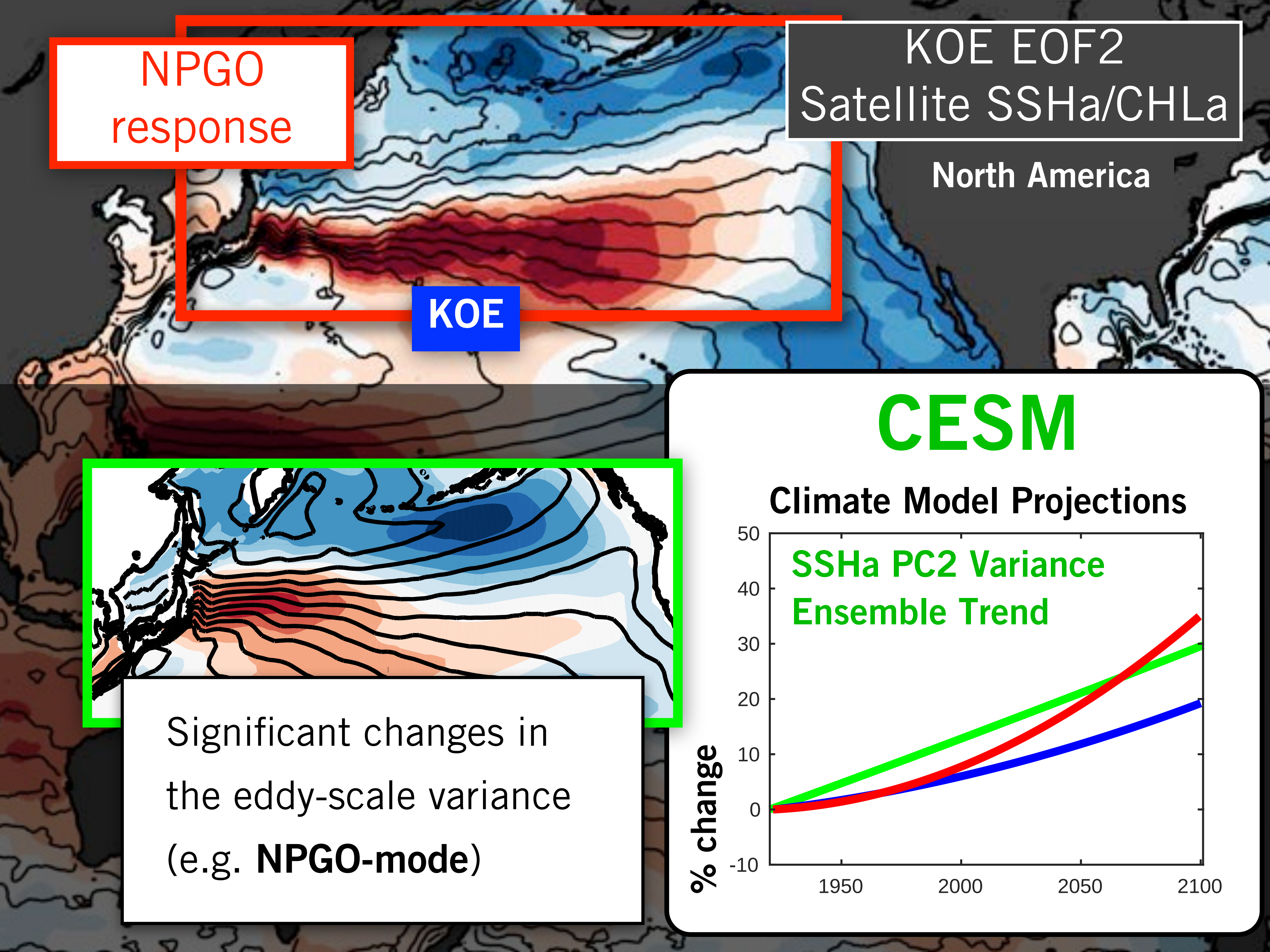
How does climate impact the **EDDY-SCALE** variance in the KOE?


EDDY-SCALE (< 300KM)
Satellite Covariance
SSHa/CHLa
Asia
North America
KOE
Eddy Kinetic Energy KOE
R=0.52
2
0
-2
-4
2000
2005
2010
2015
NPGO 2yr lead

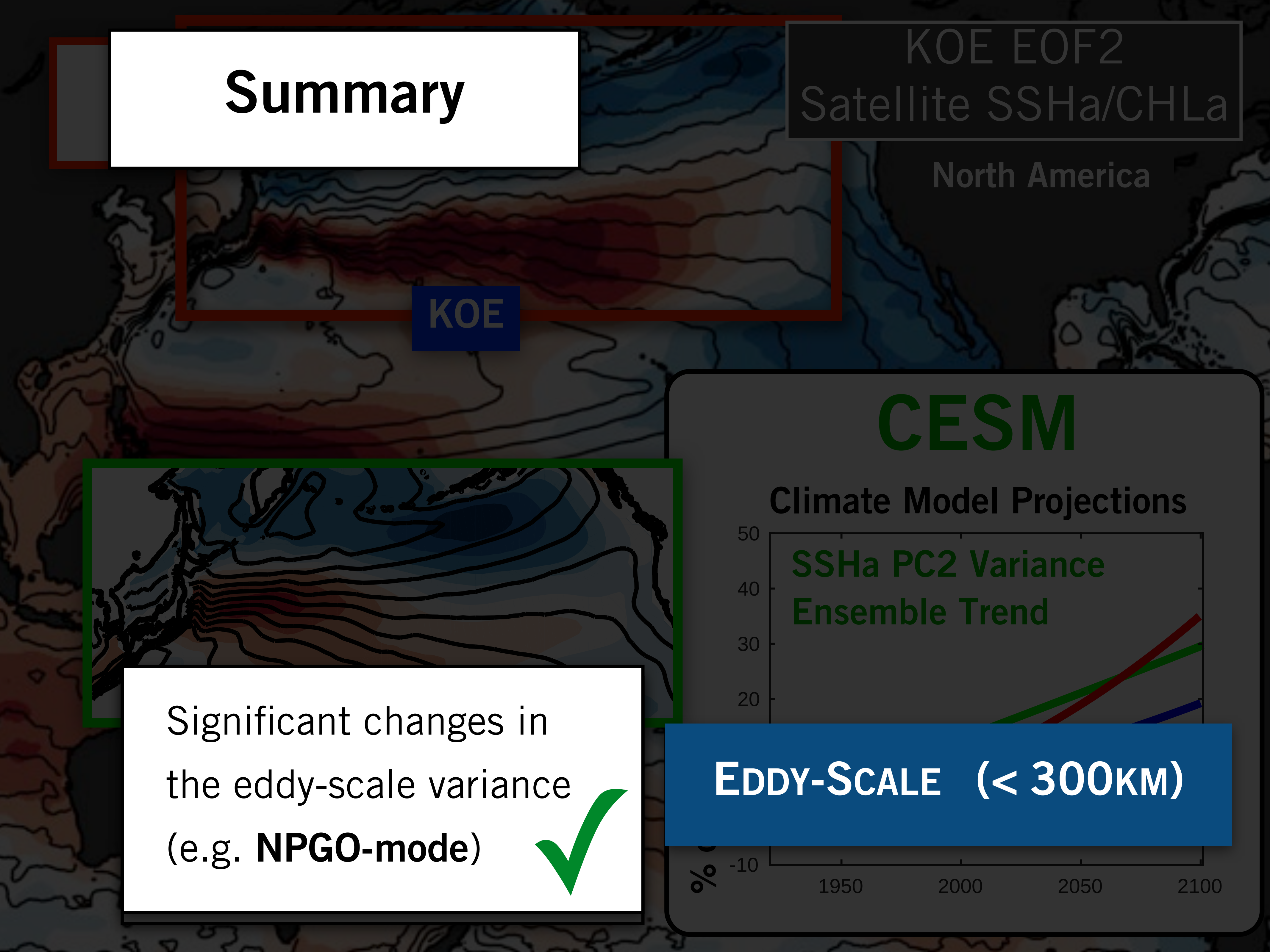


NPGO response
KOE EOF2
Satellite SSHa/CHLa
North America
KOE
Eddy Kinetic Energy KOE
R=0.52
2
0
-2
-4
NPGO 2yr lead
2000
2005
2010
2015


NPGO
response
KOE
KOE EOF2
SSHa PC2 Variance (all members)
stand dev
6
5
4
3
2
1
50
40
30
20
10
0
-10
SSHa PC2 Variance
Ensemble Trend
% change
1950
2000
2050
2100
CESM
Climate Model Projections


NPGO
response
KOE EOF2
Satellite SSHa/CHLa
North America
KOE
CESM
Climate Model Projections
SSHa PC2 Variance
Ensemble Trend
% change
50
40
30
20
10
0
-10
1950
2000
2050
2100
Significant changes in
the eddy-scale variance
(e.g. **NPGO-mode**)

Summary



Significant changes in the eddy-scale variance (e.g. **NPGO-mode**) ✓

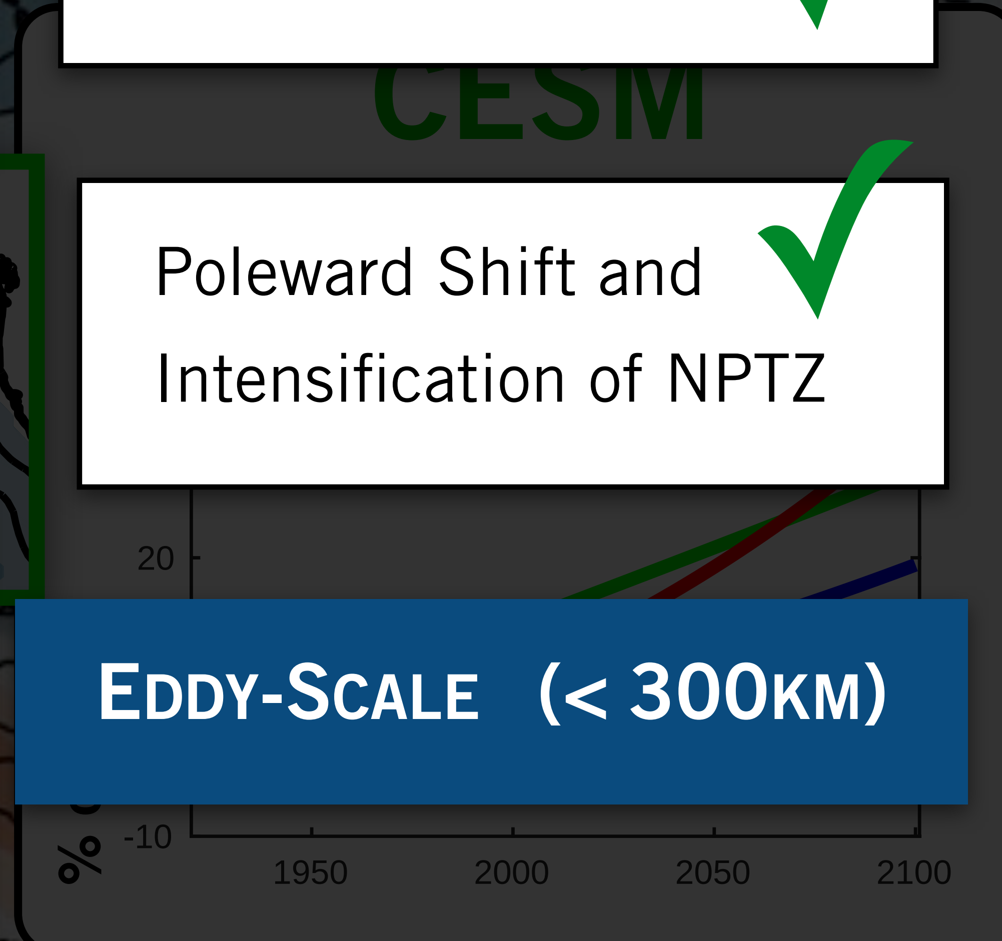
EDDY-SCALE (< 300KM)

Summary
Climate Change Impact on PTAs

Large-Scale (< 300km)

Stronger NPTZ Variance and Seasonal Migration (e.g. **PDO-mode**) ✓

Poleward Shift and Intensification of NPTZ ✓

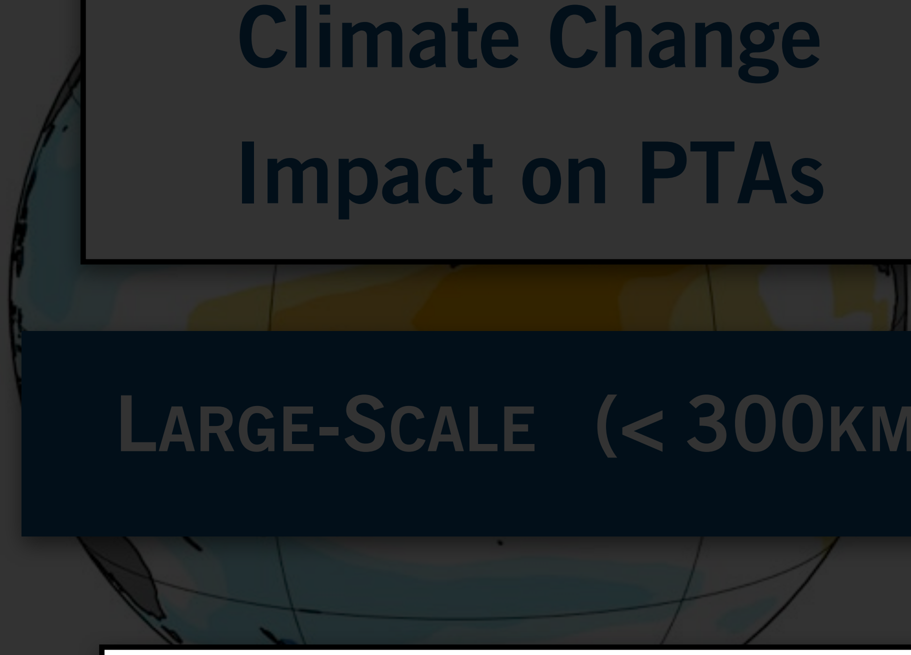


Significant changes in the eddy-scale variance (e.g. **NPGO-mode**) ✓

Eddy-Scale (< 300km)

WINTER (JFM)

Summary
Climate Change
Impact on PTAs



Significant intensification and poleward shift in the mean KOE

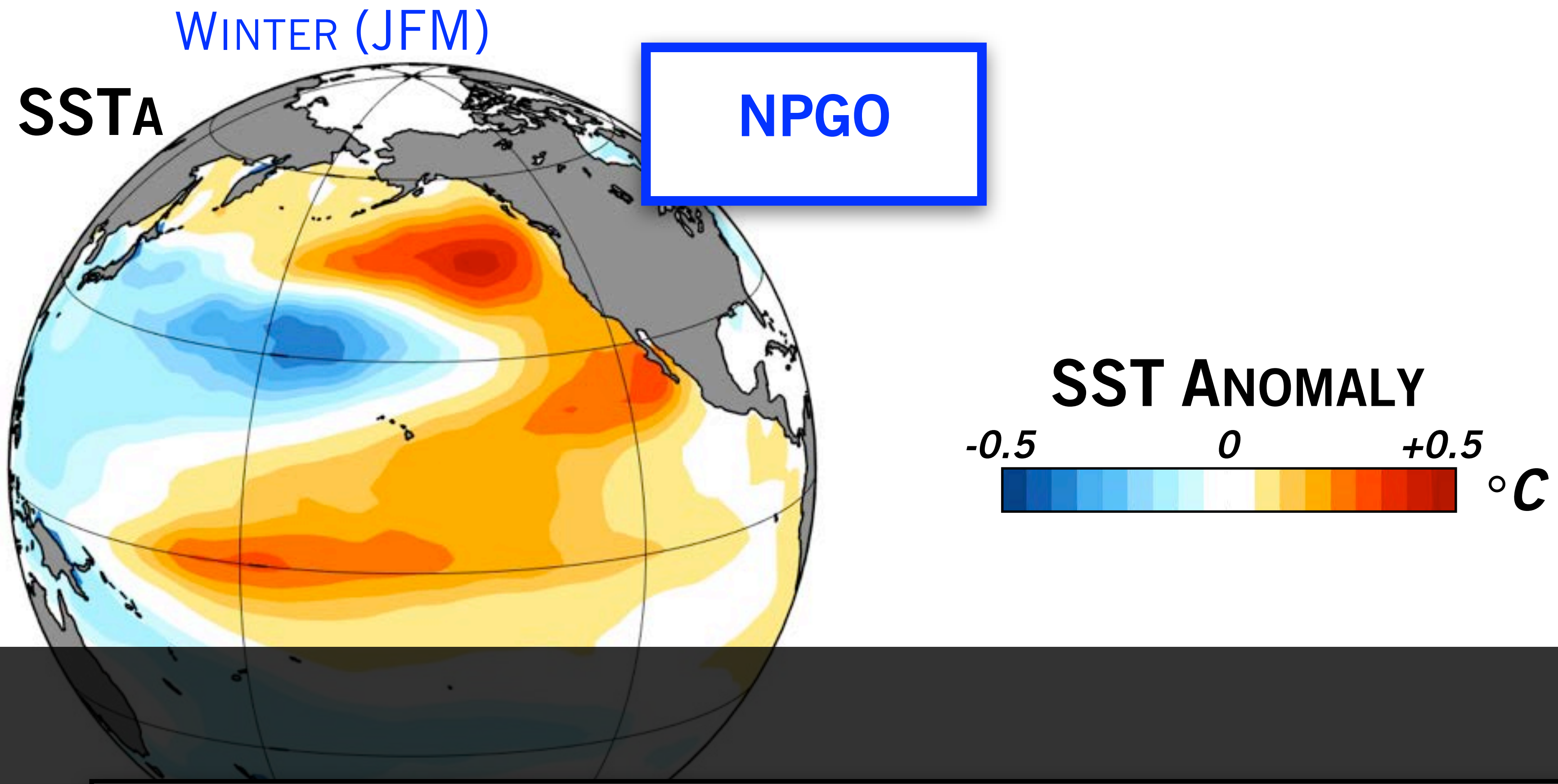
LARGE-SCALE (< 300KM)

Significant changes in the variance of seasonal

(e.g. **NPGO-mode**)

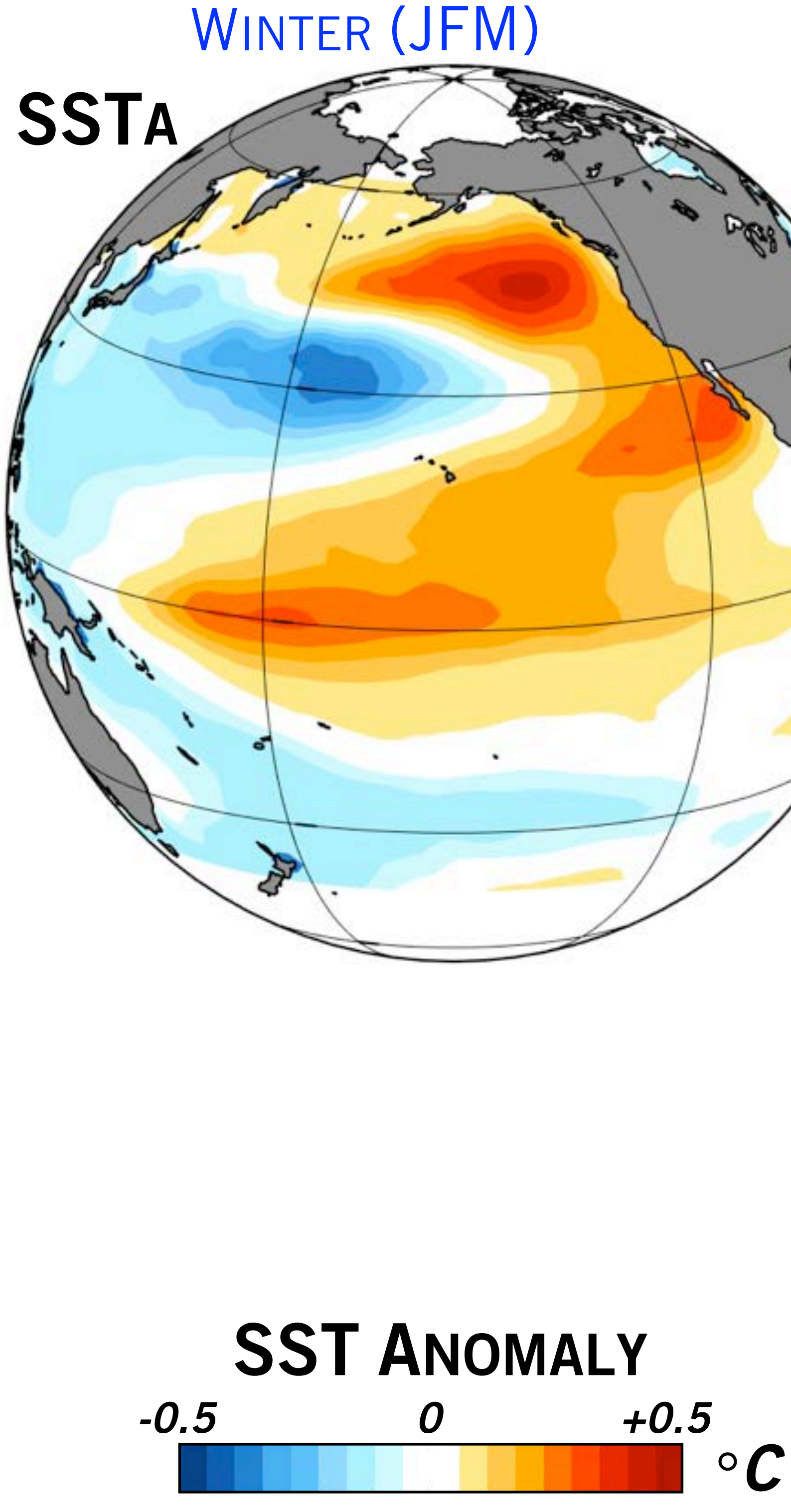
QUESTION:

Why are the mode PDO and NPGO modes getting stronger in CESM under anthropogenic forcing?

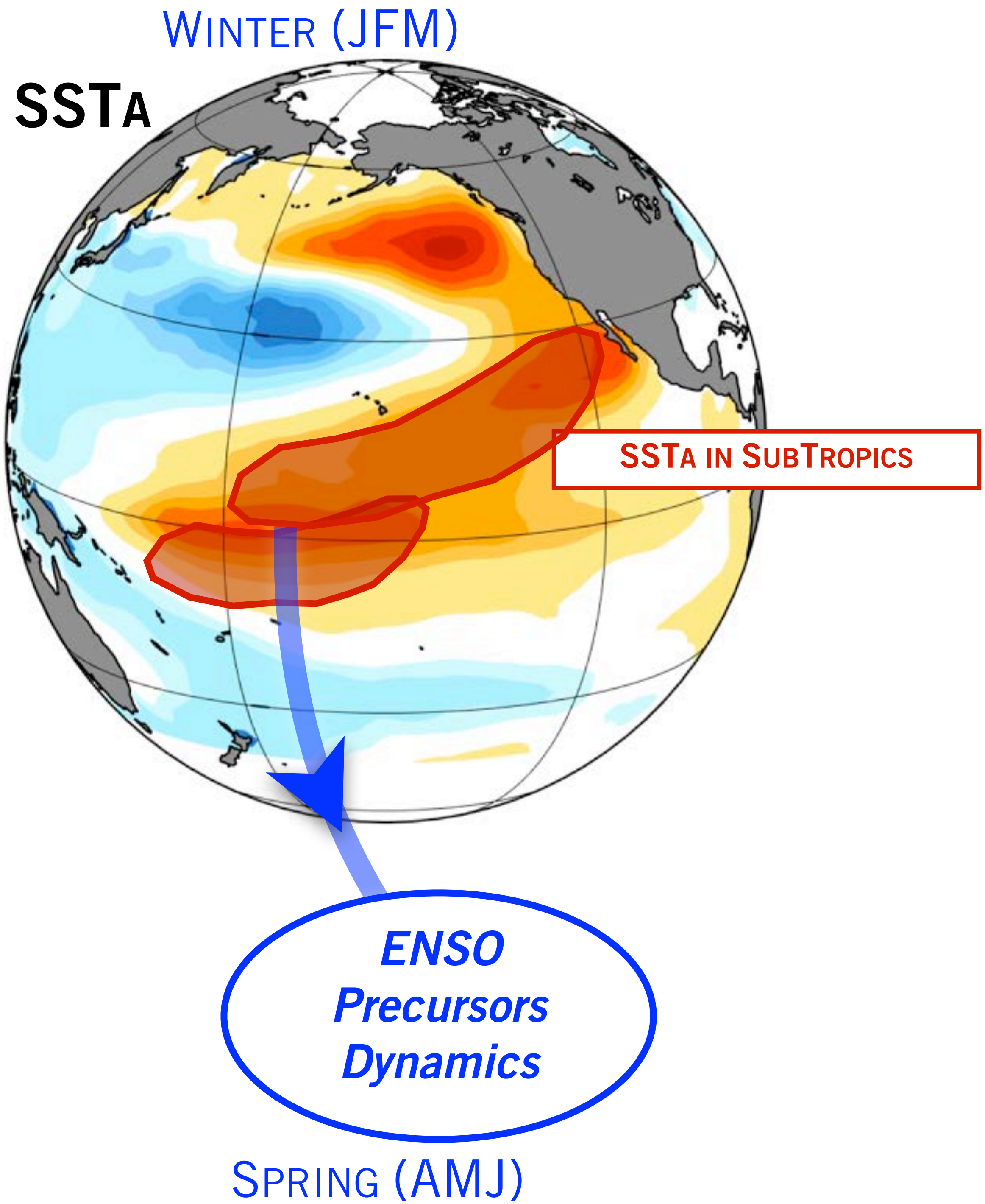


QUESTION:

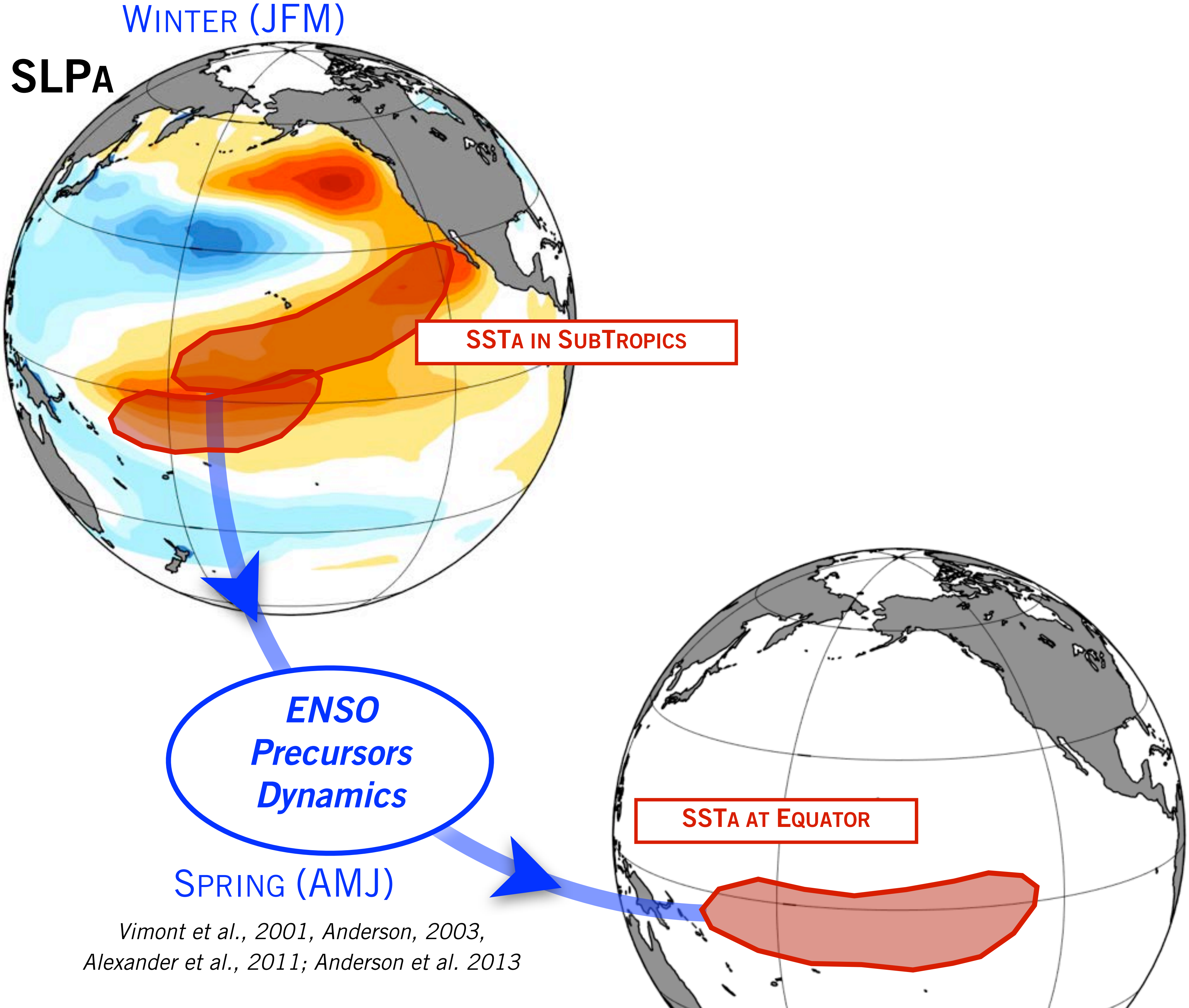
Why are the mode PDO and NPGO modes getting stronger in CESM under anthropogenic forcing?

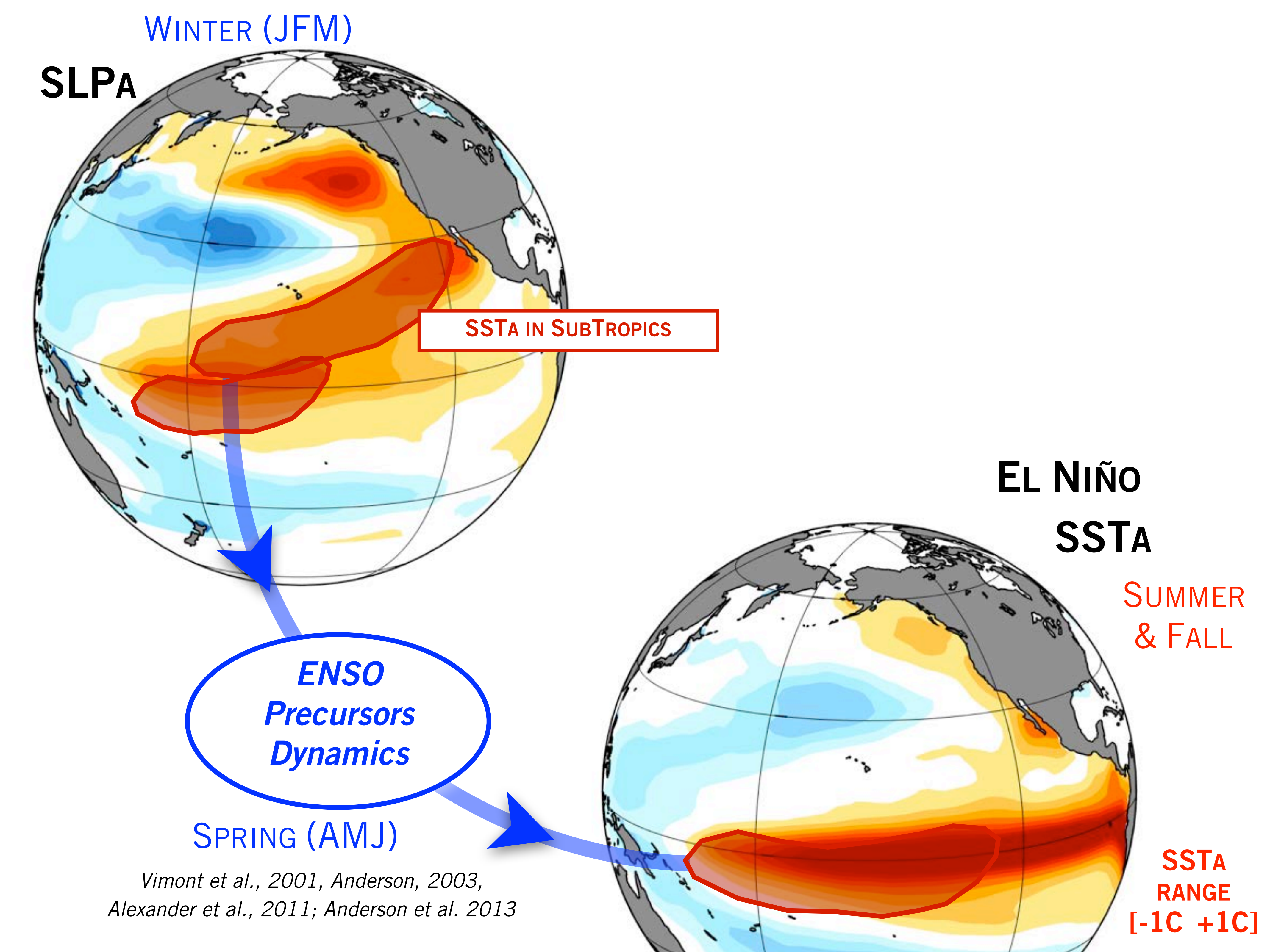


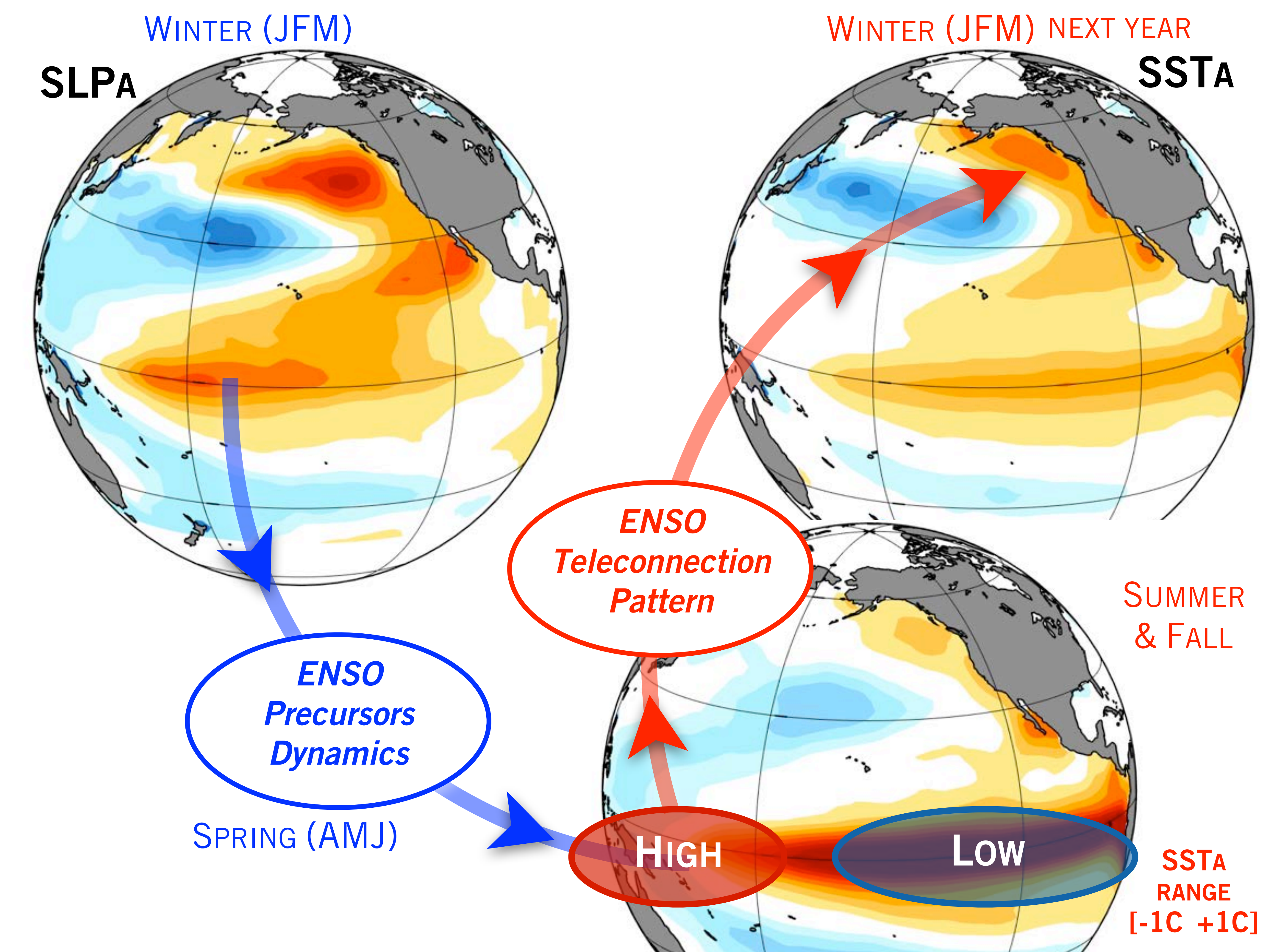
Winter (JFM)
SSTa
SST Anomaly
-0.5
0
+0.5
°C



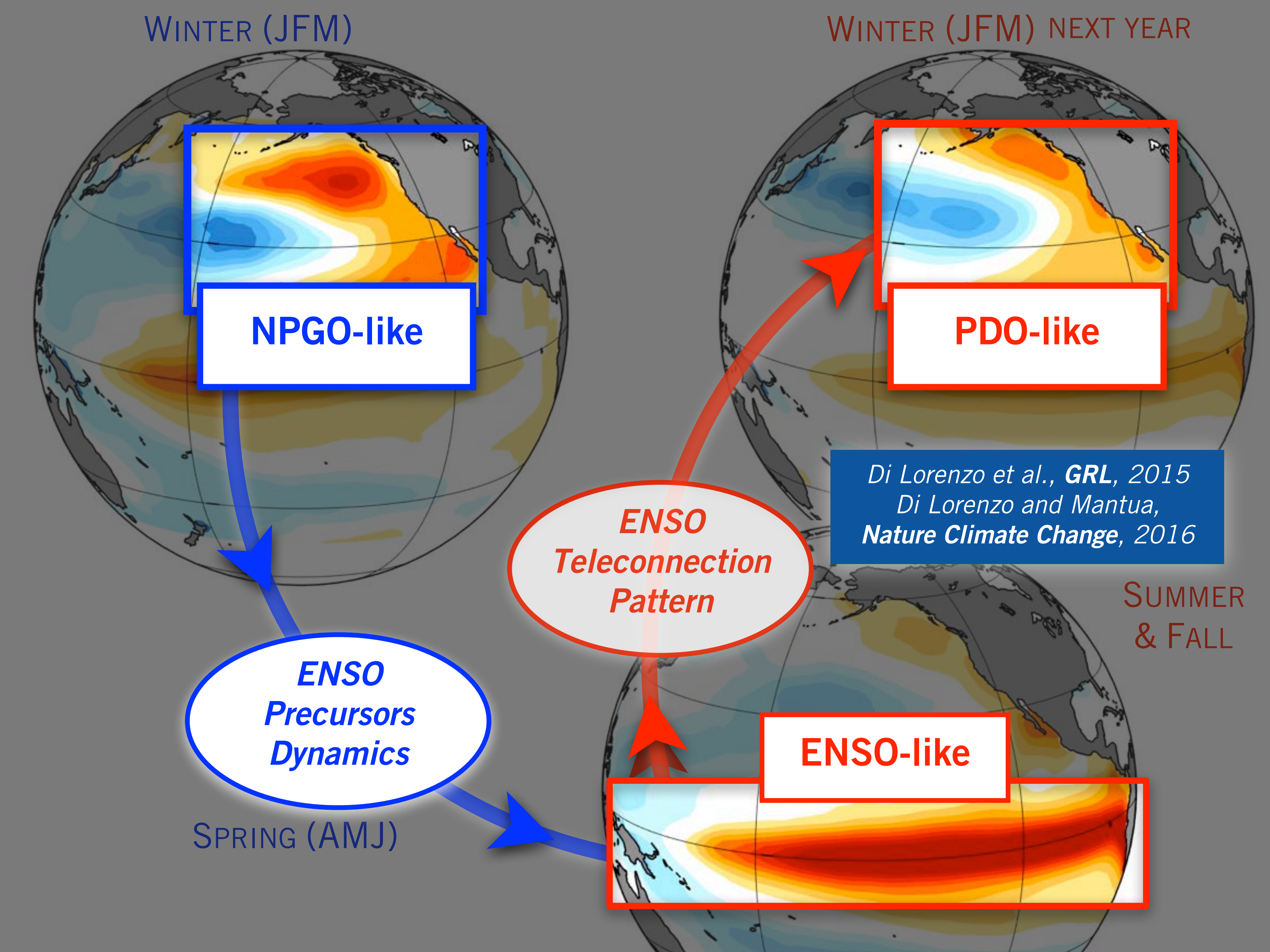
Vimont et al., 2001, Anderson, 2003, Alexander et al., 2011; Anderson et al. 2013


WINTER (JFM)
SLPA
SSTA IN SUBTROPICS
ENSO
Precursors
Dynamics
SSTA AT EQUATOR
SPRING (AMJ)
Vimont et al., 2001, Anderson, 2003,
Alexander et al., 2011; Anderson et al. 2013

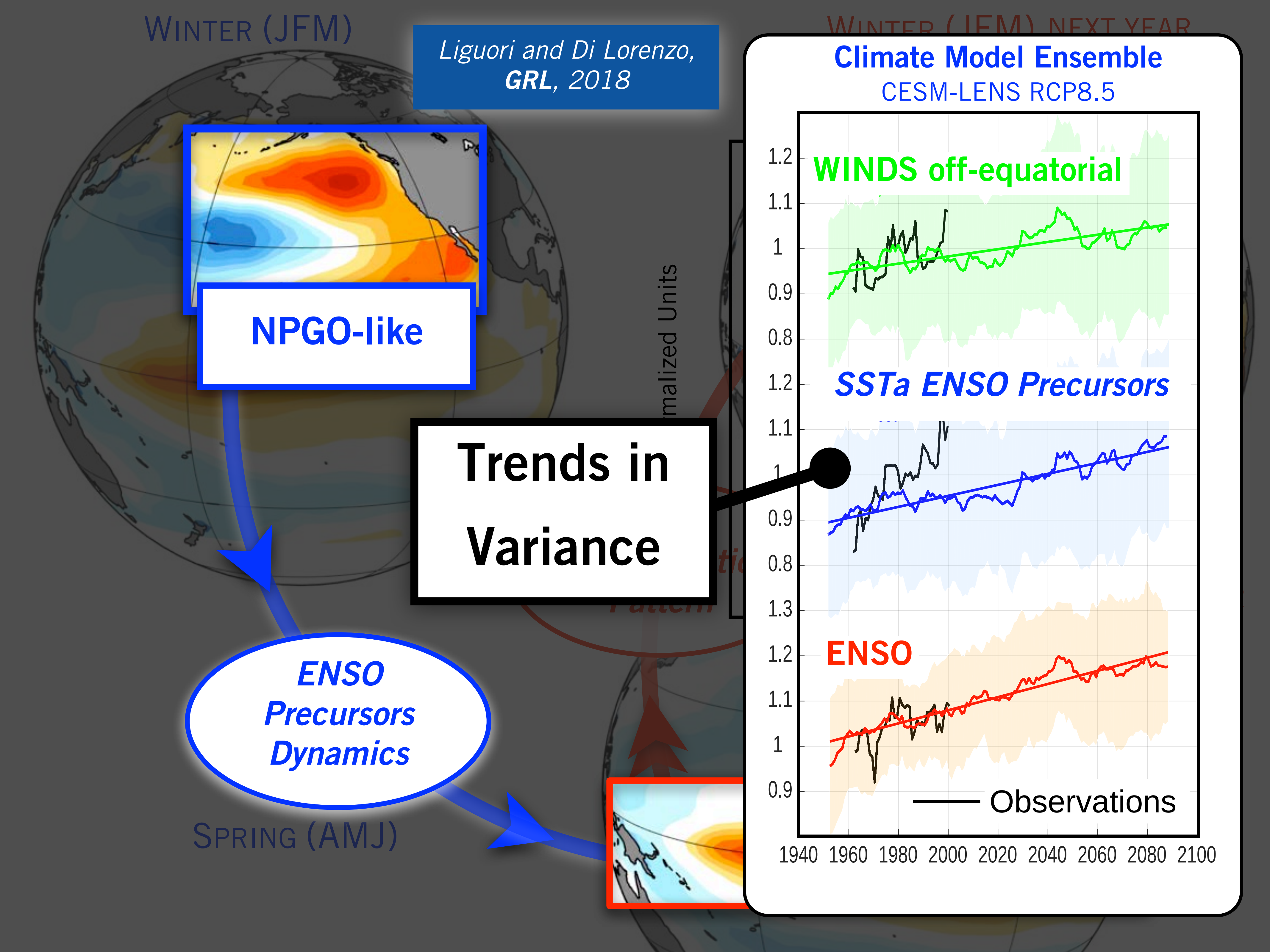

Winter (JFM)
SLPa
SSTa in SubTropics
ENSO
Precursors
Dynamics
Spring (AMJ)
Vimont et al., 2001, Anderson, 2003,
Alexander et al., 2011; Anderson et al. 2013
El Niño
SSTa
Summer
& Fall
SSTa
range
[-1C +1C]



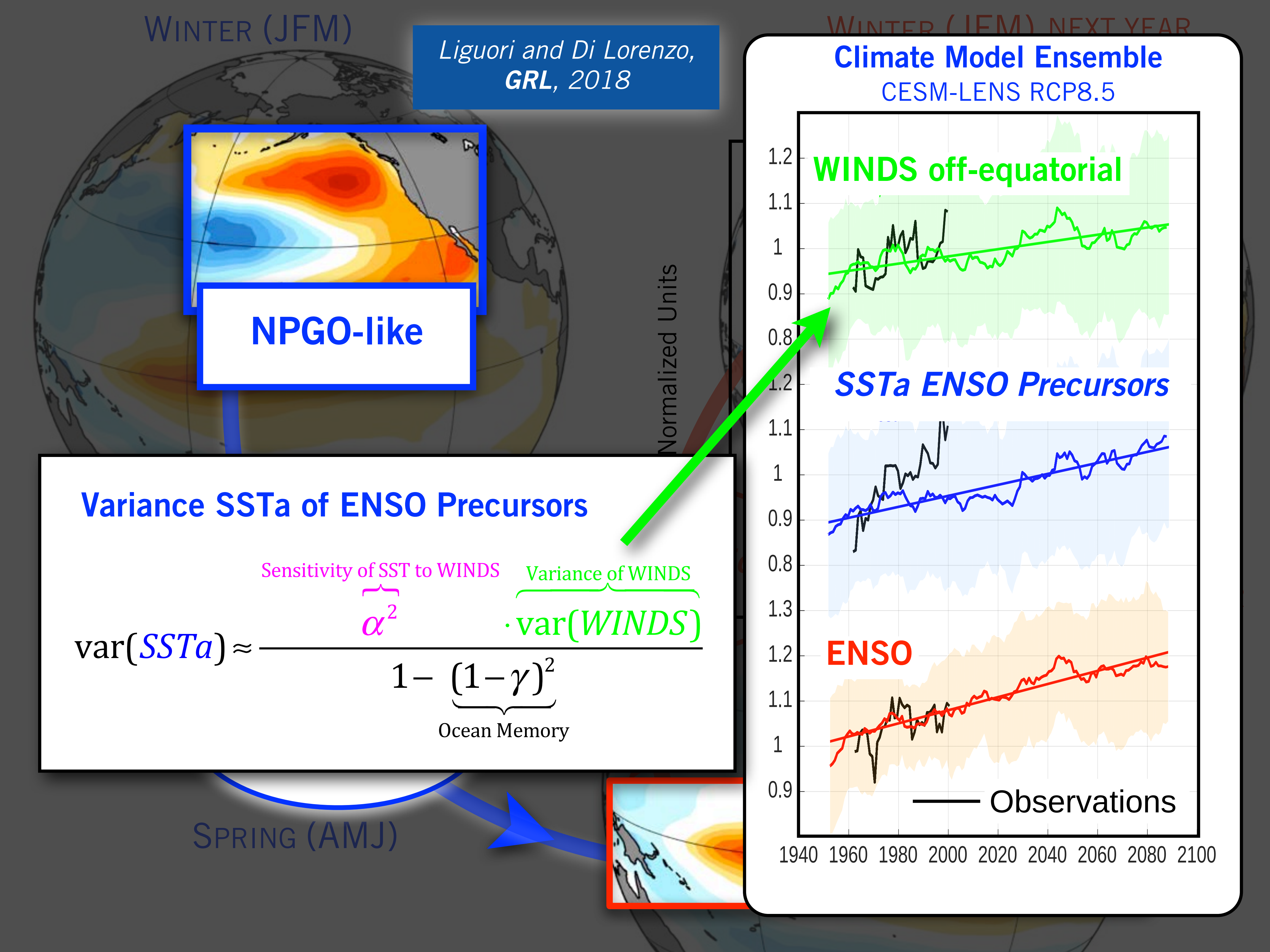
WINTER (JFM)
SLPA
WINTER (JFM) NEXT YEAR
SSTA
ENSO
Teleconnection
Pattern
SUMMER
& FALL
ENSO
Precursors
Dynamics
SPRING (AMJ)
HIGH
LOW
SSTA
RANGE
[-1C +1C]



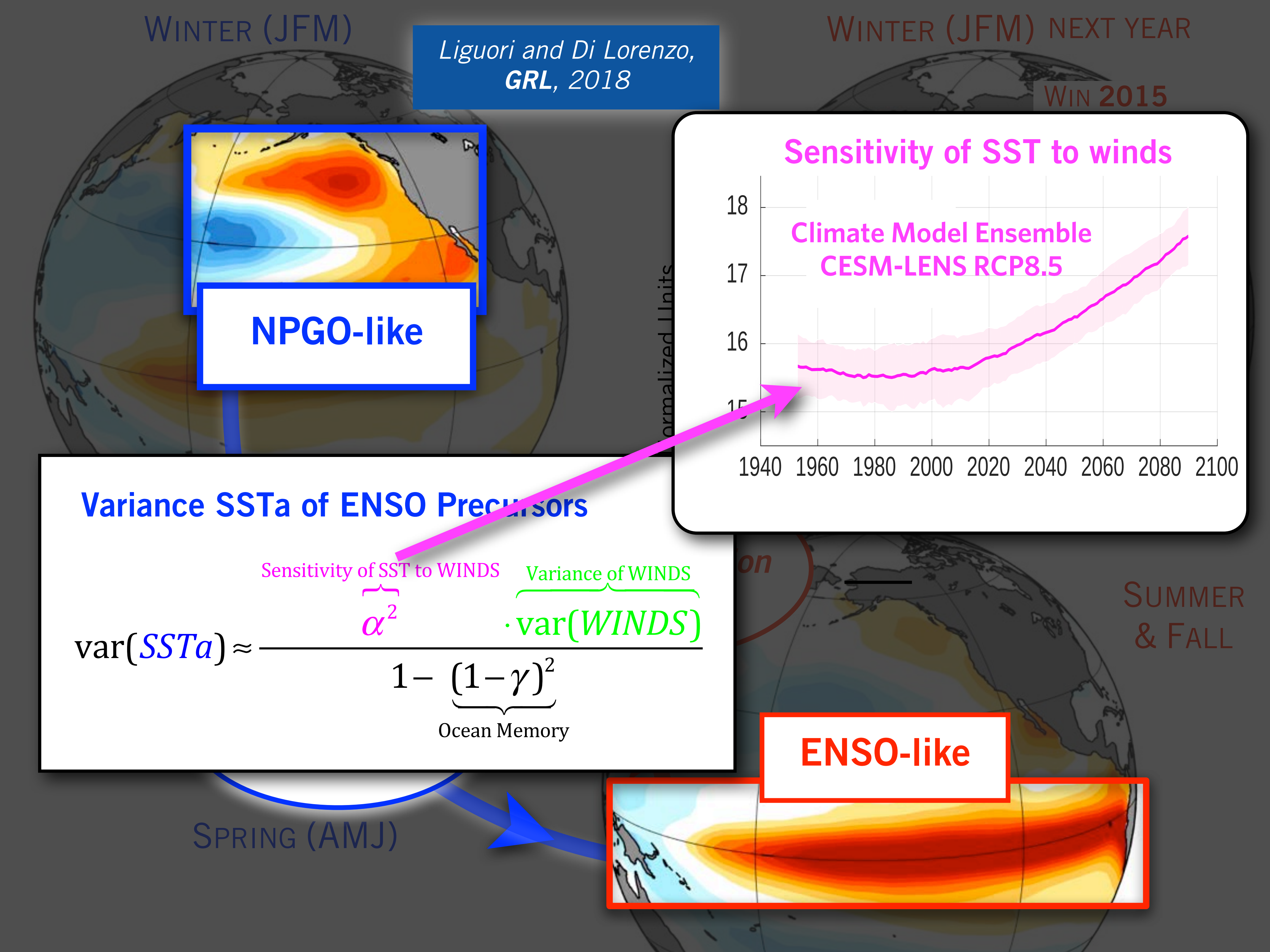
WINTER (JFM)
WINTER (JFM) NEXT YEAR
NPGO-like
PDO-like
Di Lorenzo et al., GRL, 2015
Di Lorenzo and Mantua,
Nature Climate Change, 2016
ENSO
Teleconnection
Pattern
SUMMER
& FALL
ENSO
Precursors
Dynamics
ENSO-like
SPRING (AMJ)



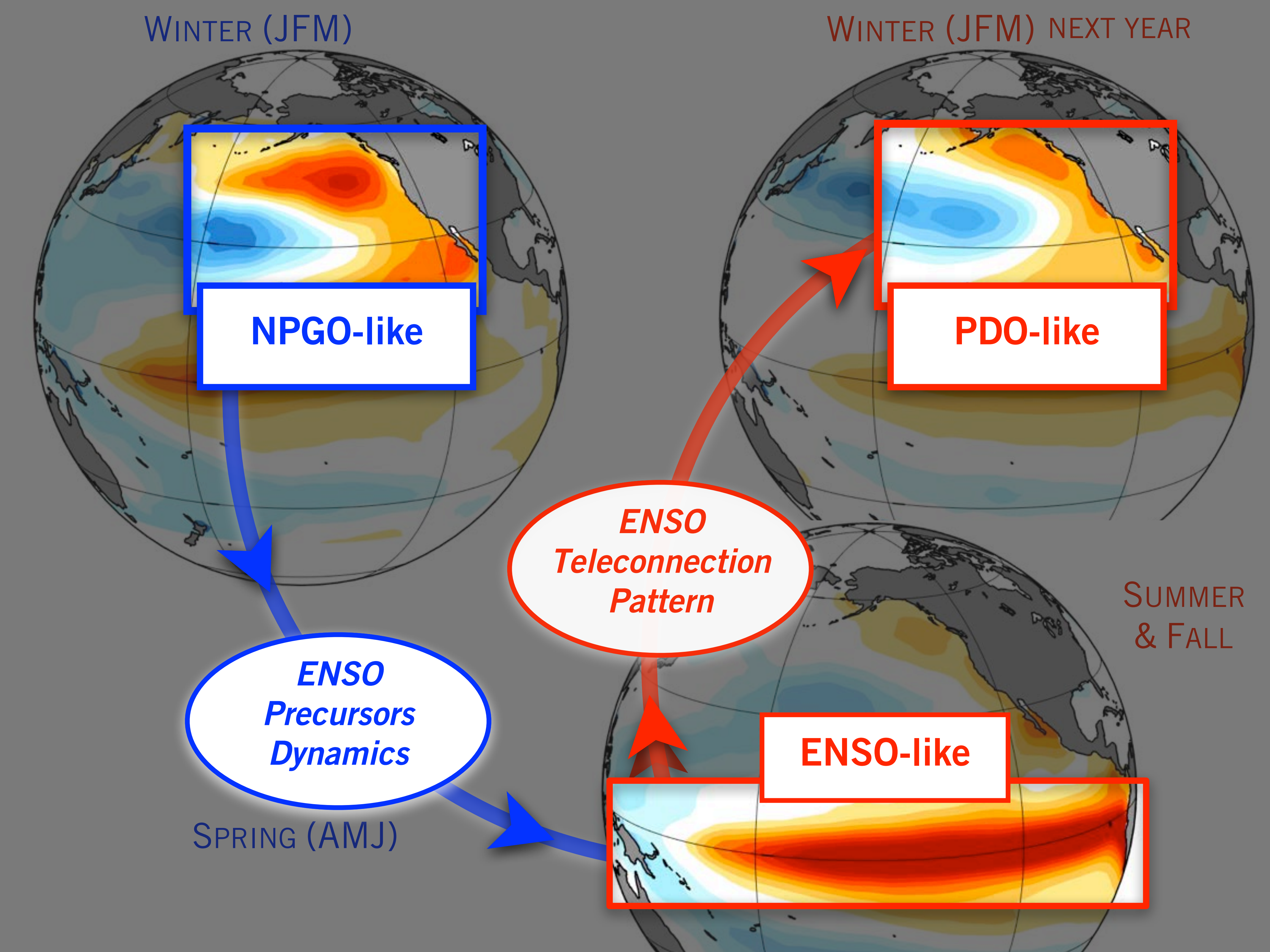
Winter (JFM)
Liguori and Di Lorenzo, GRL, 2018
Winter (JFM) next year
NPGO-like
Trends in Variance
ENSO Precursors Dynamics
Spring (AMJ)
Climate Model Ensemble
CESM-LENS RCP8.5
WINDS off-equatorial
SSTa ENSO Precursors
ENSO
Observations
1.2
1.1
1
0.9
0.8
1.3
1940 1960 1980 2000 2020 2040 2060 2080 2100



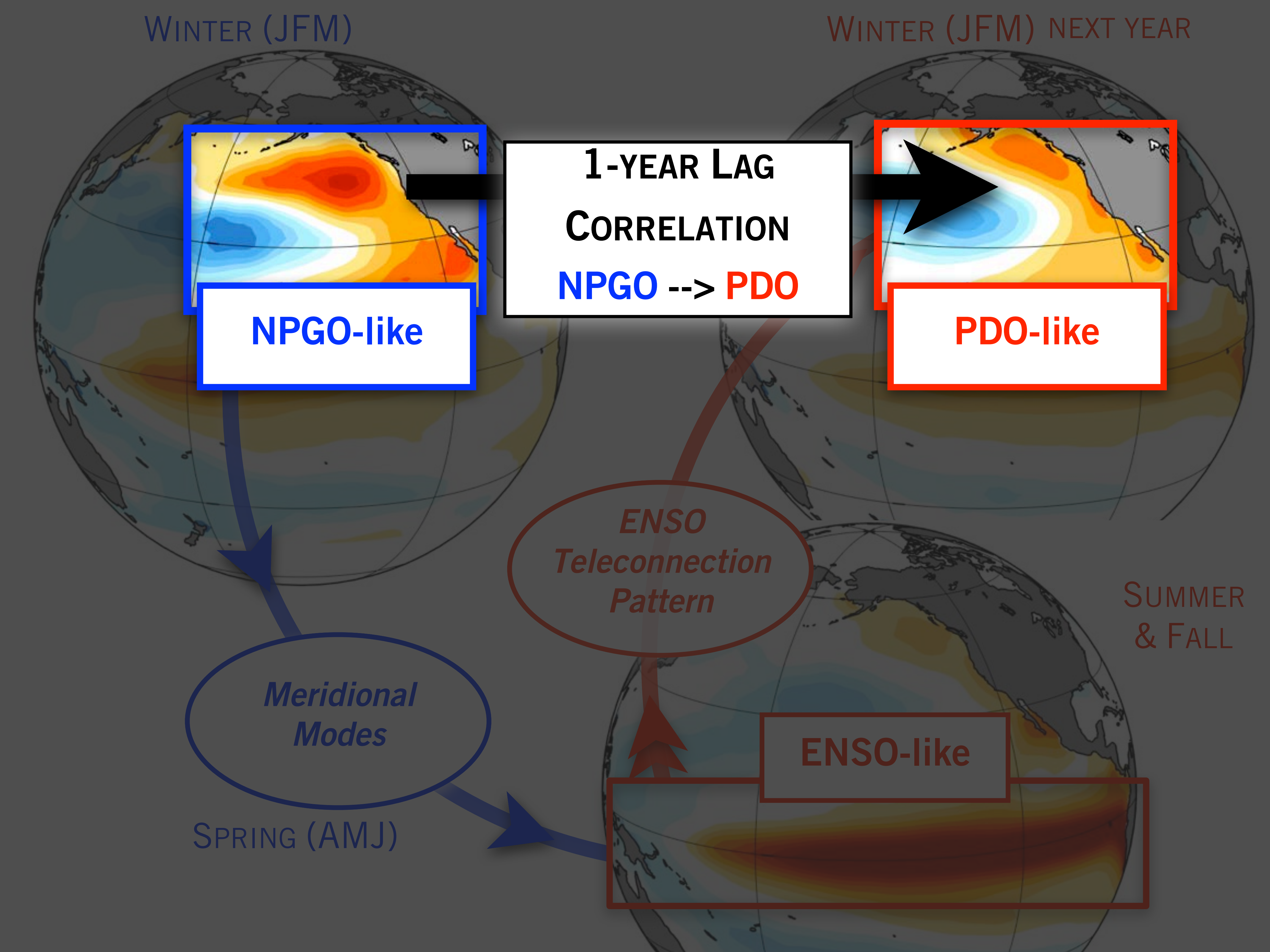
Winter (JFM)
Liguori and Di Lorenzo, GRL, 2018
Winter (JFM) next year
NPGO-like
Spring (AMJ)
Variance SSTa of ENSO Precursors
Sensitivity of SST to WINDS
Variance of WINDS
$$\mathrm{var}(SSTa) \approx \frac{\alpha^2 \cdot \mathrm{var}(WINDS)}{1-(1-\gamma)^2}$$
Ocean Memory
Climate Model Ensemble
CESM-LENS RCP8.5
Normalized Units
WINDS off-equatorial
SSTa ENSO Precursors
ENSO
Observations



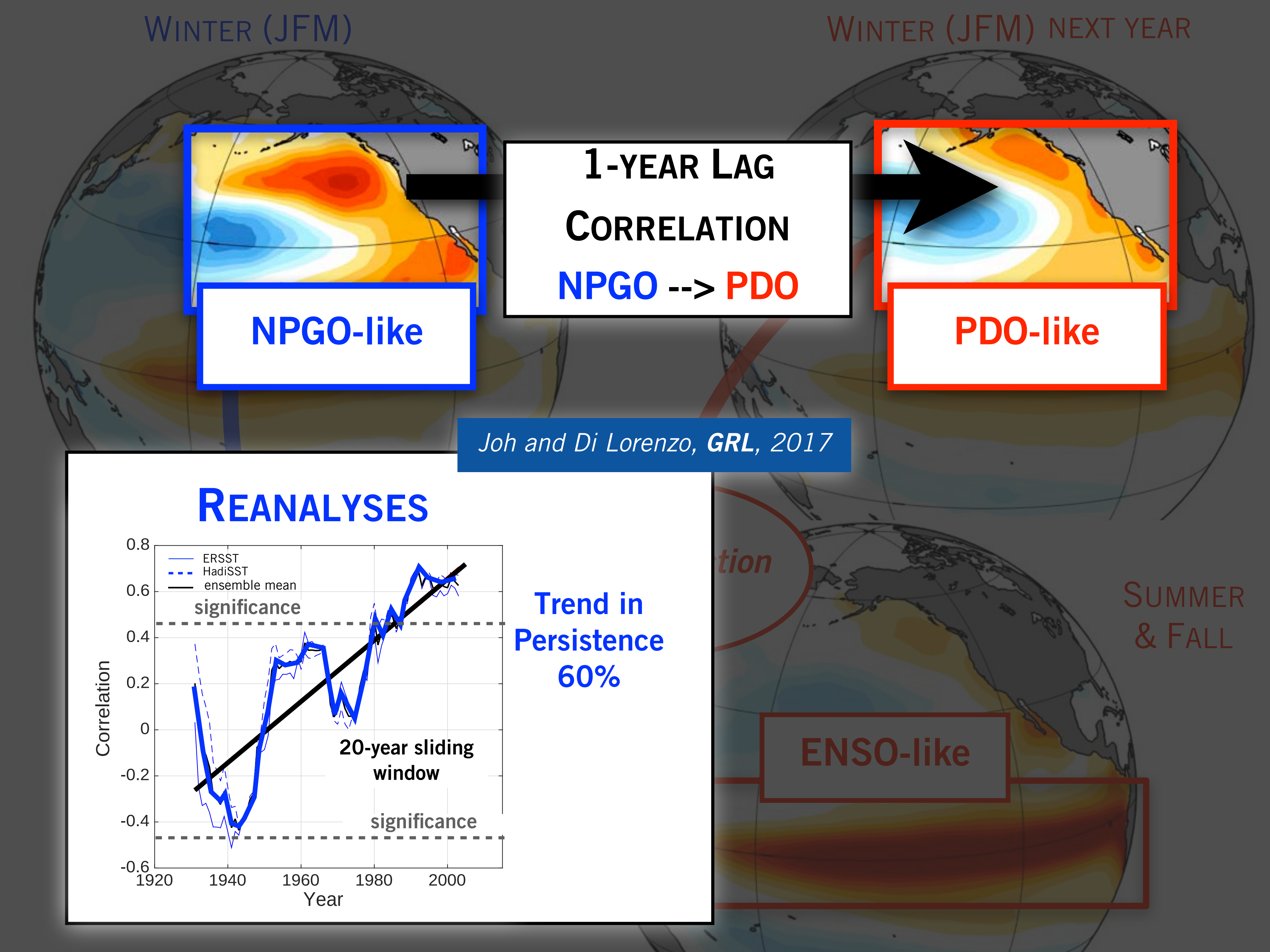
WINTER (JFM)
Liguori and Di Lorenzo, GRL, 2018
WINTER (JFM) NEXT YEAR
WIN 2015
NPGO-like
Sensitivity of SST to winds
18
17
16
15
Climate Model Ensemble
CESM-LENS RCP8.5
1940 1960 1980 2000 2020 2040 2060 2080 2100
Variance SSTa of ENSO Precursors
Sensitivity of SST to WINDS
Variance of WINDS
$$\mathrm{var}(SSTa) \approx \frac{\overbrace{\alpha^2}^{\text{Sensitivity of SST to WINDS}} \cdot \overbrace{\mathrm{var}(WINDS)}^{\text{Variance of WINDS}}}{1 - \underbrace{(1-\gamma)^2}_{\text{Ocean Memory}}}$$
Ocean Memory
SUMMER & FALL
ENSO-like
SPRING (AMJ)



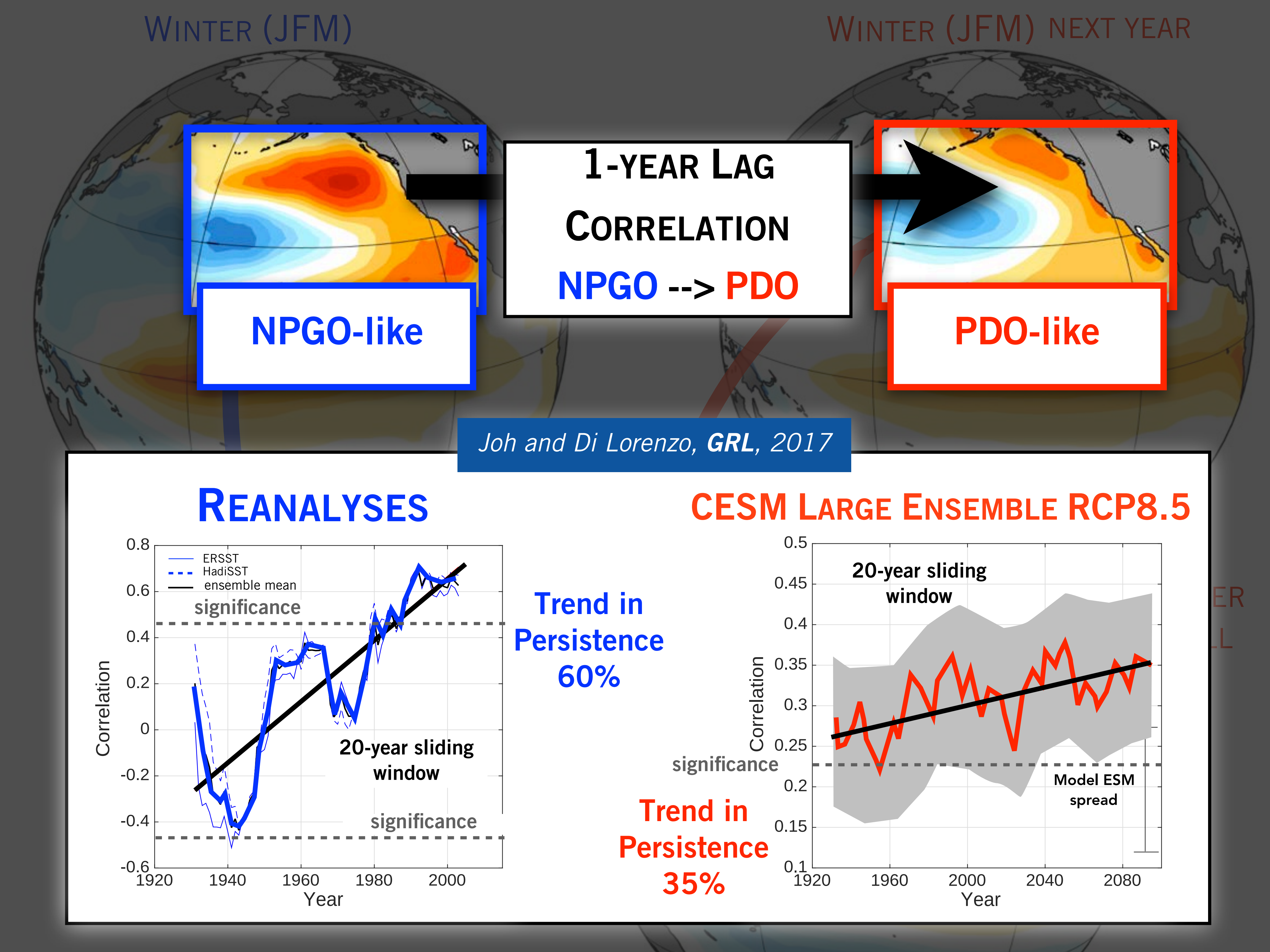
WINTER (JFM)
WINTER (JFM) NEXT YEAR
NPGO-like
PDO-like
ENSO Teleconnection Pattern
SUMMER & FALL
ENSO Precursors Dynamics
ENSO-like
SPRING (AMJ)



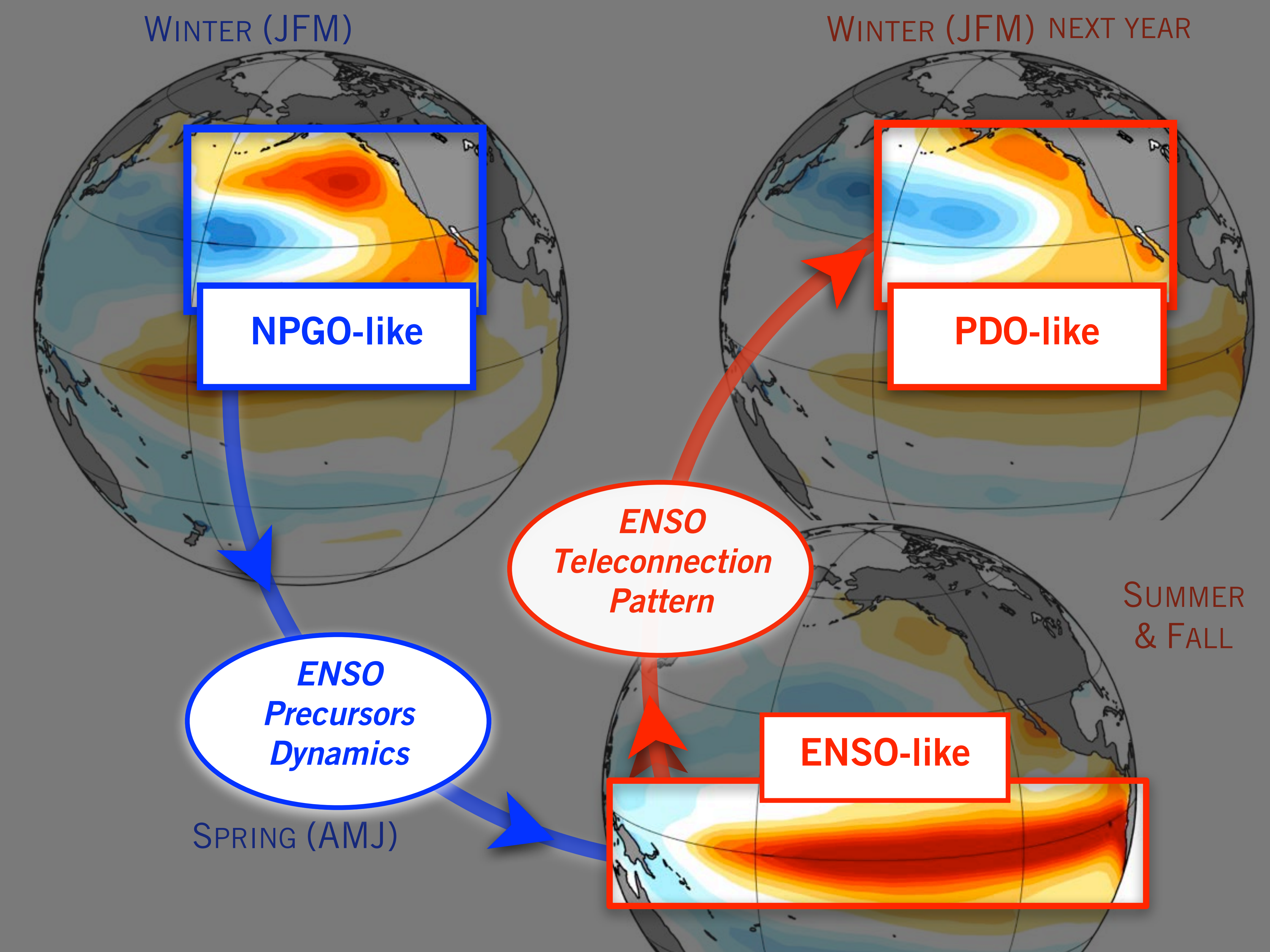
WINTER (JFM)
WINTER (JFM) NEXT YEAR
1-YEAR LAG
CORRELATION
NPGO --> PDO
NPGO-like
PDO-like
ENSO
Teleconnection
Pattern
SUMMER
& FALL
Meridional
Modes
ENSO-like
SPRING (AMJ)



WINTER (JFM)
WINTER (JFM) NEXT YEAR
1-YEAR LAG CORRELATION
NPGO --> PDO
NPGO-like
PDO-like
Joh and Di Lorenzo, GRL, 2017
REANALYSES
Trend in Persistence 60%
ERSST
HadiSST
ensemble mean
significance
significance
20-year sliding window
Correlation
Year
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
1920
1940
1960
1980
2000
SUMMER & FALL
ENSO-like



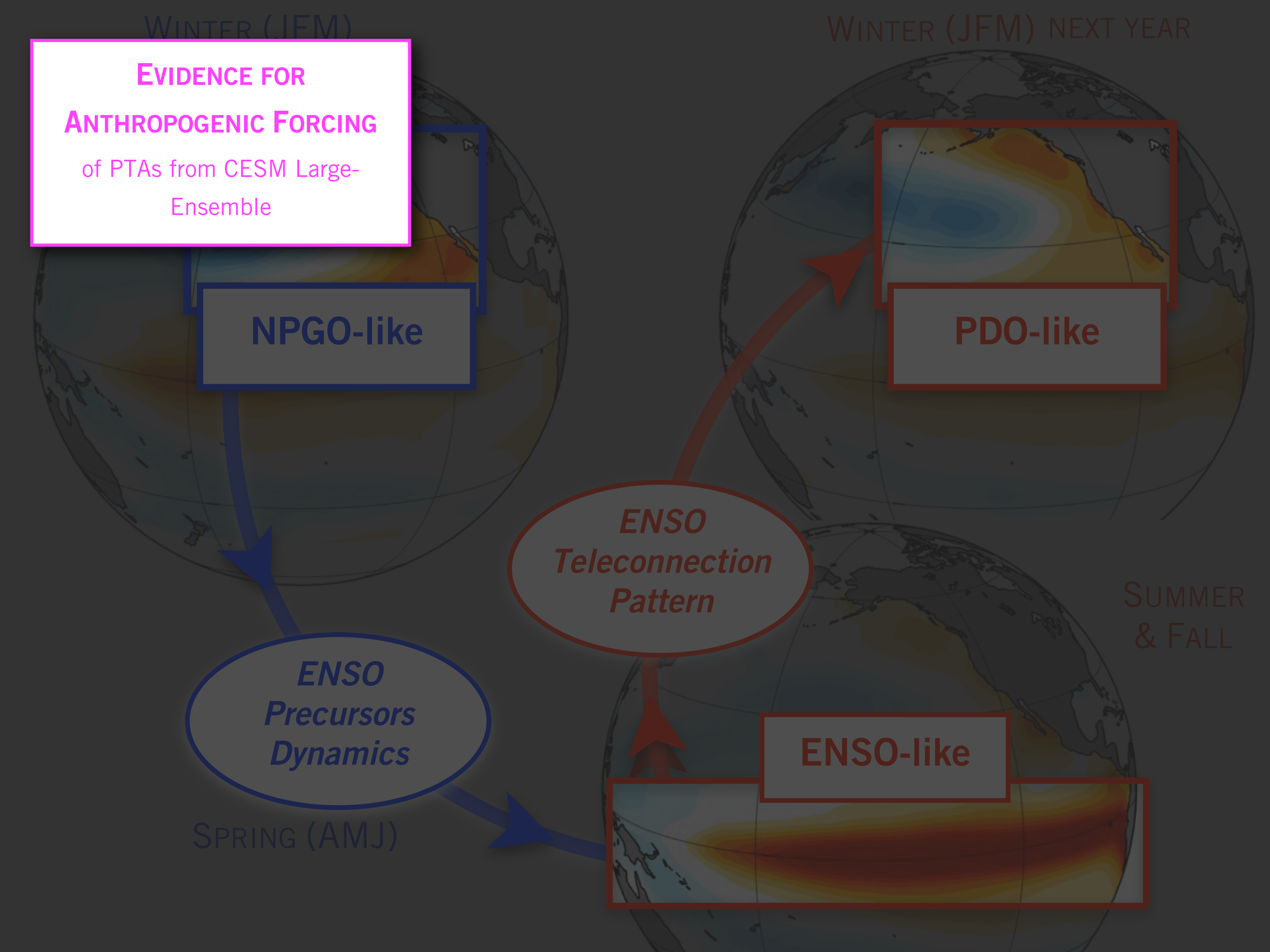
Winter (JFM)
Winter (JFM) next year
1-year Lag Correlation
NPGO --> PDO
NPGO-like
PDO-like
Joh and Di Lorenzo, GRL, 2017
Reanalyses
CESM Large Ensemble RCP8.5
ERSST
HadiSST
ensemble mean
significance
20-year sliding window
Correlation
Year
Trend in Persistence 60%
Trend in Persistence 35%
Model ESM spread
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
1920
1940
1960
1980
2000
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
1920
1960
2000
2040
2080

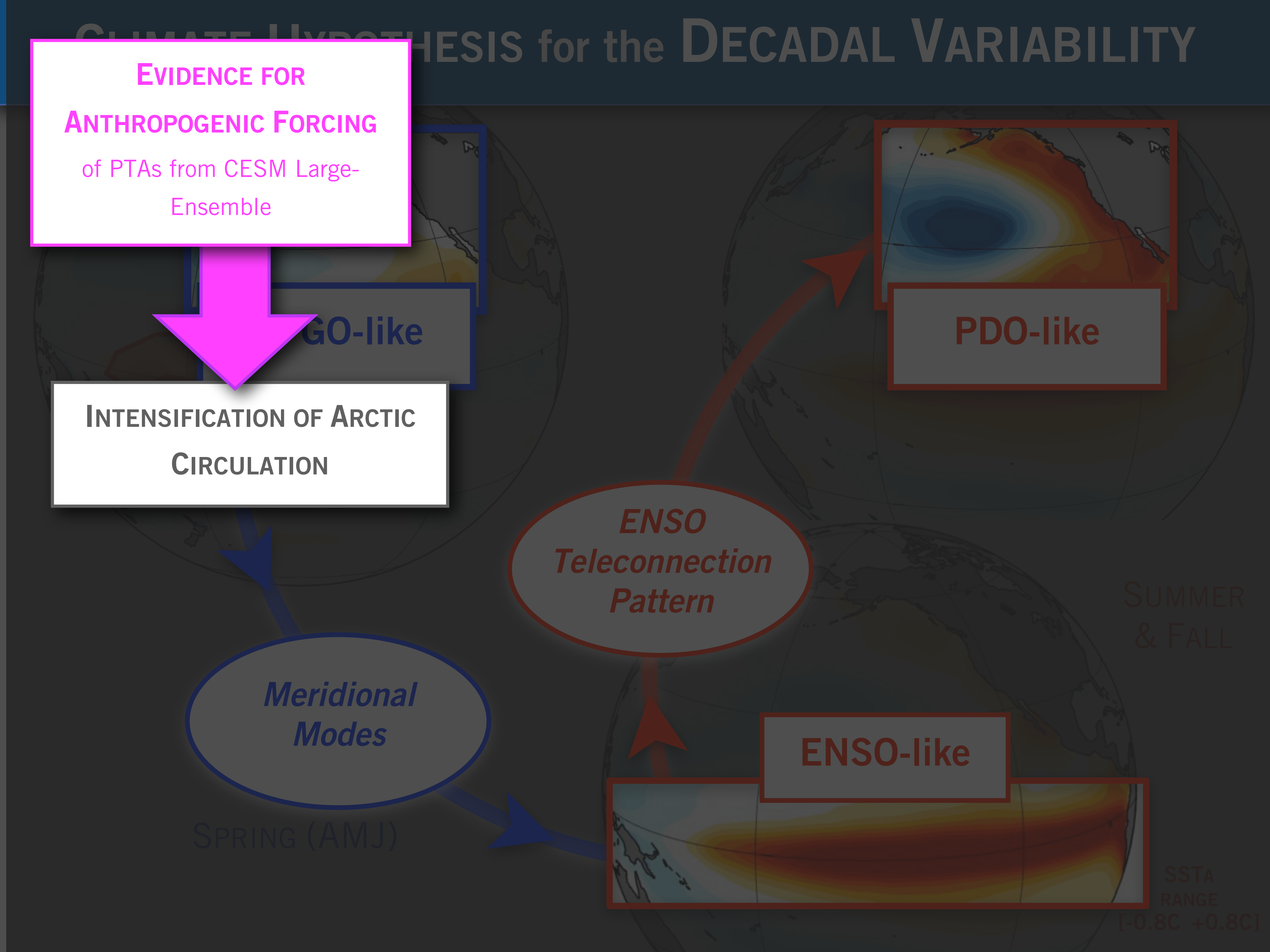


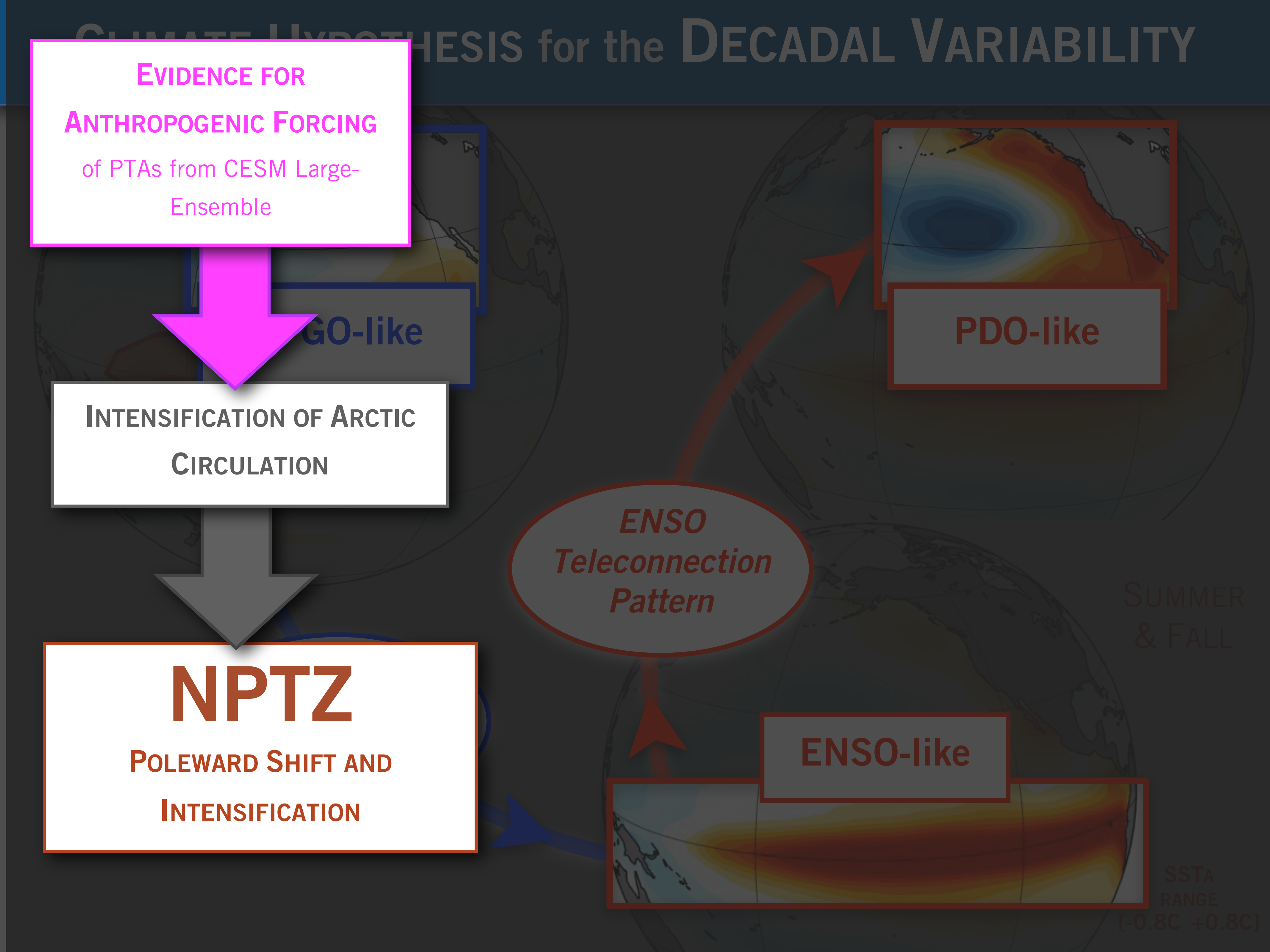
WINTER (JFM)
WINTER (JFM) NEXT YEAR
NPGO-like
PDO-like
ENSO Teleconnection Pattern
SUMMER & FALL
ENSO Precursors Dynamics
ENSO-like
SPRING (AMJ)

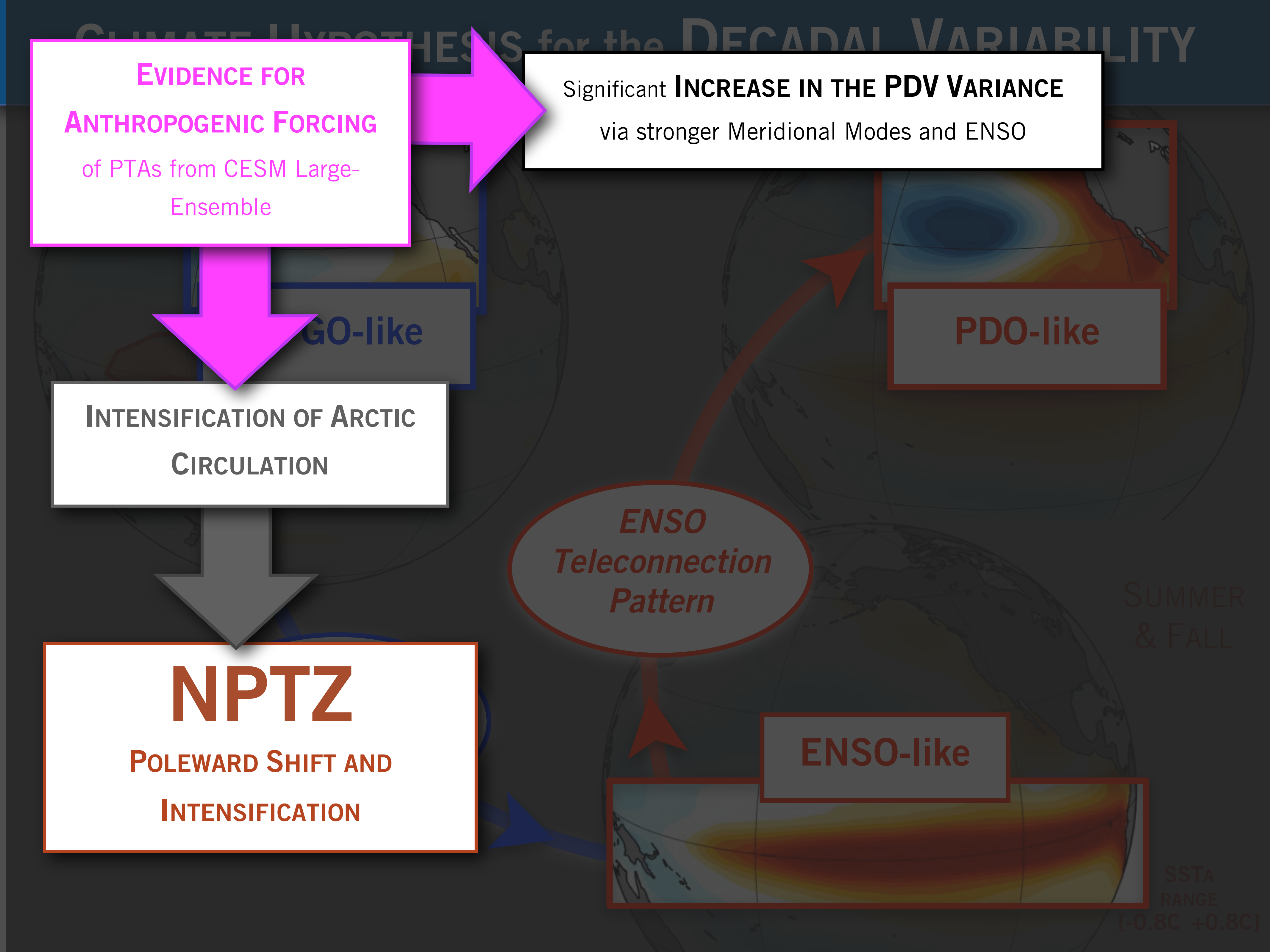
Evidence for Anthropogenic Forcing

of PTAs from CESM Large-Ensemble

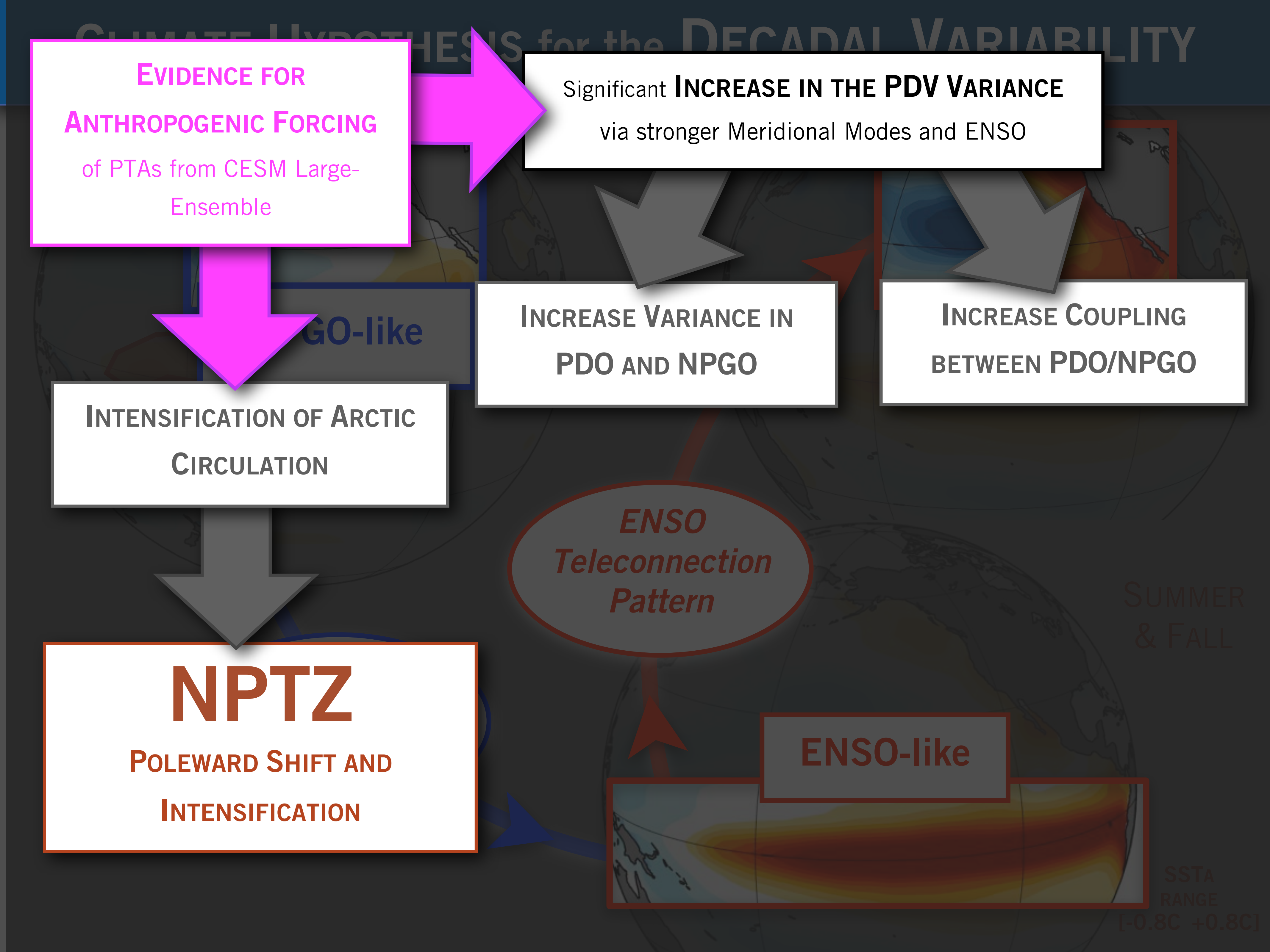



HESIS for the Decadal Variability
Evidence for Anthropogenic Forcing
of PTAs from CESM Large-Ensemble
GO-like
PDO-like
Intensification of Arctic Circulation
ENSO Teleconnection Pattern
Summer & Fall
Meridional Modes
ENSO-like
Spring (AMJ)
SSTA RANGE
[-0.8C +0.8C]

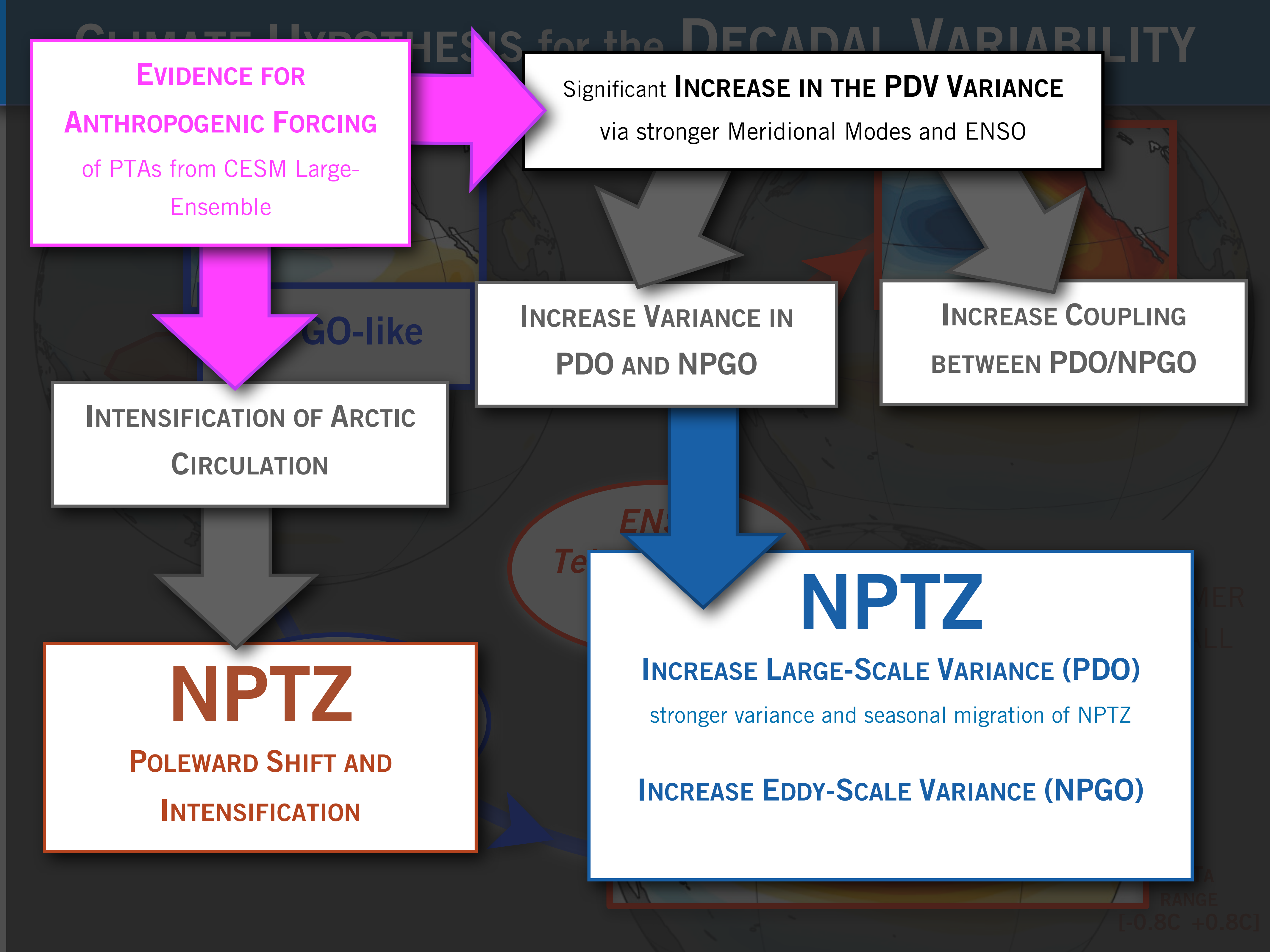

HESIS for the DECADAL VARIABILITY
EVIDENCE FOR ANTHROPOGENIC FORCING
of PTAs from CESM Large-Ensemble
GO-like
PDO-like
INTENSIFICATION OF ARCTIC CIRCULATION
ENSO Teleconnection Pattern
SUMMER & FALL
NPTZ
POLEWARD SHIFT AND INTENSIFICATION
ENSO-like
SSTA RANGE
[-0.8C, +0.8C]



DECADAL VARIABILITY
EVIDENCE FOR ANTHROPOGENIC FORCING
of PTAs from CESM Large-Ensemble
Significant INCREASE IN THE PDV VARIANCE
via stronger Meridional Modes and ENSO
GO-like
PDO-like
INTENSIFICATION OF ARCTIC CIRCULATION
ENSO Teleconnection Pattern
SUMMER & FALL
NPTZ
POLEWARD SHIFT AND INTENSIFICATION
ENSO-like
SSTA RANGE
[-0.8C +0.8C]



Evidence for Anthropogenic Forcing of PTAs from CESM Large-Ensemble
Significant Increase in the PDV Variance via stronger Meridional Modes and ENSO
Increase Variance in PDO and NPGO
Increase Coupling between PDO/NPGO
GO-like
Intensification of Arctic Circulation
ENSO Teleconnection Pattern
NPTZ
Poleward Shift and Intensification
ENSO-like
Summer & Fall


EVIDENCE FOR
ANTHROPOGENIC FORCING
of PTAs from CESM Large-Ensemble
Significant INCREASE IN THE PDV VARIANCE
via stronger Meridional Modes and ENSO
INCREASE VARIANCE IN
PDO AND NPGO
INCREASE COUPLING
BETWEEN PDO/NPGO
INTENSIFICATION OF ARCTIC
CIRCULATION
NPTZ
POLEWARD SHIFT AND
INTENSIFICATION
NPTZ
INCREASE LARGE-SCALE VARIANCE (PDO)
stronger variance and seasonal migration of NPTZ
INCREASE EDDY-SCALE VARIANCE (NPGO)

http://oces.us
THANK YOU!
Significant INCREASE IN THE PDV VARIANCE
INCREASE COUPLING
ARTICLES
PUBLISHED ONLINE: 11 JULY 2016 | DOI: 10.1038/NCLIMATE3082
2016
nature climate change
Multi-year persistence of the 2014/15 North Pacific marine heatwave
Emanuele Di Lorenzo1* and Nathan Mantua2
AGU PUBLICATIONS 2018
Geophysical Research Letters
RESEARCH LETTER
10.1002/2017GL076548
Meridional Modes and Increasing Pacific Decadal Variability Under Anthropogenic Forcing
Giovanni Liguori1 and Emanuele Di Lorenzo1
1School of Earth and Atmospheric Sciences, Georgia Institute of Technology, Atlanta, GA, USA
AGU PUBLICATIONS 2017
Geophysical Research Letters
RESEARCH LETTER
10.1002/2017GL075930
Special Section:
Midlatitude Marine Heatwaves: Forcing and Impacts
Key Points:
• Multiyear SST warm events in the Northeast Pacific typically emerge as a winter NPGO-like warm pattern and transition to a PDO-like pattern in the following winter
• The coupling between winter NPGO and the following winter PDO is a robust climate teleconnection in both observations and the CESM-LENS over the period 1920-2100
• A stronger NPGO-PDO coupling is predicted under anthropogenic forcing in the CESM-LENS and leads to more prolonged and larger area multiyear marine heatwaves
Supporting Information:
• Supporting Information S1
Increasing Coupling Between NPGO and PDO Leads to Prolonged Marine Heatwaves in the Northeast Pacific
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Abstract The marine heatwave of 2014/2015 in the Northeast Pacific caused significant impacts on marine ecosystems and fisheries. While several studies suggest that land and marine heatwaves may intensify under climate change, less is known about the prolonged multiyear nature (~2 years) of the Northeast Pacific events. Examination of reanalysis products and a 30-member climate model ensemble confirms that prolonged multiyear marine heatwaves are linked to the dynamics of the two dominant modes of winter sea surface temperature variability in the North Pacific, the Pacific Decadal Oscillation (PDO), and the North Pacific Gyre Oscillation (NPGO). Specifically, we find a significant correlation between winter warm NPGO anomalies and the following winter PDO arising from extratropical/tropical teleconnections. In the model projections for 2100 under the RCP8.5 scenario, this NPGO/PDO 1 year lag correlation exhibits a significant positive trend (~35%) that favors more prolonged multiyear warm events (>1°C) with larger spatial coverage (~18%) and higher maximum amplitude (~0.5°C for events >2°C) over the Northeast Pacific.
Plain Language Summary Between the winters of 2014 and 2015 the Northeast Pacific experienced the largest and longest marine heatwave ever recorded in the instrumental record. A