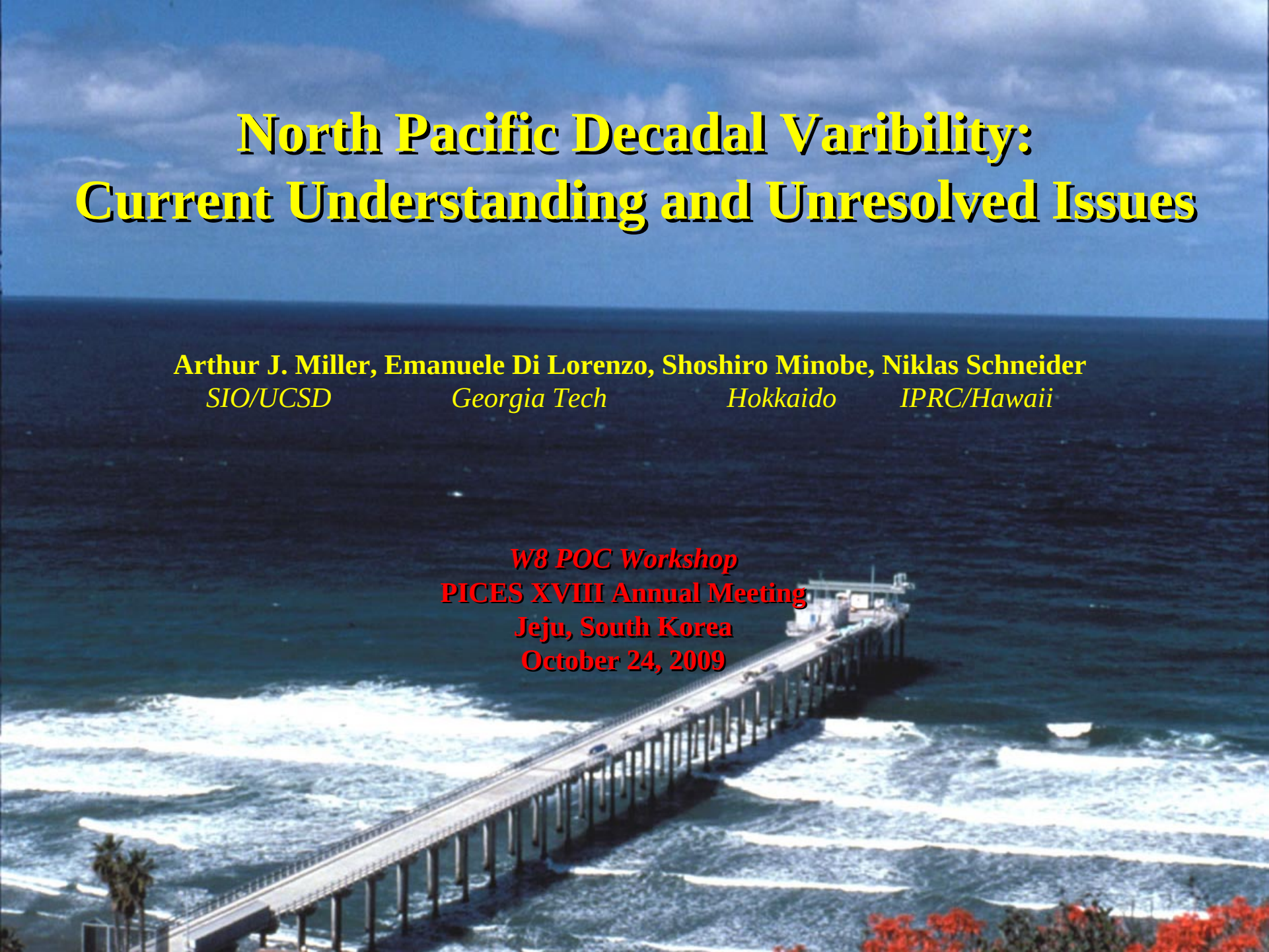
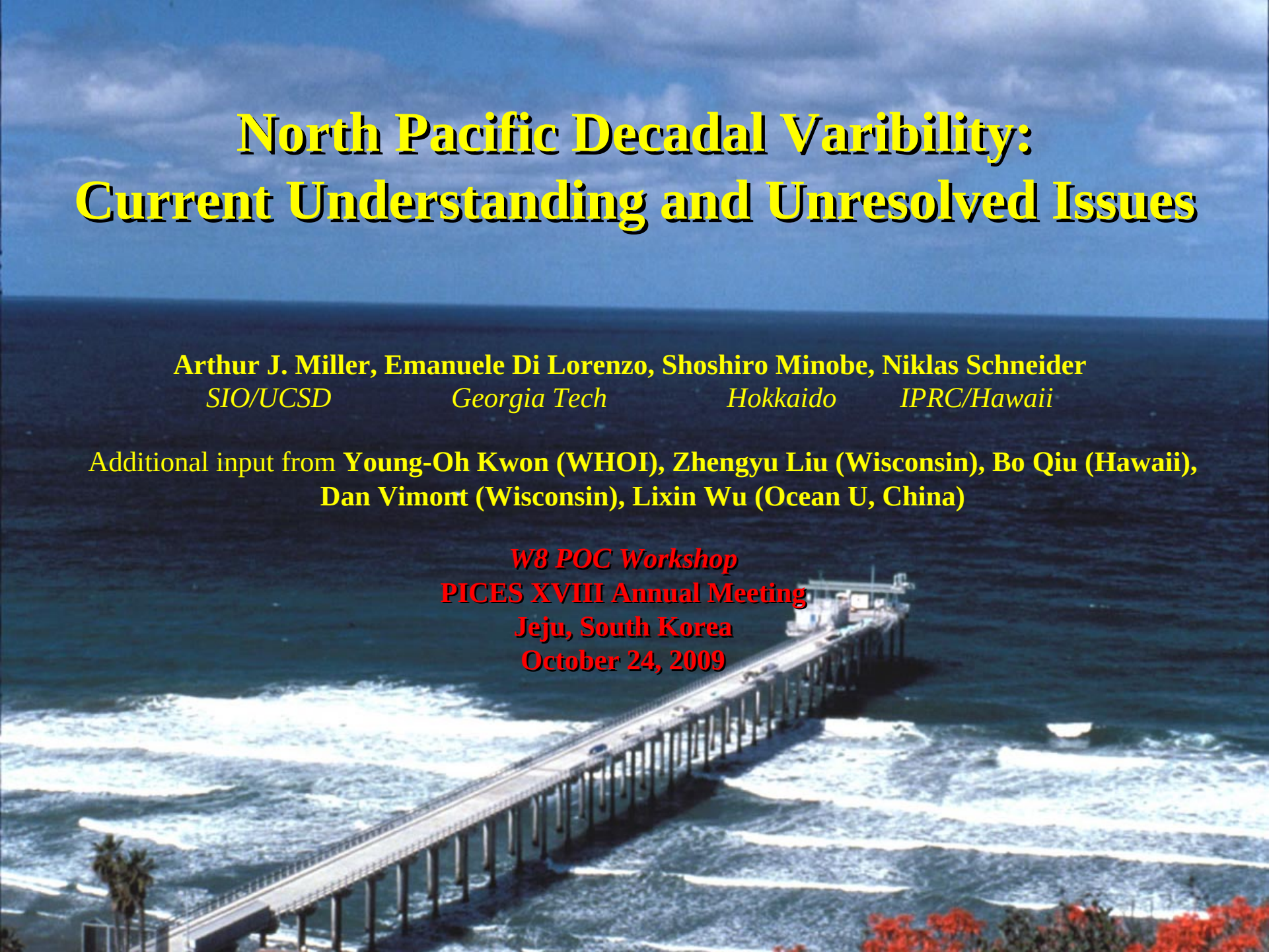
North Pacific Decadal Varibility: Current Understanding and Unresolved Issues

Arthur J. Miller, Emanuele Di Lorenzo, Shoshiro Minobe, Niklas Schneider
SIO/UCSD *Georgia Tech* *Hokkaido* *IPRC/Hawaii*



W8 POC Workshop
PICES XVIII Annual Meeting
Jeju, South Korea
October 24, 2009



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Additional input from **Young-Oh Kwon (WHOI), Zhengyu Liu (Wisconsin), Bo Qiu (Hawaii), Dan Vimont (Wisconsin), Lixin Wu (Ocean U, China)**

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North Pacific Decadal Varibility: Current Understanding and Unresolved Issues

Objectives

1. *Organize ideas from previous talks in this workshop (no repeat slides!)*

2. *Add other ideas that were not discussed*

3. *Assess current understanding and unresolved issues*

Apologies to those whose ideas were neglected!

North Pacific Decadal Varibility: Current Understanding and Unresolved Issues

Initial Considerations….

1. *Observations clearly indicate NP PDV exists*
2. *Oceanic decadal variability can be largely reconstructed by surface flux forcing combined with ocean dynamical response*
3. *Atmospheric response to this SST is not obvious*
4. *Couple feedback loops may exist but have not been conclusively demonstrated*
5. *Predictable components exist in the ocean that may be exploited by biologists*

Sources of North Pacific Decadal Variability

1. Tropical Teleconnections (requires tropical decadal mechanism)
   a. Atmospheric (ENSO-like)
      - canonical SST pattern
      - basin-scale thermocline response
   b. Oceanic (ENSO-like)
      - eastern boundary thermocline response

2. Subduction Modes

3. Midlatitude Gyre Modes

4. Stochastic Forcing
      - oceanic spectral peaks possible
      - predictable components possible

5. Deterministic Forcing
      - solar cycles, greenhouse gases

From: 2003 S5 talk
at PICES XII, Seoul

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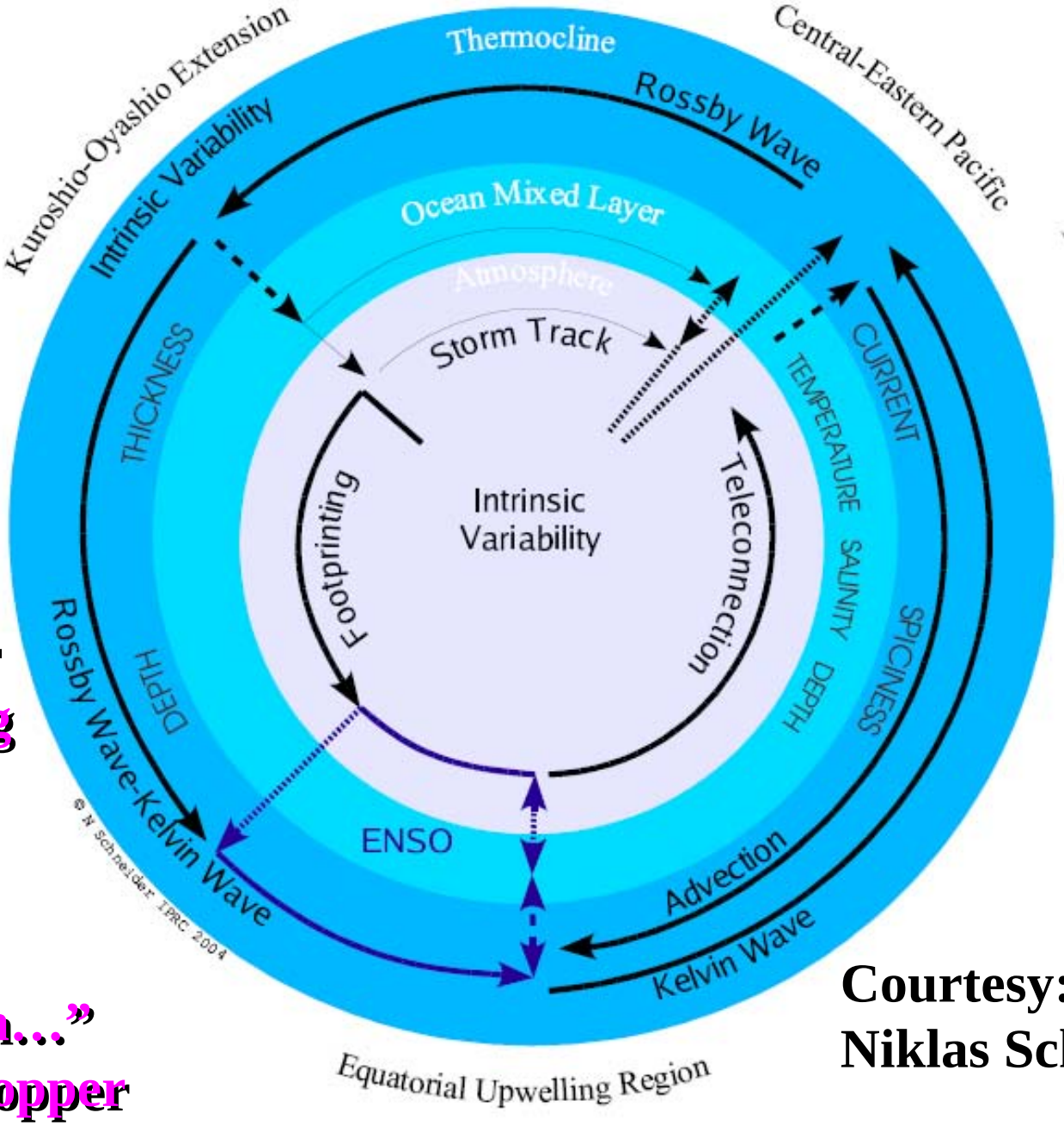
Decadal Variability Roulette Wheel……



"Make me One with Everything"
- Zen Master (to the hot-dog vendor)

"It all fits together, man…"
- Dennis Hopper

Courtesy: Niklas Schneider

Sources of North Pacific Decadal Variability

Dozens of theories and scores of simple models exist…

Testing them against observations is essential…

Recognizing the limited data record…

Greatest test is predictability of ocean and/or atmosphere…

Sources of North Pacific Decadal Variability

PDO: First EOF of SST, north of 20N; symptom but not a reason
- oceanic expression of Aleutian Low
- includes parts driven by stochastic atmospheric forcing,
tropical teleconnections, remotely forced
ocean current advection and thermocline activity,
and possibly O-A feedbacks

Deser et al.: tropical heating linked to PDO on 50-yr timescales
(Minobe pentadecadal mode; source of this period?)

Schneider and Cornuelle: PDO= ENSO, intrinsic + RW
Nigam: PDO separated from non-linear trend and
another decadal part
Yeh et al.: PDO dominance reduced in recent decades
McKinnell: PDO forced deterministically by solar
and 18.6-year tides
Qiu et al.: PDO–related forcing drives KE axis position by
Rossby waves
Nonaka et al.: KE and OE fronts respond linearly and non-linearly
to Rossby waves and upstream PV and SST

Sources of North Pacific Decadal Variability

NPGO: Second EOF of SLH; symptom but not a reason
- oceanic expression of NPO
- includes parts driven by stochastic atmospheric forcing, ocean current advection and thermocline activity, teleconnections to tropics (PMM, SFM; Vimont-Alexander), remote forcing from tropics, and possibly O-A feedbacks

Di Lorenzo et al.: NPGO linked to equatorially symmetric, global structures, and leads ENSO

Yeh et al.: NPGO dominance increases in recent decades

Wu et al.: PDO more significant impact on tropics than NPGO

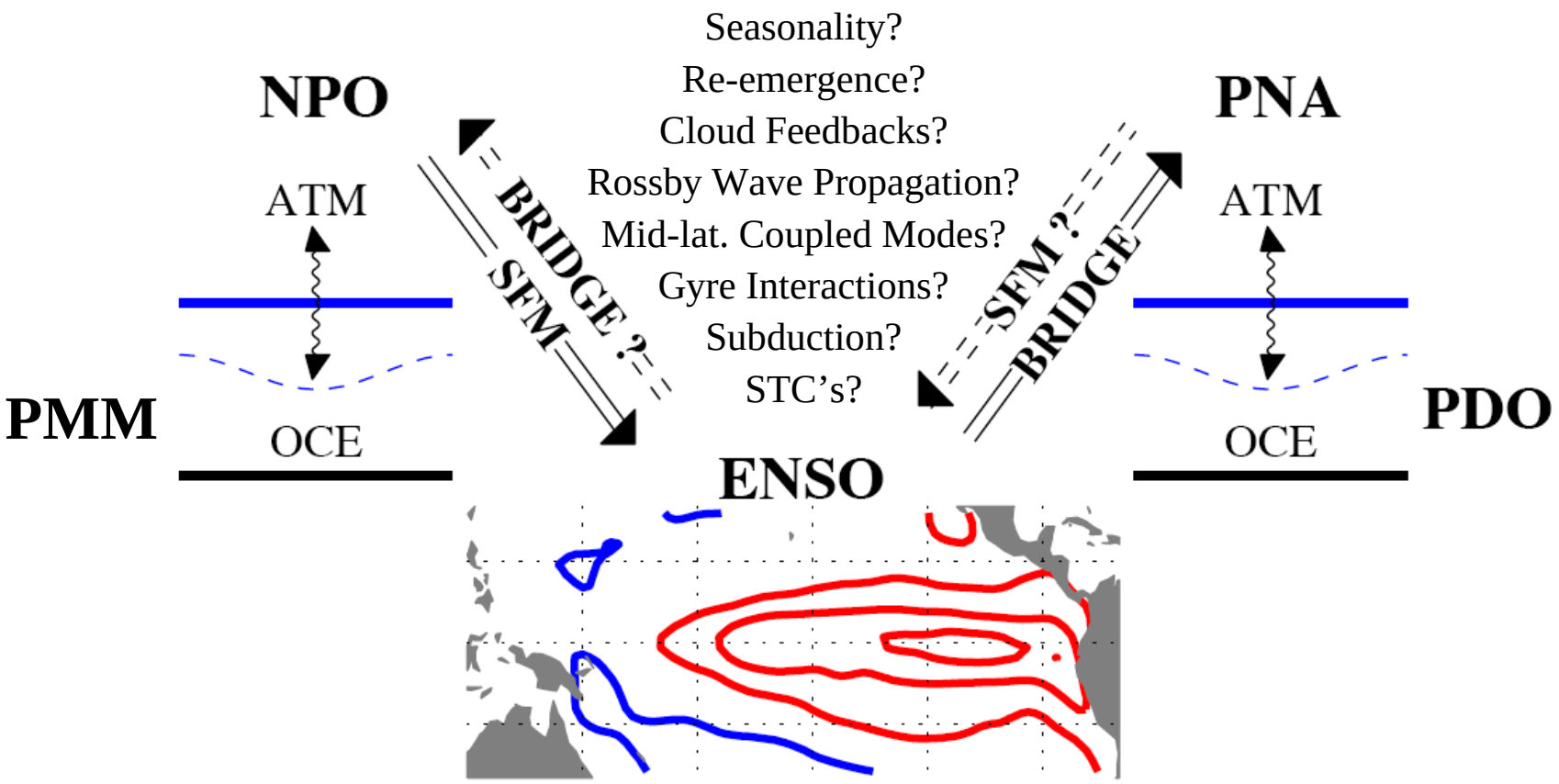
Qiu et al.: NPGO–related forcing drives KE strength by Rossby waves, a la Ceballos et. al.

Taguchi: NPGO-related forcing drives frontal-scale KE patterns
=> fronts increase baroclinicity in overlying atmosphere

Schneider: Ekman pumping (adiabatic) effects of SST fronts on tropospheric vorticity

Pacific Climate Variability: Tropical-Extratropical Coupling Associated with the Seasonal Footprinting Mechansim

Courtesy: Dan Vimont



Is there a resulting decadal oscillation?

Sources of North Pacific Decadal Variability

2. Midlatitude Gyre Modes

Latif and Barnett (1996; 1996): Combination of gyre adjustment to an initial wind-stress curl pattern, with lagged SST change, and atmospheric response that switches the sign of the initial wind stress curl pattern

Ideas were provocative, but details did not pan out…

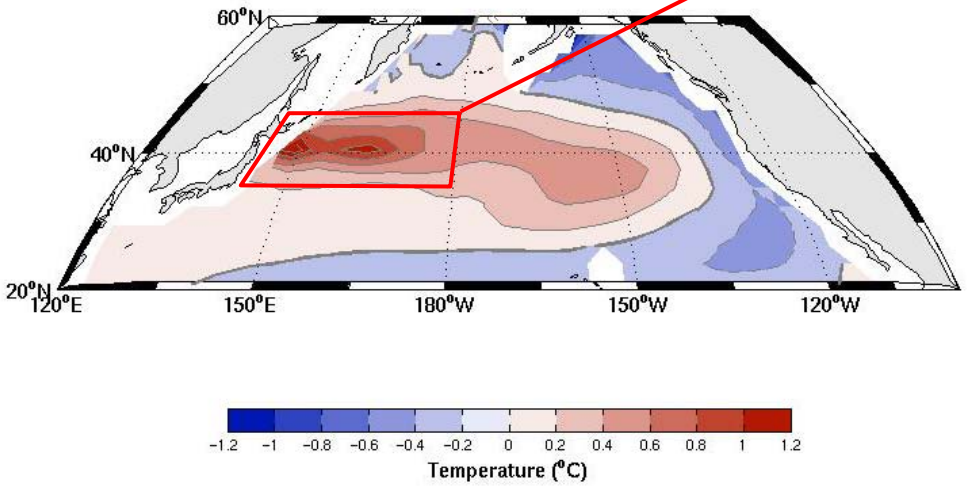
Qiu: used observed curl response to SST to build simple lagged, delayed oscillator model

Kwon and Deser (2007): Long run of CCSM3 reveals 16-peak

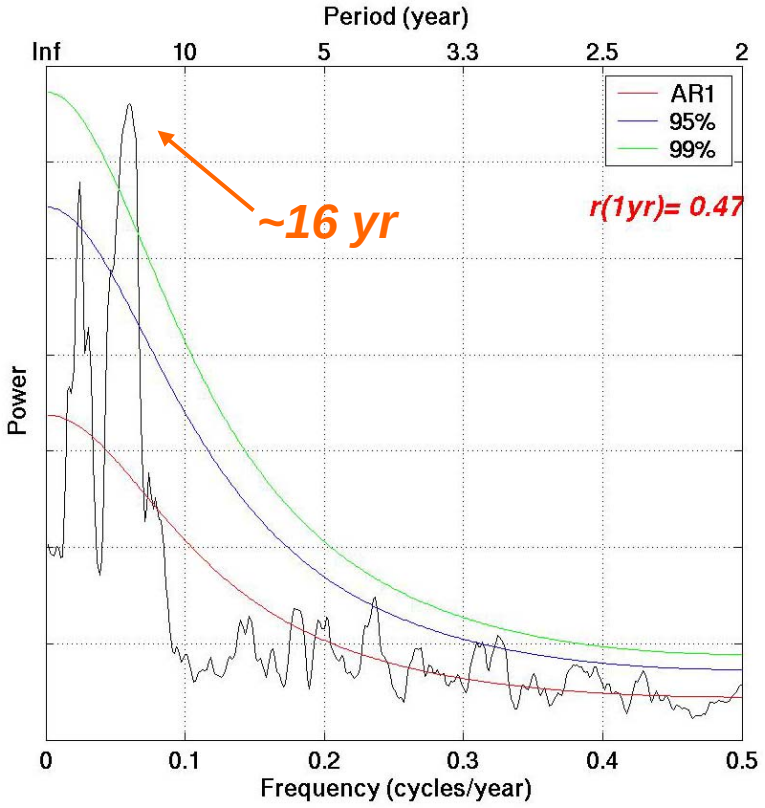
Note: weak tropical teleconnection => “pure” midlatitude mode

CCSM2 North Pacific Decadal Variability (CCSM2 control integration: Year 350-999)

Winter SST EOF 1 (21%)



Kuroshio Extension SST Index

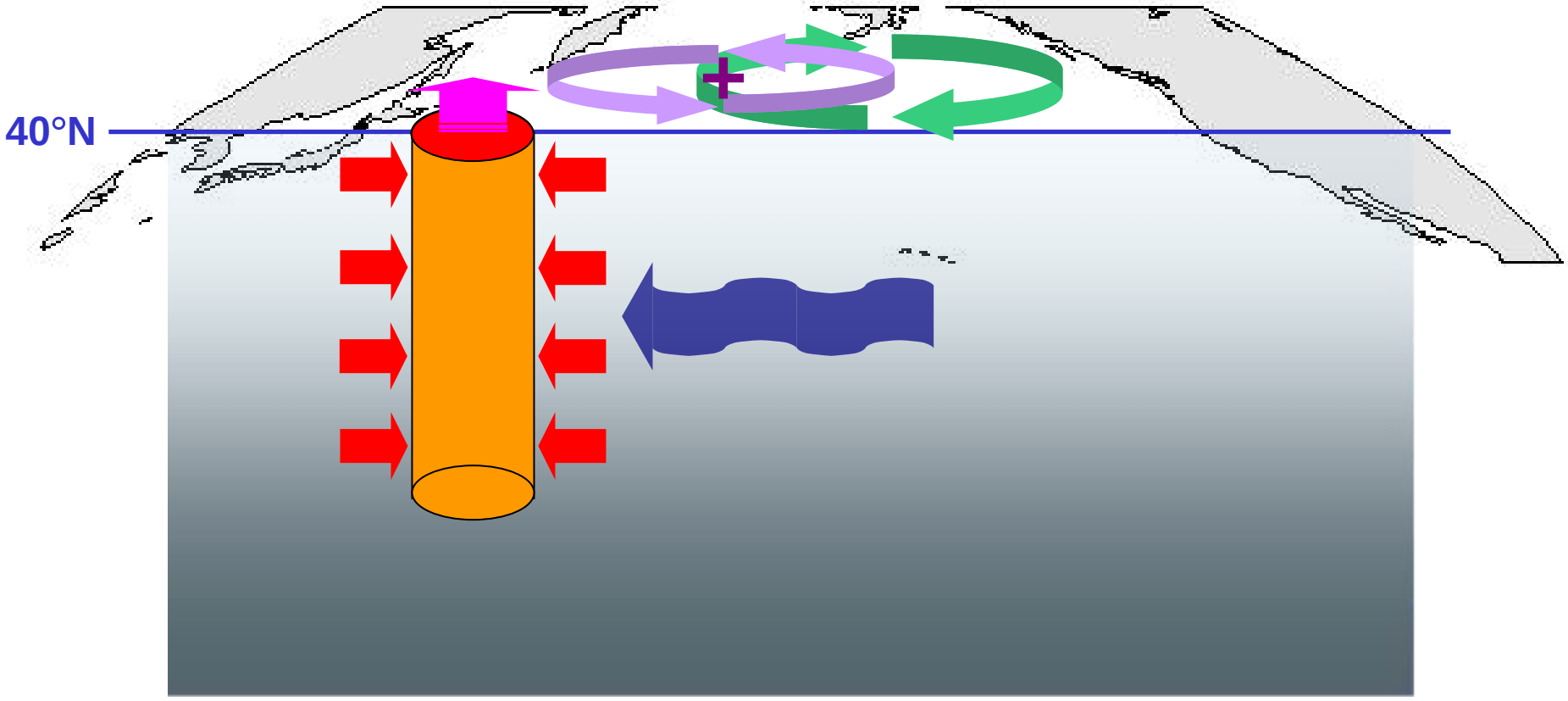


Kwon and Deser (2007, J. Climate)

Courtesy: Young-Oh Kwon

Ocean-Atmosphere Coupled Mode in CCSM2

(~16-yr Time Selection: First Mode Baroclinic Adjustment)



Courtesy: Young-Oh Kwon

Kwon and Deser (2007, J. Climate)

Ocean-Atmosphere Coupled Mode in CCSM2

(~16-yr Time Selection: First Mode Baroclinic Adjustment)

Negative Wind Stress Curl Anomaly

In the Central North Pacific

: Northward shift of zero wind stress curl line

~ 4 years

Geostrophic Heat Flux Convergence

In the Kuroshio Extension

: Northward shift of gyre boundary

~ 1 years

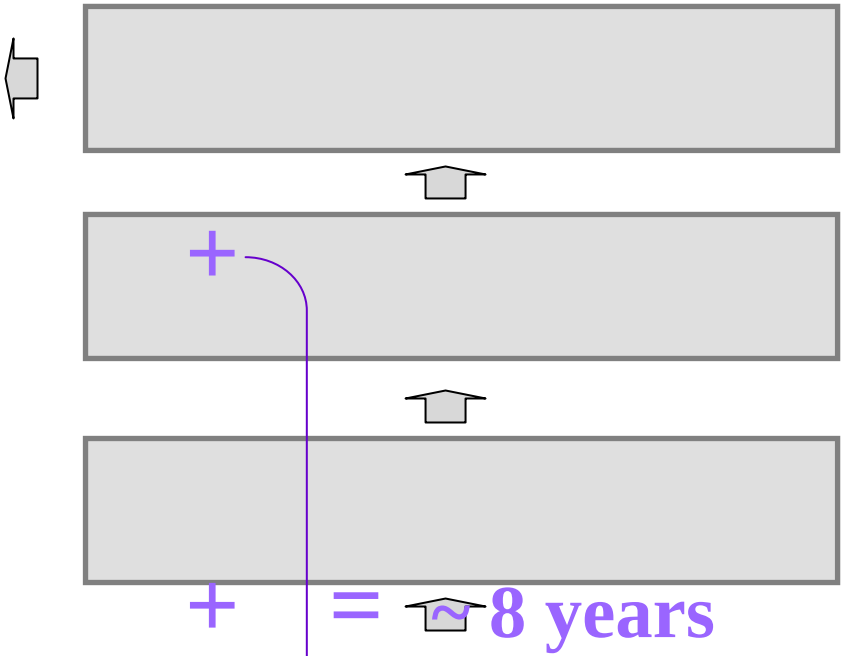
Warmer SST Anomaly

In the Kuroshio Extension

~ 1 years

Ocean-to-Atmosphere Surface Heat Flux Anomaly

In the Kuroshio Extension



+ + + = ~8 years

Positive Wind Stress Curl Anomaly

In the central North Pacific

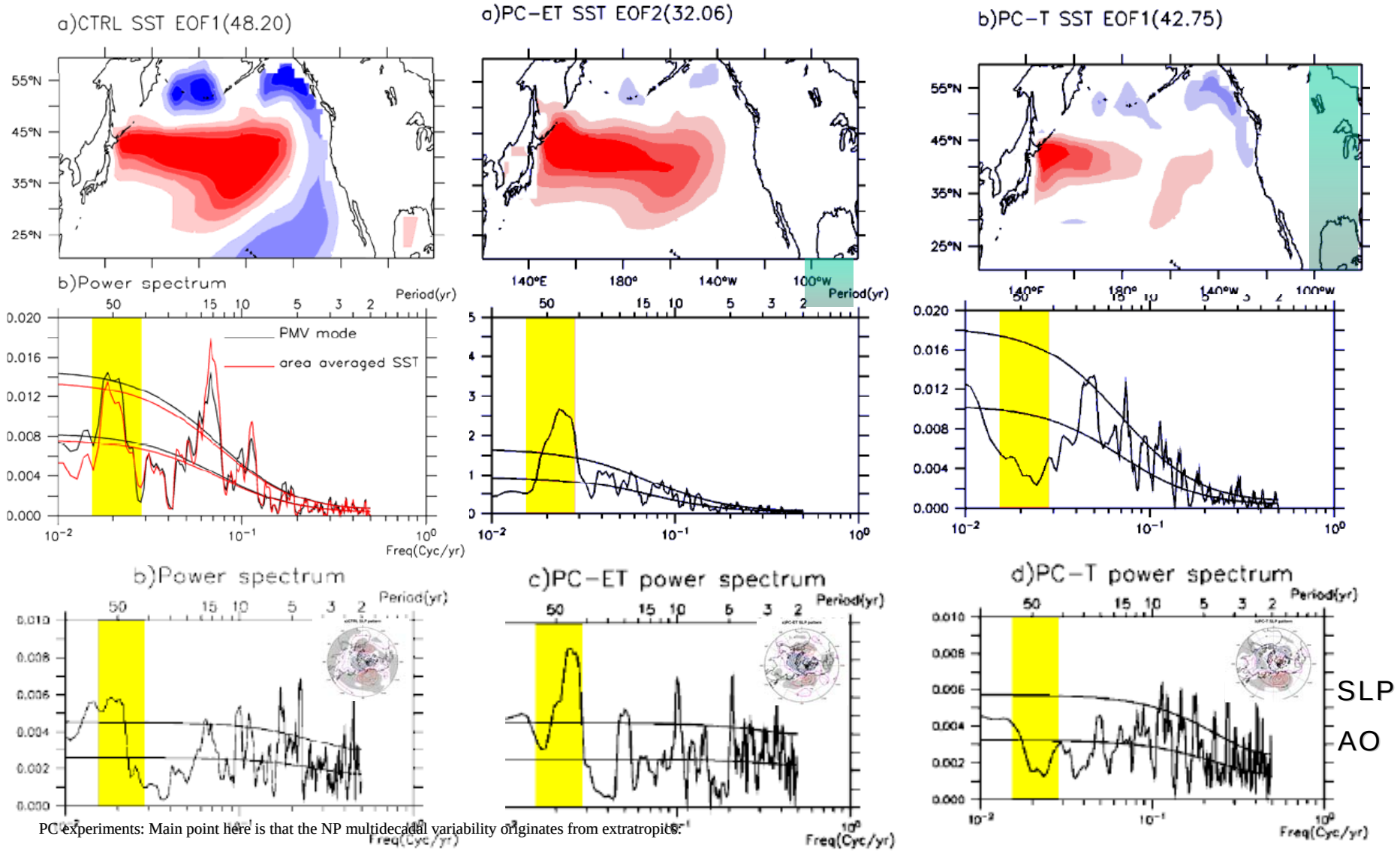
~ 2 years

: Eastward advection and expansion

Courtesy: Young-Oh Kwon

NPM: Region of Ocean-Atmos. Interaction (CCSM3)

CTRL PC-ET (Courtesy: Z. Liu) PC-T



PC experiments: Main point here is that the NP multidecadal variability originates from extratropics.

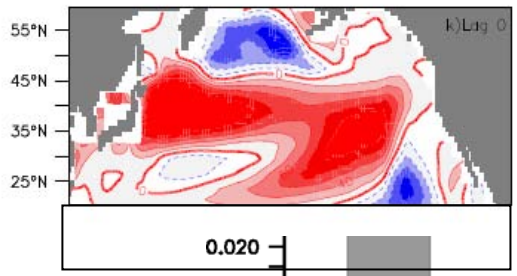
The 50-yr peak in CTRL (left) persists in PC-ET (middle) coupling shut-off 20S-20N), but disappears in PC-T (right) coupling shut-off north of 20N).

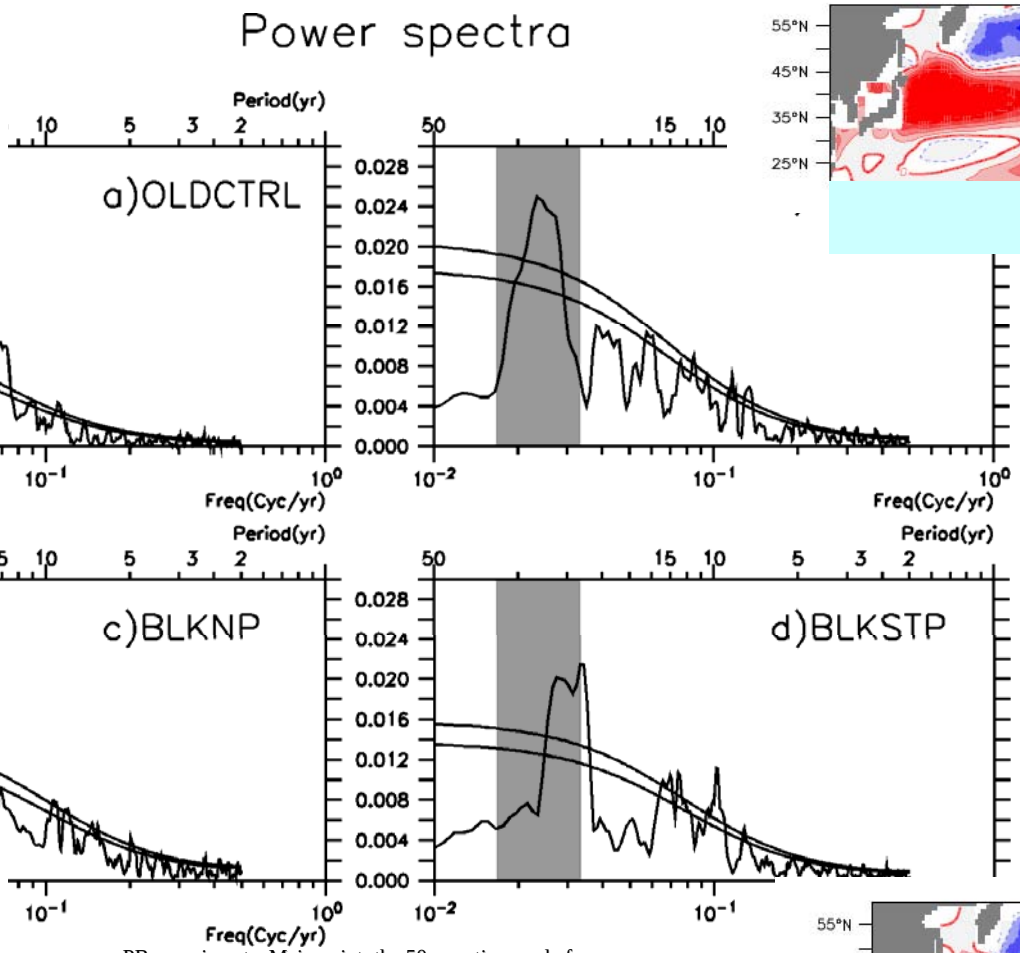
2nd point: The 50-year peak is significant in both the SST (middle row) and atmosphere (AO, bottom row, EOF1 of SLP), so the atmosphere knows the extratropical ocean, but unclear if extratropical coupilng is critical to the existence of the mode.

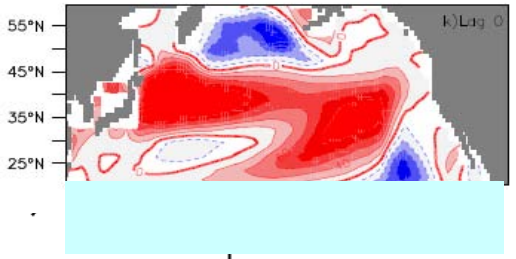
Zhong et al., 2008, JC

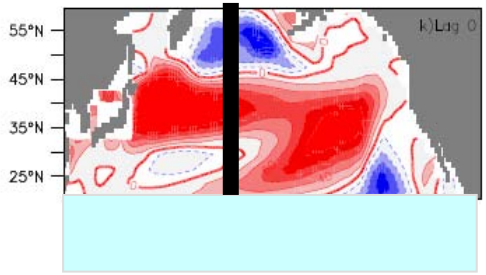
NPM: Origin of Ocean Dynamics

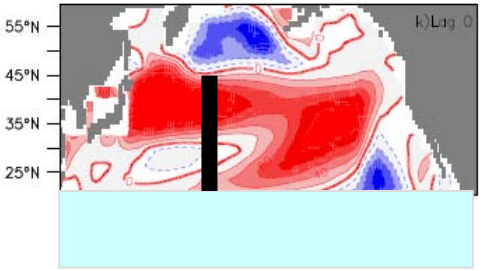
Origin: Subpolar Route ! (Courtesy: Z. Liu)











PB experiments: Main point: the 50-year time scale from subpolar North Pacific ocean.

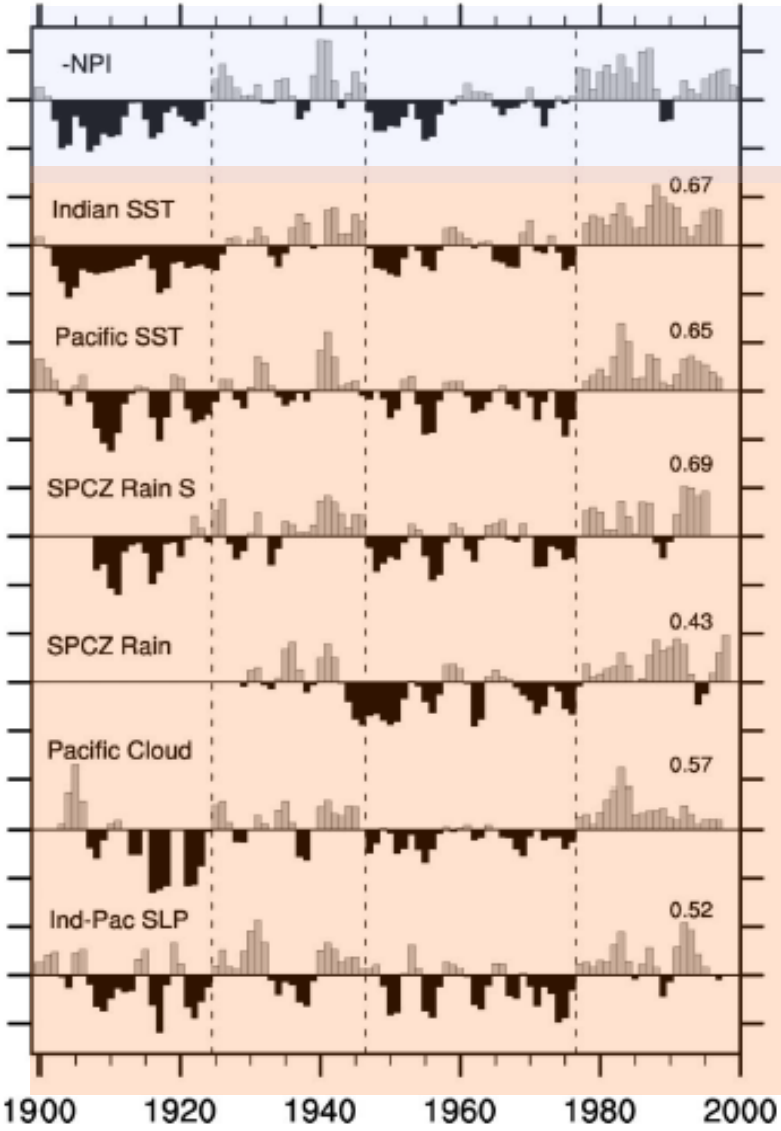
(top left) CTRL, (top right, PC-ET, no coupling in tropics), (bottom left) PB (blackline) along 180oE across entire Pacific (no 50-yr peak!)

(bottom right) PB only to 40N (bllackline) 50-year peak appears again.

Zhong and Liu, 2009, JPO

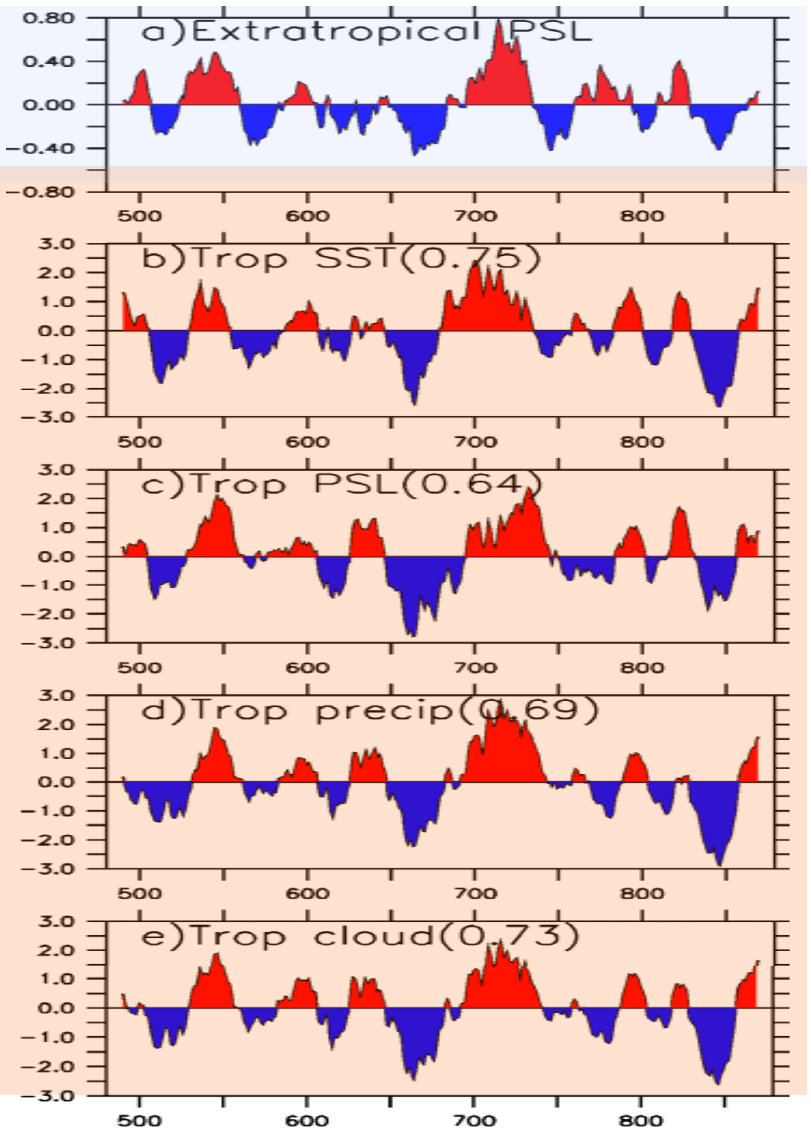
<NP, TP> Coherence =/= Tropical Origin!

Observation (Courtesy: Z. Liu) **CCSM3**



NP

TP



Main point: diagnostics does not tell tropical or extratropical origin: same diagnostics as Deser et al. (2004), suggesting coherence of multedecadal variability between NP and tropics in the observation (left, Deser et al. 04) and CCSM3 (Zhong et al., 2008) CTRL. But, as shown before, in CCSM3, the origin is in the extratropical N. Pacific, even thought the tropical-NP same cohereence.

Sources of North Pacific Decadal Variability

4. Stochastic Forcing

- oceanic spectral peaks possible

- predictable components possible

Hasselmann model: White noise spectrum reddened by ocean, with feedback parameter flattening the spectrum at low-freq

Ocean dynamical effects:

- Spatial resonance: preferred spatial scales of atmosphere transformed into preferred temporal scales of ocean
  - Jin (1997), Saravanan and McWilliams (1998)
    Weng and Neelin (1997): ocean advection and/or waves
- Latitudinally varying beta-effect:
  - Qiu (2003)

Magnitude of the wind-forced SLH gradients across the KE jet is sensitive to the period of the wind forcing (Qiu, 2003)

- Consider the following stochastic forcing problem:

$$\frac{\partial h'}{\partial t} - c_R \frac{\partial h'}{\partial x} = F(x)W(t),$$

"white" curl forcing in the east

- Taking the SSH difference across the zonal jet, the power spectrum for $\langle \delta h' \rangle$ under $|\widehat{W}(\omega)|^2 = 1$ is:

$$|\langle \widehat{\delta h'} \rangle(\omega)|^2 = \frac{T^2}{\pi^2 L^2}\left[\sin^2\left(\frac{\pi L}{T c_{RA}}\right) + \sin^2\left(\frac{\pi L}{T c_{RB}}\right) - 2\sin\left(\frac{\pi L}{T c_{RA}}\right)\sin\left(\frac{\pi L}{T c_{RB}}\right)\cos\left(\frac{2\pi C}{T c_{RB}} - \frac{2\pi C}{T c_{RA}}\right)\right].$$

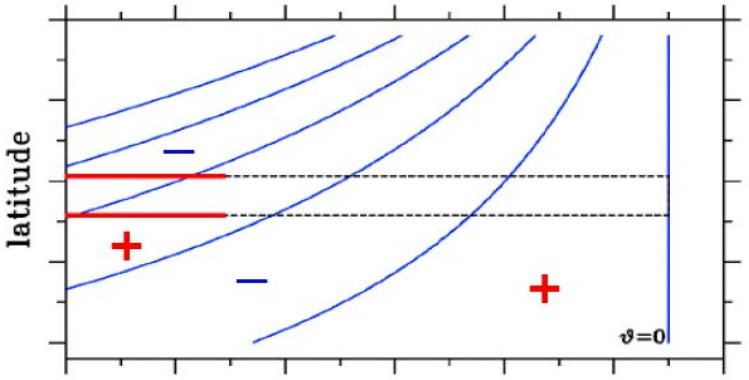
power of KE jet currents response has peak when beta=beta(y)

- In between these two limits, an optimum T exists for which $|\langle \widehat{\delta h'} \rangle|^2$ is a maximum. Using values appropriate for the N Pacific, we have:

$$T_{optimum} \simeq 10 \text{ yrs.}$$

- This "preferred" forcing period is *not* very sensitive to the detailed values of the chosen C, L, A and B.

optimum period -> peak



Courtesy: Bo Qiu

Unresolved Issues of North Pacific Decadal Variability

- Does NPO have a tropically forced component
- Low-frequency dynamics of SST, SFM in subtropics: mechanism of midlatitude-tropical decadal variability?
- Atmospheric response to KOE SST, especially frontal scale
- Role of Ekman pumping of the atmosphere by frontal structures.
- Phasing of PDO and NPGO influence on KOE strength and position
- Intrinsic KOE variability: Nuisance or Need?
- Subduction of thermal/spiciness anomalies to tropics
- Intrinsic versus solar and tidal effects
- Additional predictable components and applications
- Is ice cover just a symptom or a coupled contributor?
- Global change, intensification of the hydrological cycle
- Sort out all the indices!

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PICES XVIII Annual Meeting

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Thanks to everyone for the contributions!

An observationally constrained air-sea coupled system

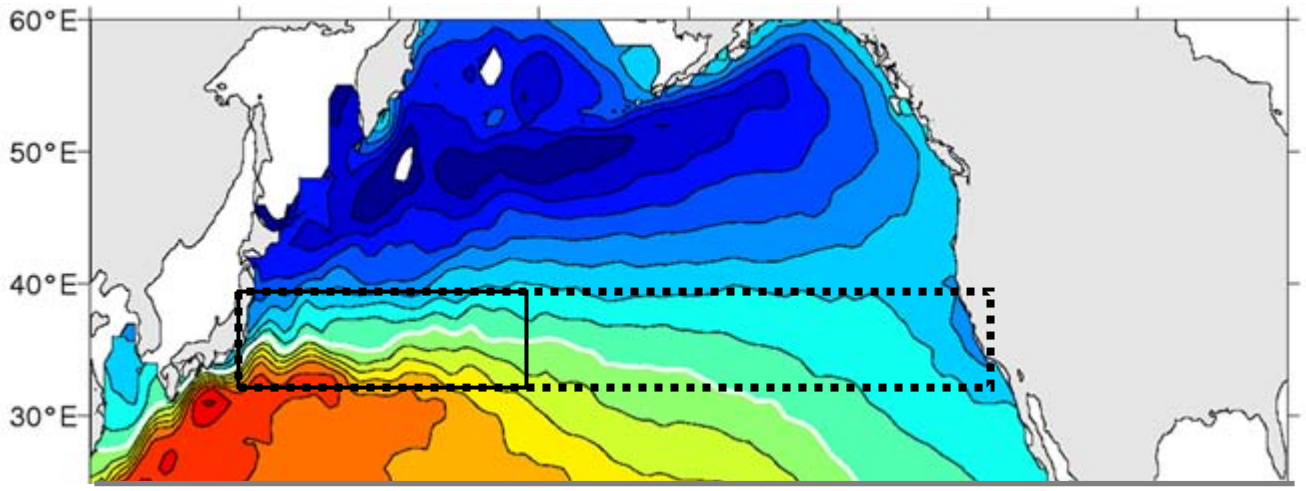
(Qiu, Schneider, Chen, 2007)

$$\frac{\partial h(x,t)}{\partial t} - c_R \frac{\partial h(x,t)}{\partial x} = -\frac{g' \,\mathrm{curl}\boldsymbol{\tau}}{\rho_o g f} \qquad (1)$$

$$\frac{\partial T(t)}{\partial t} = a\,\overline{h(t)} - \lambda T(t) + q(t) \qquad (2)$$

$$-\frac{g' \,\mathrm{curl}\boldsymbol{\tau}}{\rho_o g f} = \sum_{n=1}^{2} \sin\left(\frac{n\pi x}{W}\right) w_n(t) + b \sin\left(\frac{2\pi x}{W}\right) T(t) \qquad (3)$$

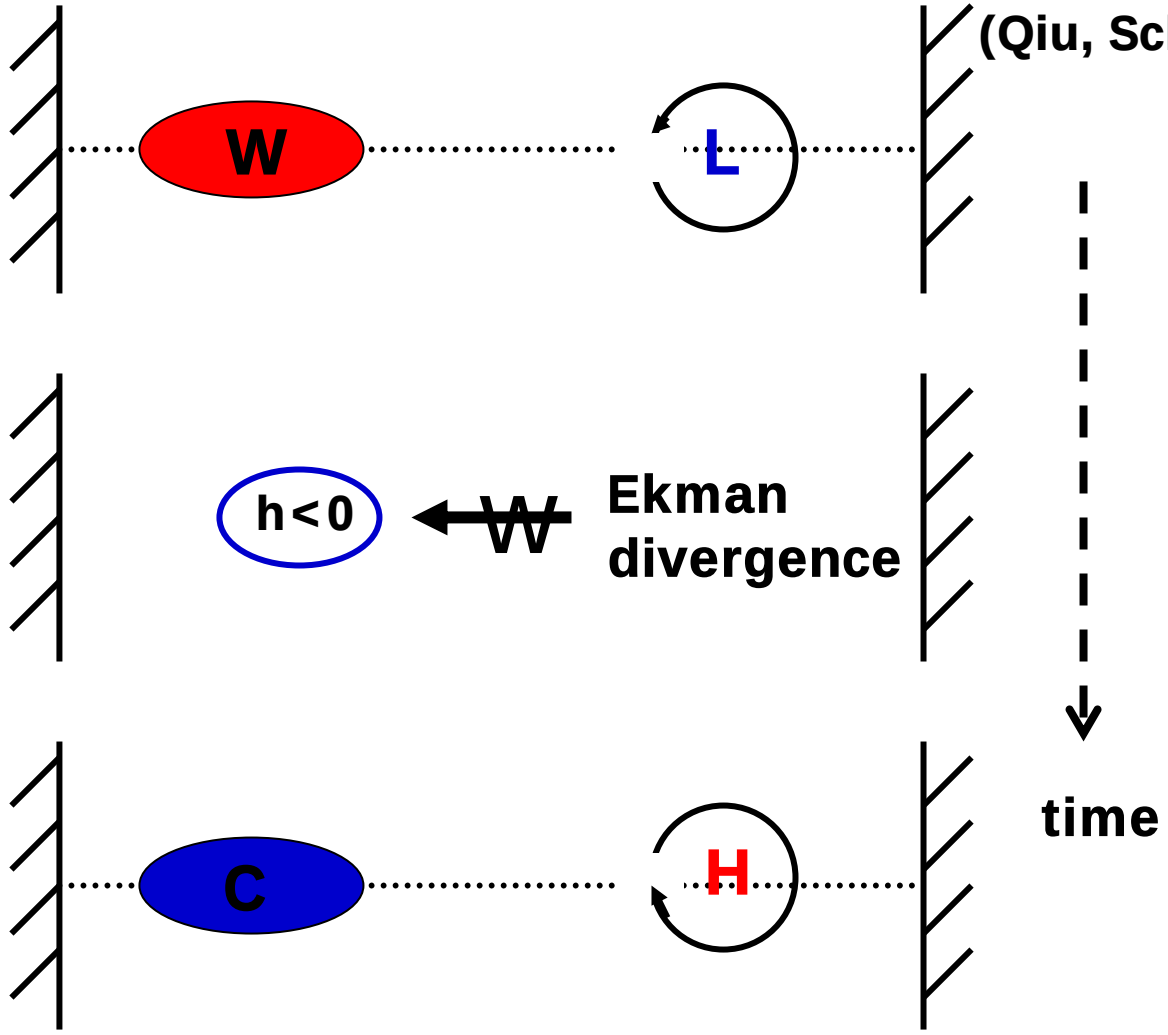
intrinsic **feedback**



x=-W x=-W+L x=0

Courtesy:
Bo Qiu

Schematic for the coupled oscillation



half of the optimal period ~ (W / 2) / c_R

Courtesy: Bo Qiu

Coupled Ocean-Atmosphere Response to PDO and NPGO SST Forcing

Partial-coupling Experiment (FOAM model):

Courtesy: Lixin Wu

Impose PDO and NPGO SST forcing over the North Pacific (north of 20N) while O/A remains fully coupled elsewhere.

Preliminary Conclusions:

1. PDO SST forcing tends to have a more significant impact on the tropics than the NPGO SST forcing

2. Positive feedbacks for PDO-PNA and NPO-NPGO are implied in PC expts: