THE PACIFIC DECADAL OSCILLATION, REVISITED

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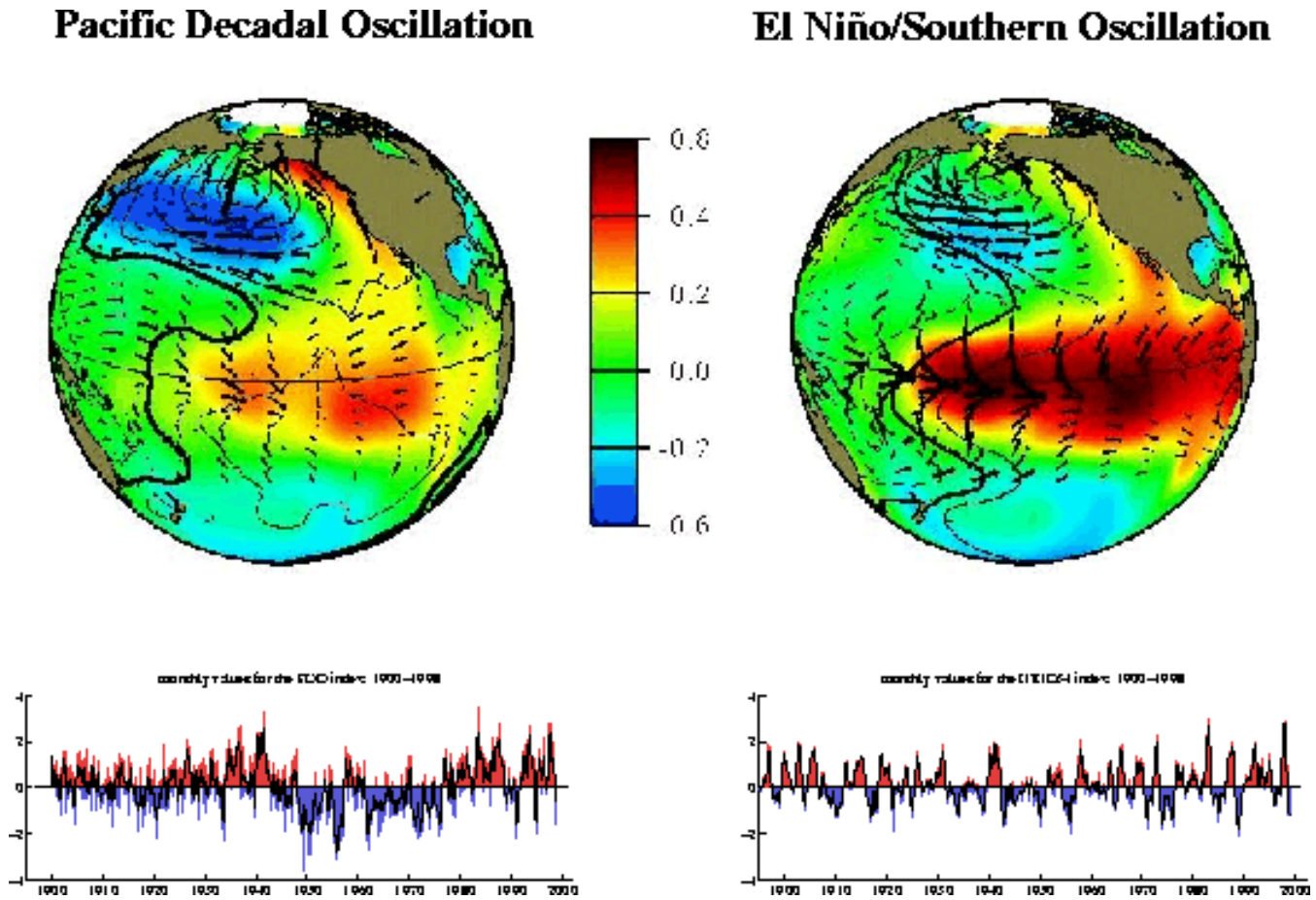
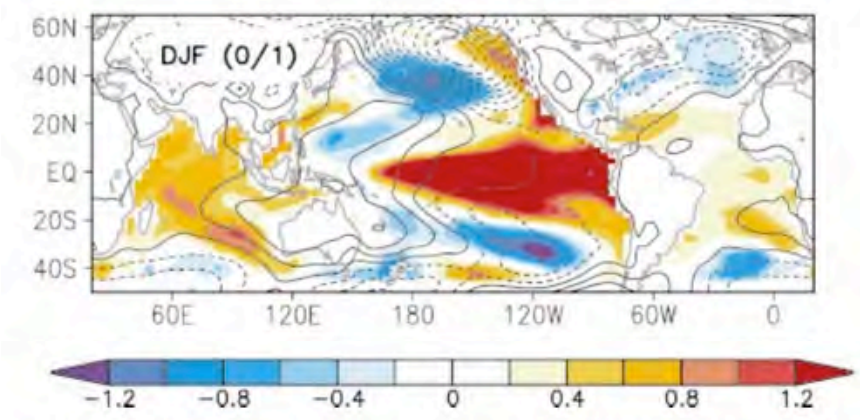
PDO and ENSO

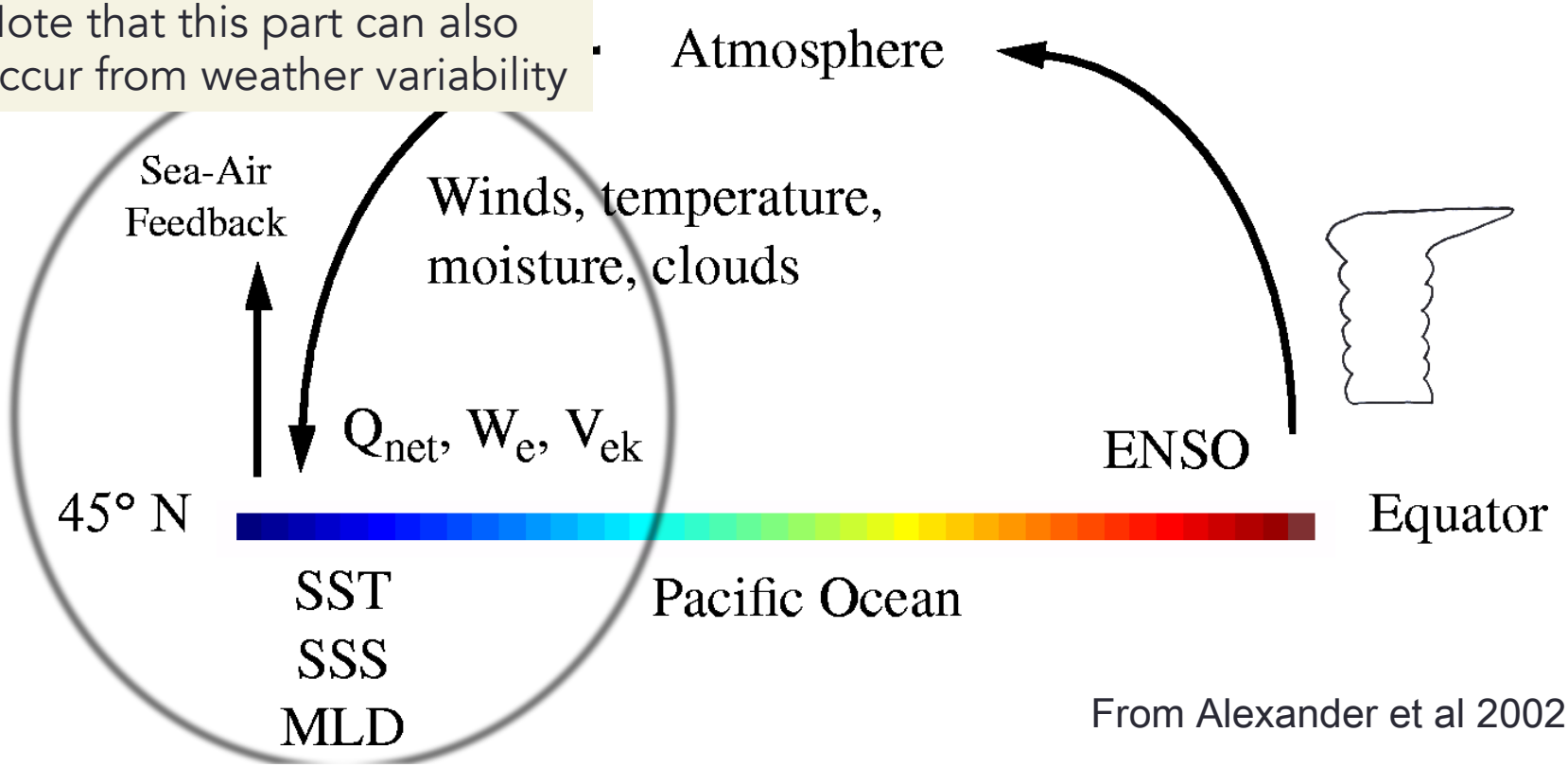

Pacific Decadal Oscillation
El Niño/Southern Oscillation
0.6
0.4
0.2
0.0
-0.2
-0.6

ENSO forces remote changes in global oceans via the "Atmospheric Bridge"

Observed ENSO composite (warm-cold events)



Note that this part can also occur from weather variability

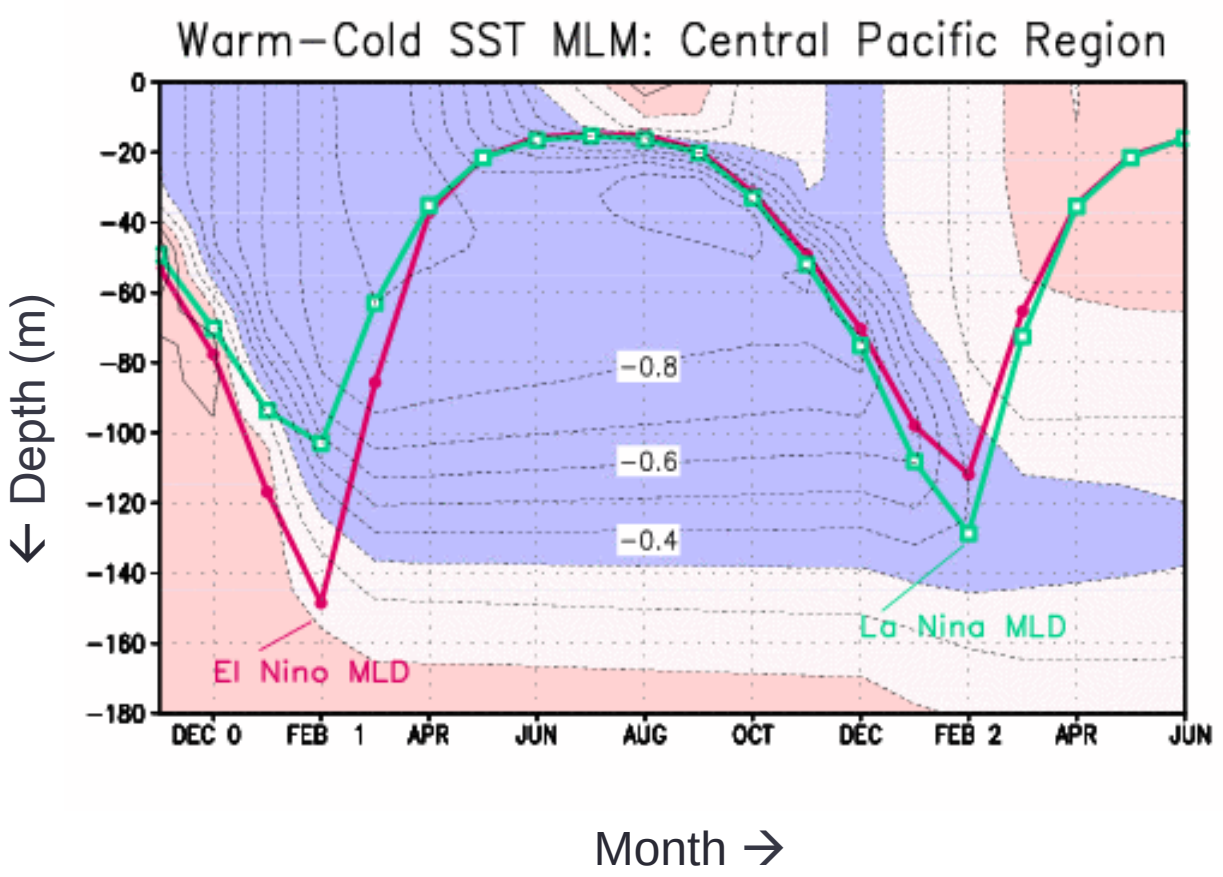


From Alexander et al 2002

"Re-emergence" : SST anomalies can recur in consecutive winters in the extratropics

Depth vs. time cross-section of ocean temperature anomalies (°C) in the central Pacific

Thick lines indicate seasonal evolution of the depth of the "mixed layer" (where heat is well-mixed)

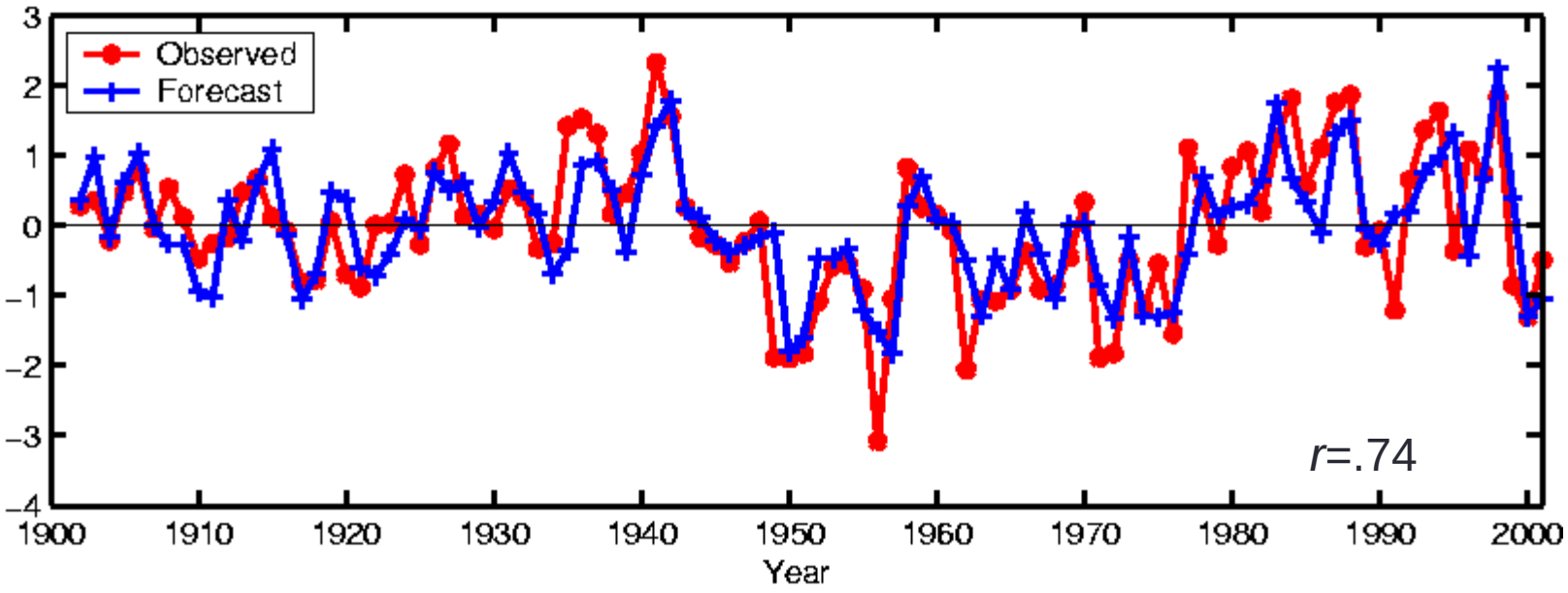


From Alexander et al 2002

PDO depends on ENSO and re-emergence

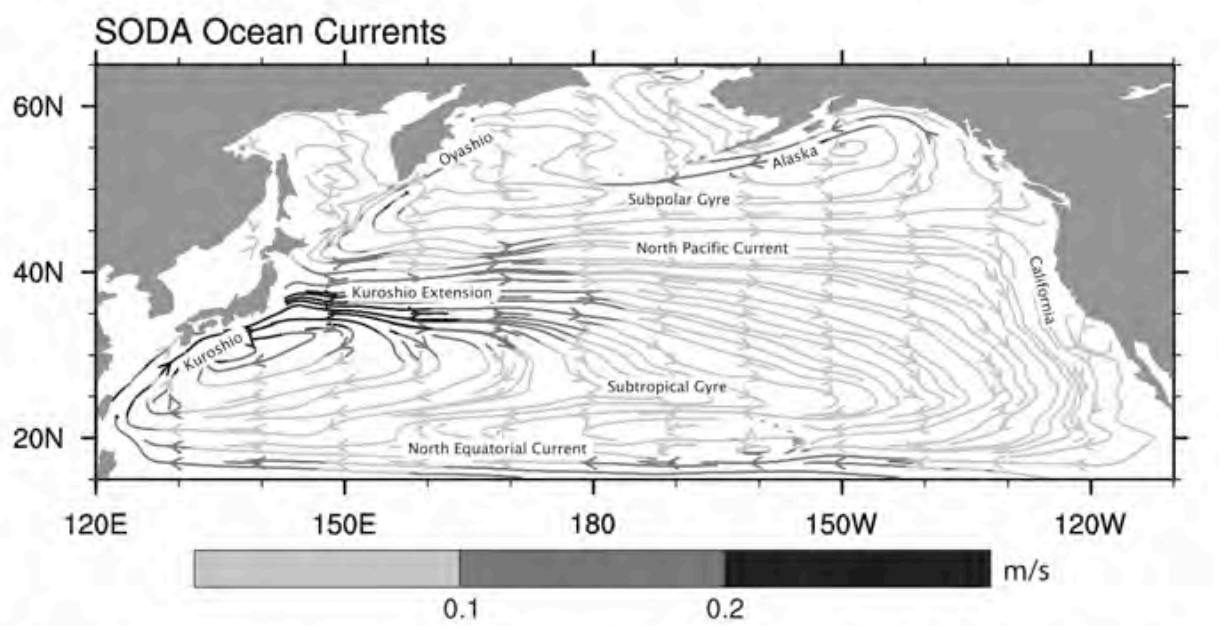
$$PDO_{(this\ year)} = 0.6 \times PDO_{(last\ year)} + 0.6 \times ENSO_{(this\ year)} + weather\ noise$$

ENSO forcing of simple AR1 model, or "reddened ENSO"



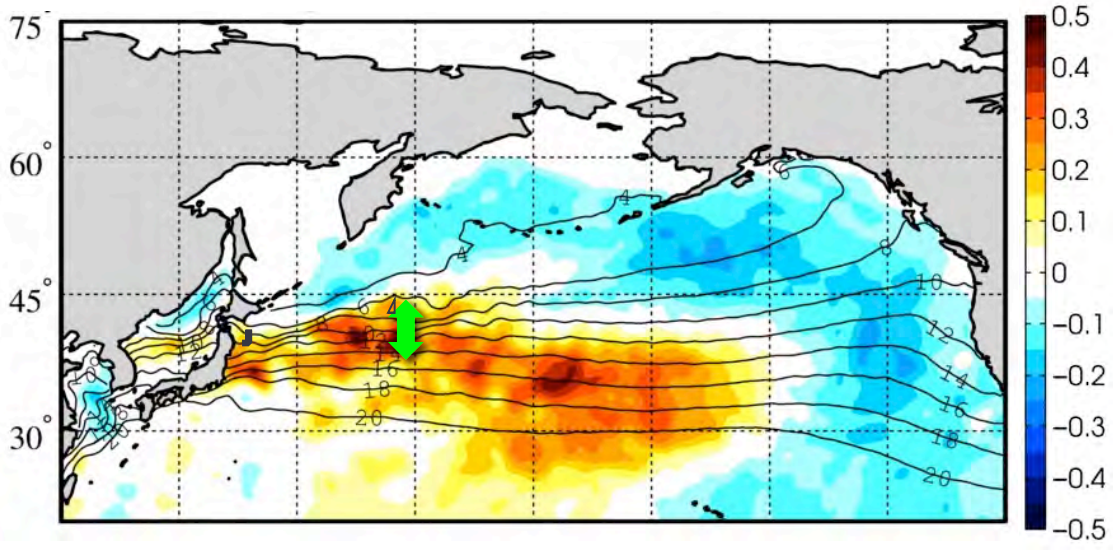
$$Forecast:\ PDO_{(this\ year)} = .6PDO_{(last\ year)} + .6ENSO_{(this\ year)}$$

Pacific Ocean currents and variability



Kuroshio-Oyashio Extension (KOE) system is a key component of the North Pacific ocean-atmosphere system

Shifts in the Oyashio extension (SST front) are associated with longer time scales (westward propagating Rossby waves)



"Multivariate Red Noise"

- Noise/response is local (or an index)
  - For example, air temperature anomalies force SST
  - use univariate ("local") red noise:

$$dx/dt = bx + f_s$$

where $x(t)$ is a scalar time series, $b<0$, and f_s is white noise

- Noise/response is non-local: patterns matter
  - For example, SST sensitive to atmospheric gradient
  - use multivariate red noise (Ornstein-Uhlenbeck):

$$d\mathbf{x}/dt = \mathbf{B}\mathbf{x} + \mathbf{F}_s$$

where $\mathbf{x}(t)$ is a series of maps, $\mathbf{B}$ is stable, and $\mathbf{F}_s$ is white noise (maps)

  - If $\mathbf{B}$ is nonnormal (not symmetric), transient anomaly growth is possible even though exponential growth is not
- Determine $\mathbf{B}$ with "linear inverse model" (LIM), from lagged covariability (*space and time*) statistics of x

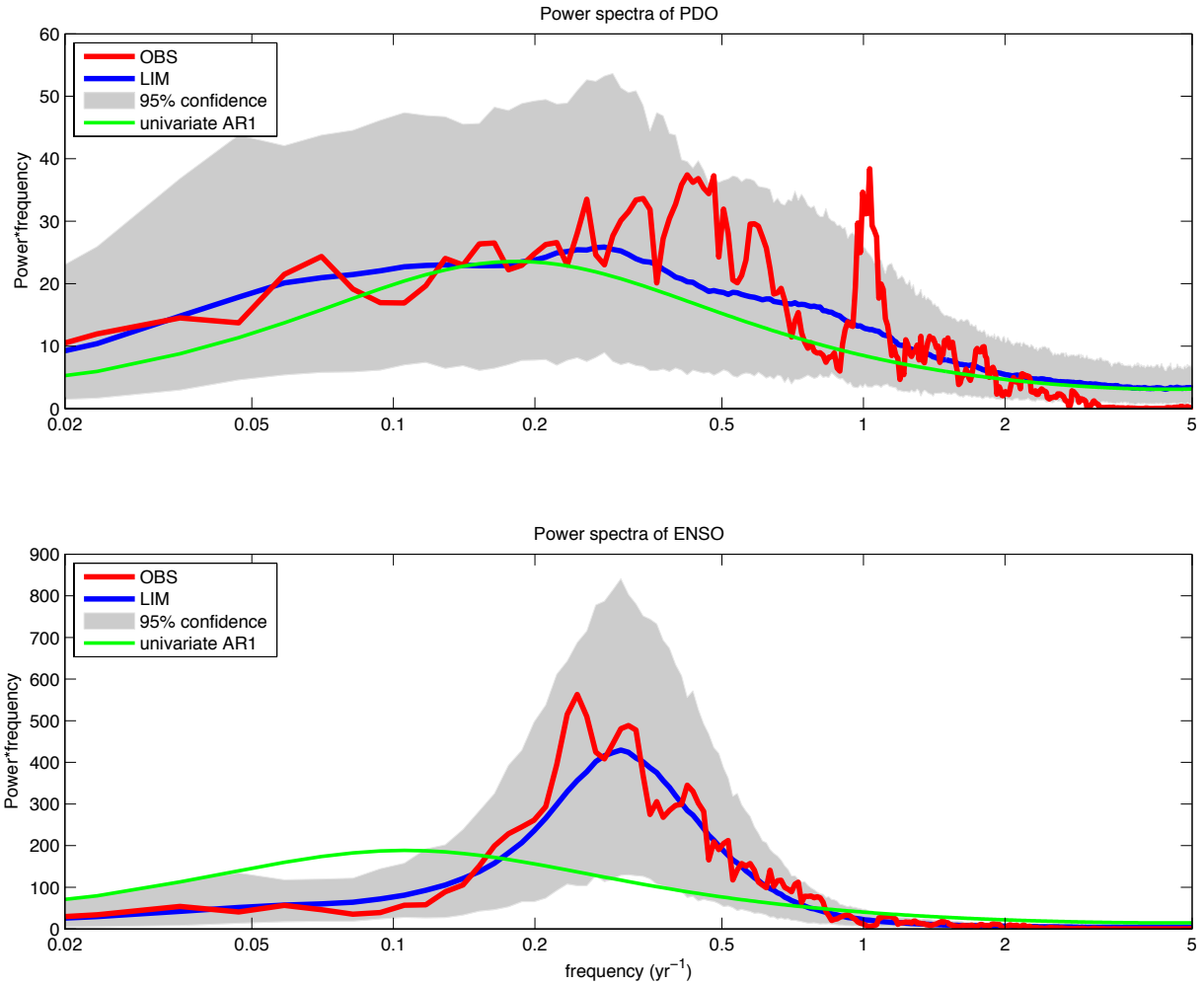
PDO/ENSO spectra

$dx/dt = Bx + F_s$

x represents seasonal mean anomalies, 1958-2008, of

- Pacific SST
- tropical thermocline depth (20°C isodepth)
- North Pacific mixed layer (30-100m) temperature

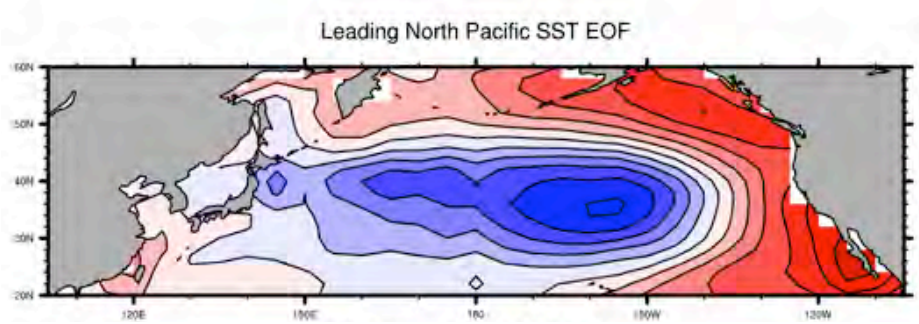
B determined from 3-month lag

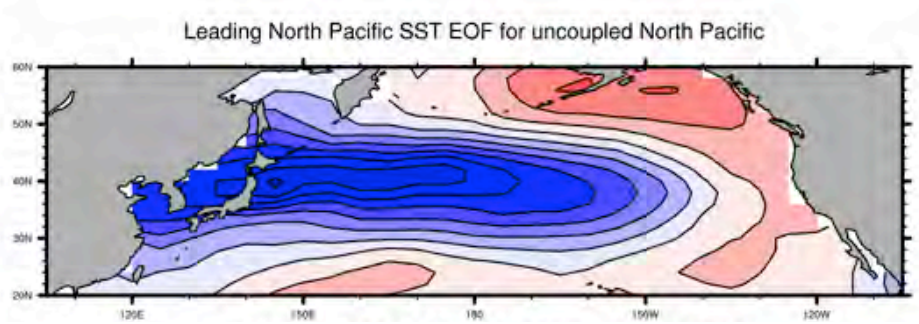


Dominant "internal" North Pacific SST mode

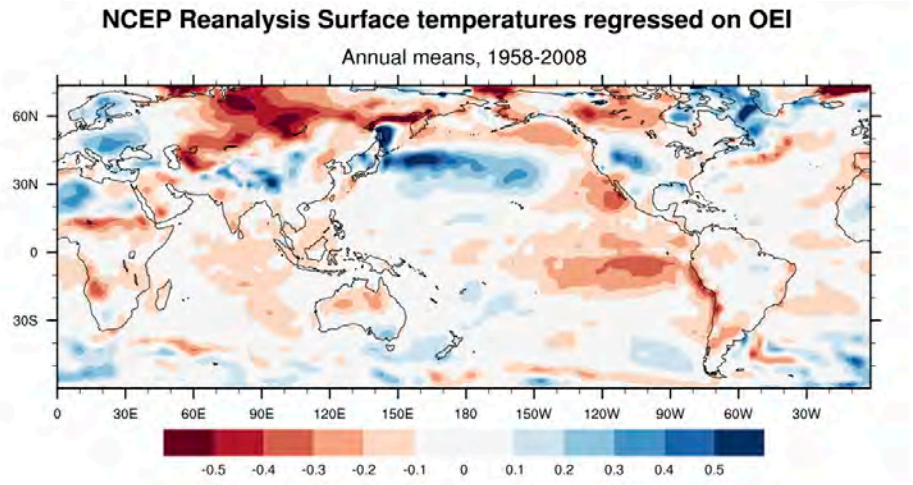
Left: Leading pattern of North Pacific seasonal variability (PDO)

Right: Leading pattern of "internal" North Pacific seasonal variability (after removing effects of tropical forcing from B)





SST pattern associated with leading EOF of SST gradient in Oyashio extension



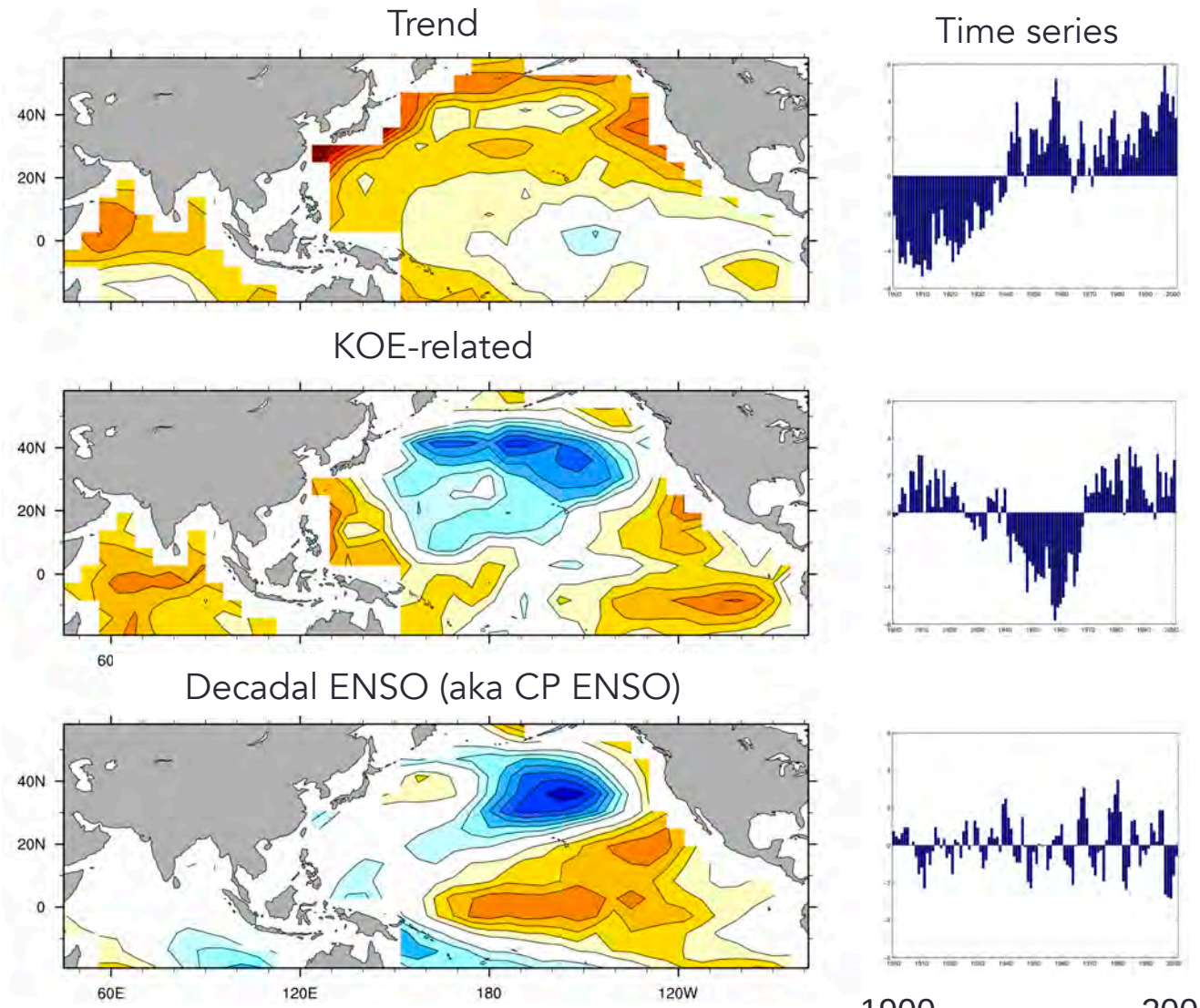
Different dynamical processes build up the PDO

Leading Pacific dynamical modes, with time series (1900-2001)

Eigenmodes determined from similar analysis of **B** but using annually averaged SST data on 5x5 grid (note: these are not EOFs)

Not shown: "Interannual ENSO"

Almost all long range skill contained in first 2 patterns



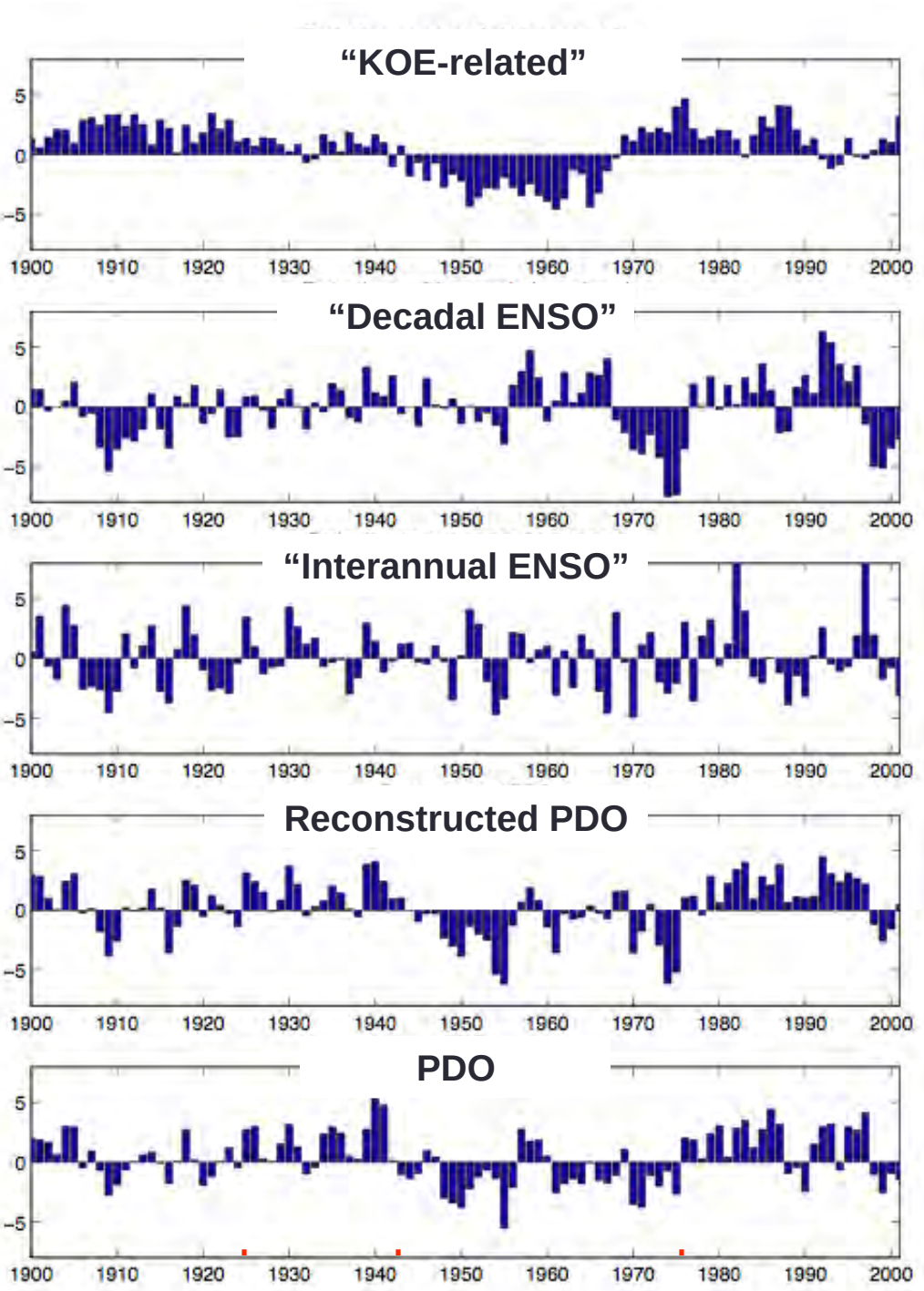
Constructing the PDO from a sum of three AR1 processes (red noises)

Time series show projection of each mode onto the PDO

PDO = KOE-related
+Decadal ENSO
+Interannual ENSO

"Regime shifts"

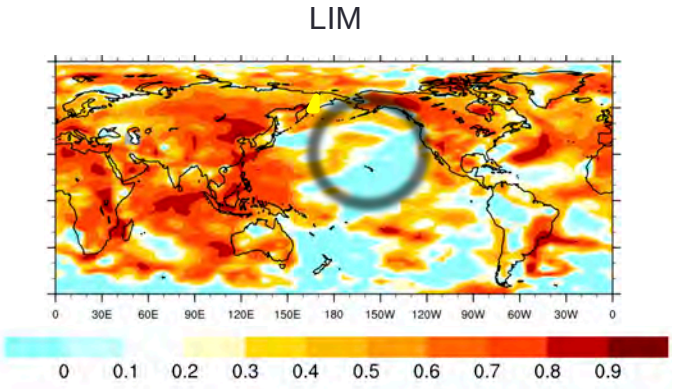
Newman 2007

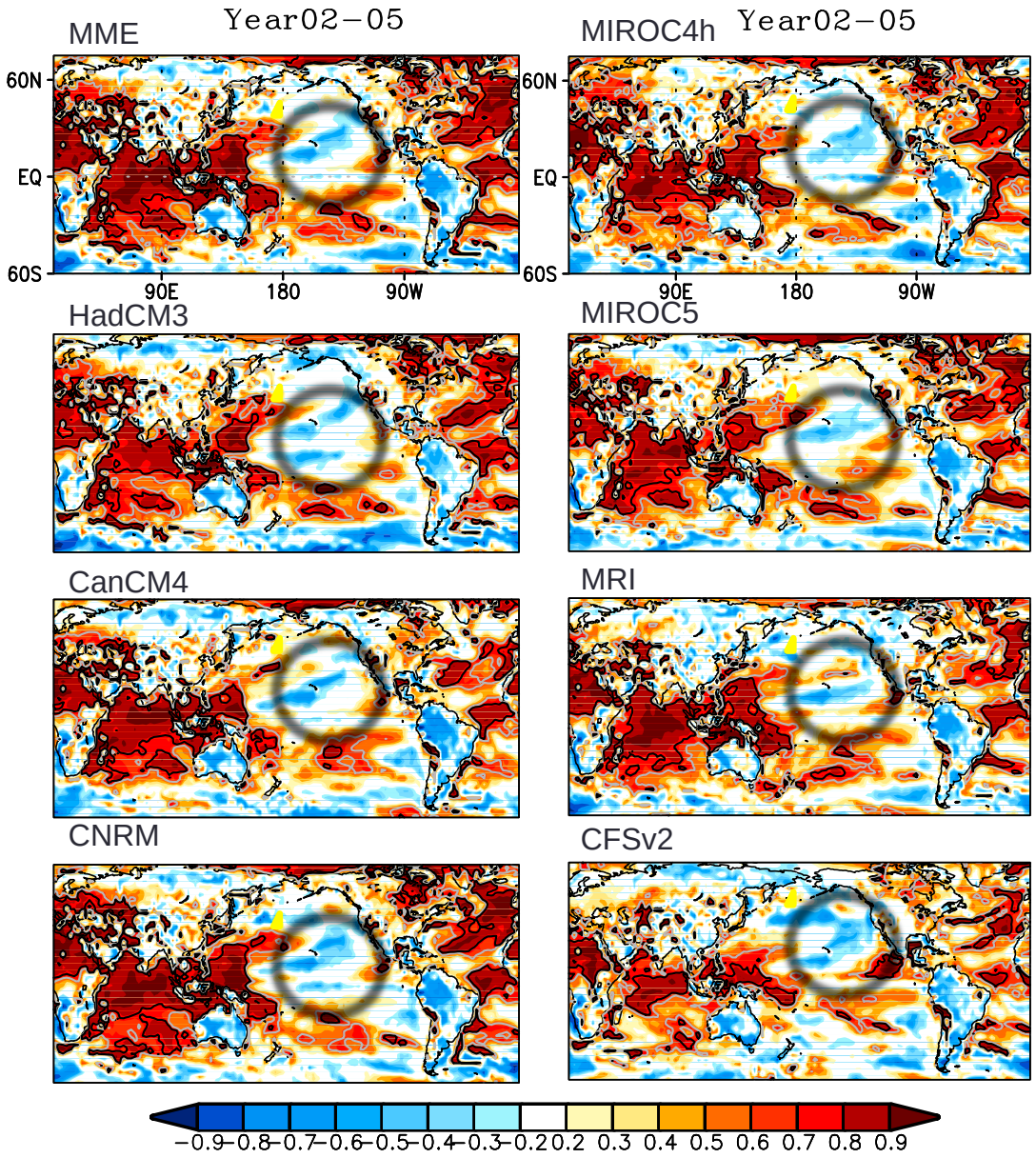


Decadal hindcast skill is *lowest* in most of the tropical and Northeast Pacific

Skill of LIM and CMIP5 CGCM decadal hindcasts, 1960-2000 (Newman 2013)

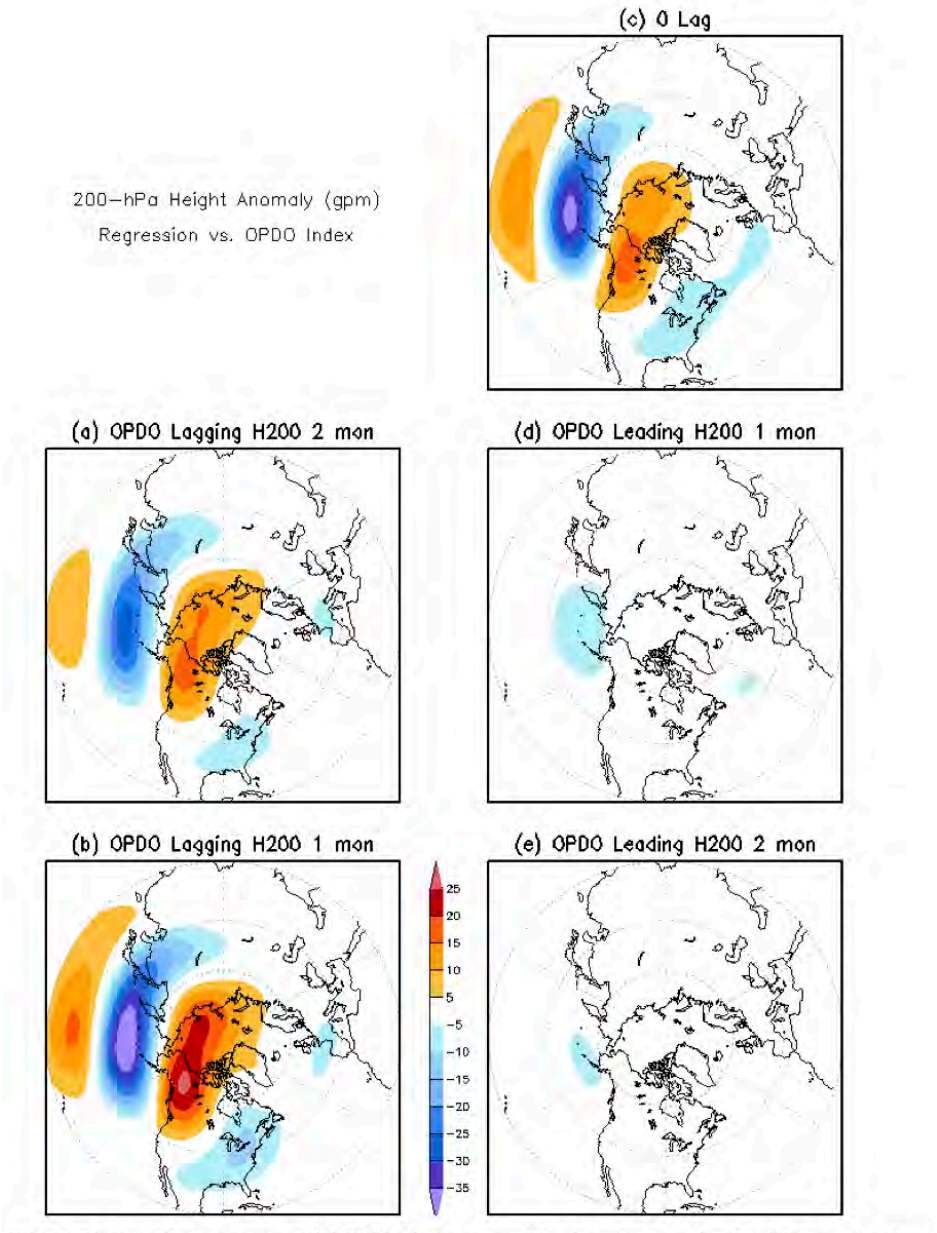
ENSO is *noise* for decadal forecasts, including for the PDO





Kim et al., GRL (2012)
ERA40/ERAI verification

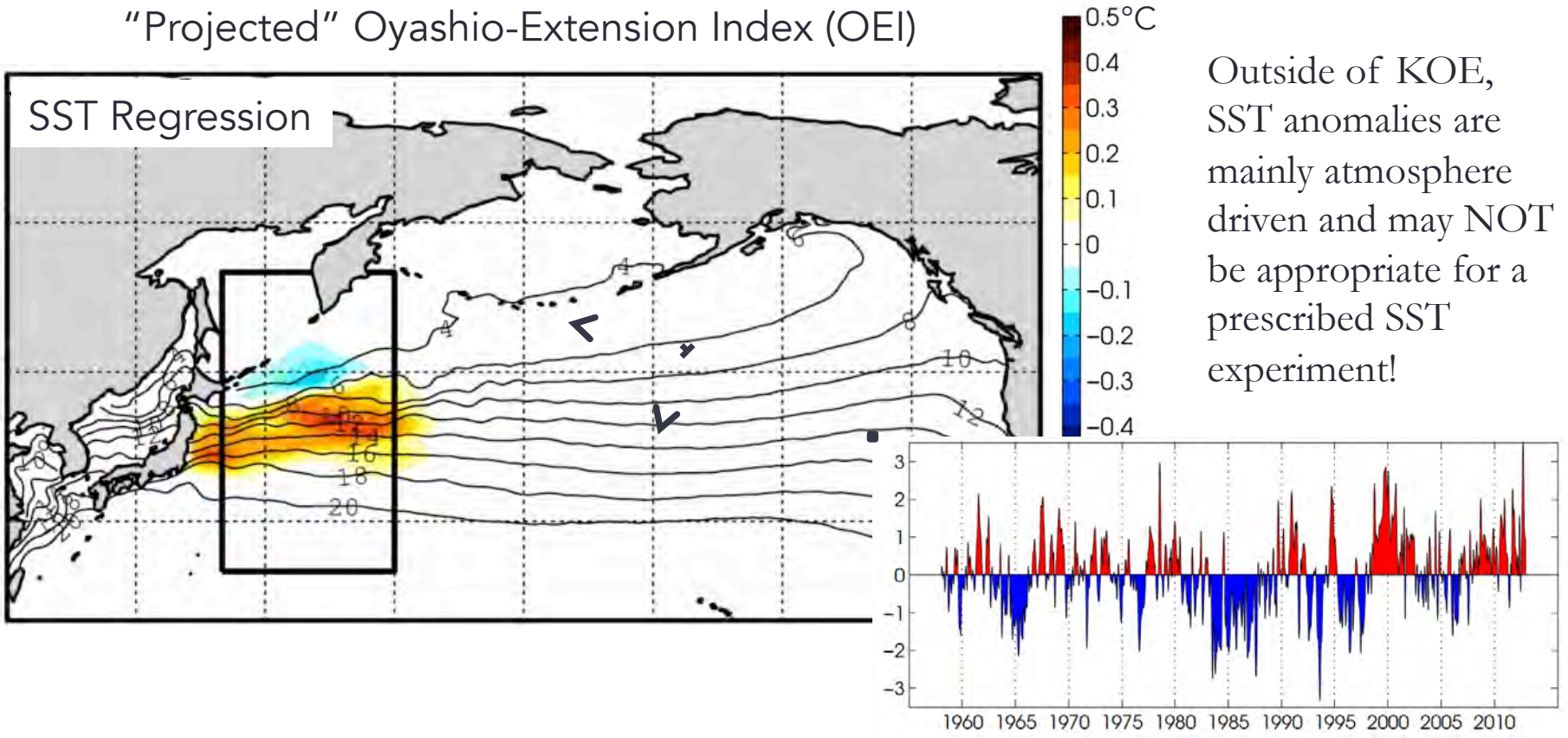
The PDO may generally provide only weak forcing of the atmosphere, but…



Kumar et al 2012

Prescribing "KOE" SST anomaly

"Projected" Oyashio-Extension Index (OEI)



Outside of KOE, SST anomalies are mainly atmosphere driven and may NOT be appropriate for a prescribed SST experiment!

- Kuroshio-Oyashio Extension (KOE) system is a key component of the North Pacific ocean-atmosphere system with connections to the PDO

➢ <u>Can an atmospheric GCM capture the atmospheric response to a shift in the Oyashio SST front?</u>

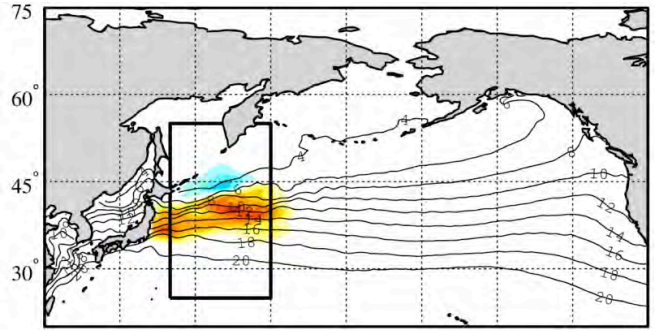
➢ <u>Is a high resolution model required?</u>

Smirnov et al. (2014)

Experimental design

- NCAR's Community Atmosphere Model, version 5 (CAM5)
- 25 warm/cold ensembles with different atmospheric initial states from control run (taken a year apart)
- Two 6-month simulations (1 Nov – 31 Mar):
  1. High-resolution (HR) – 0.25°
  2. "Low"-resolution (LR) – 1.0°

"WARM"→ Northward shift



- Identical initial land, sea-ice and atmospheric initial conditions
- Compare the *mean difference* (WARM – COLD) between the HR and LR model responses

➢ Compare to ERA-interim (1979-2012) using a lagged regression on the POEI

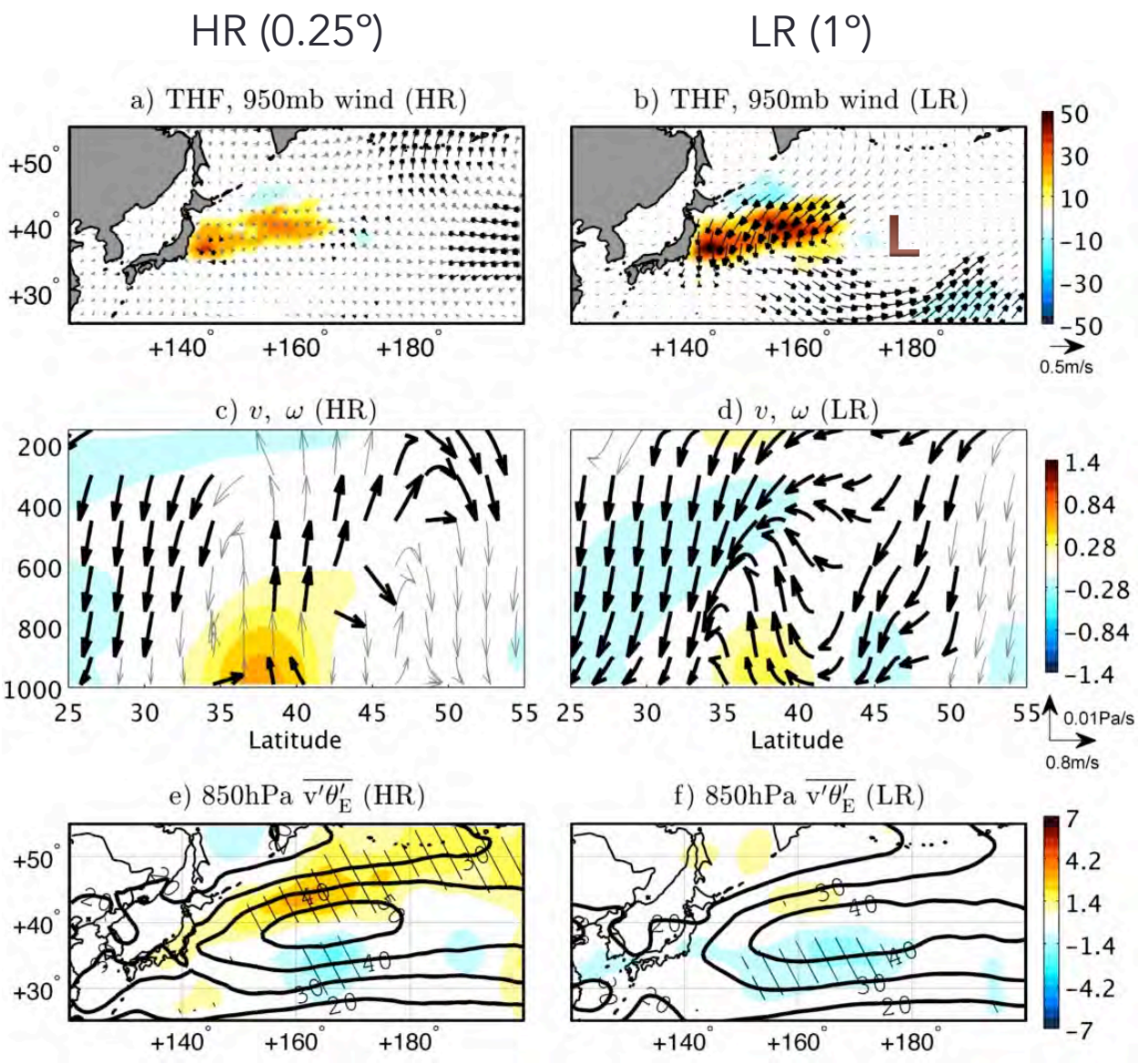
Model responses (warm-cold) to Oyashio extension shift

LR model

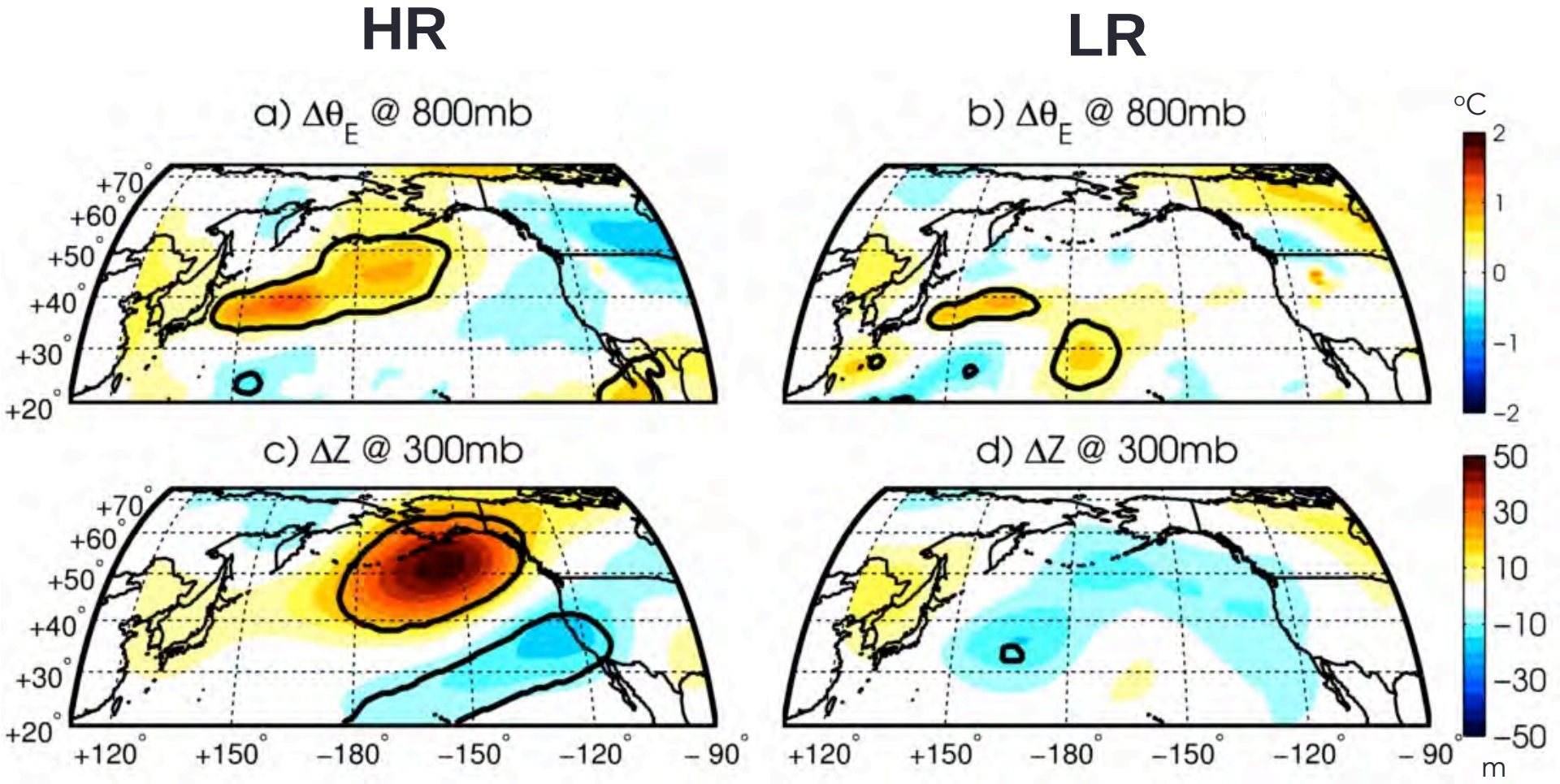
SST heating balanced by cold and dry air advected southwards by surface low to east → shallow vertical motion

HR model

SST heating balanced by intensified transport of heat and moisture northwards by storms → deep vertical motion

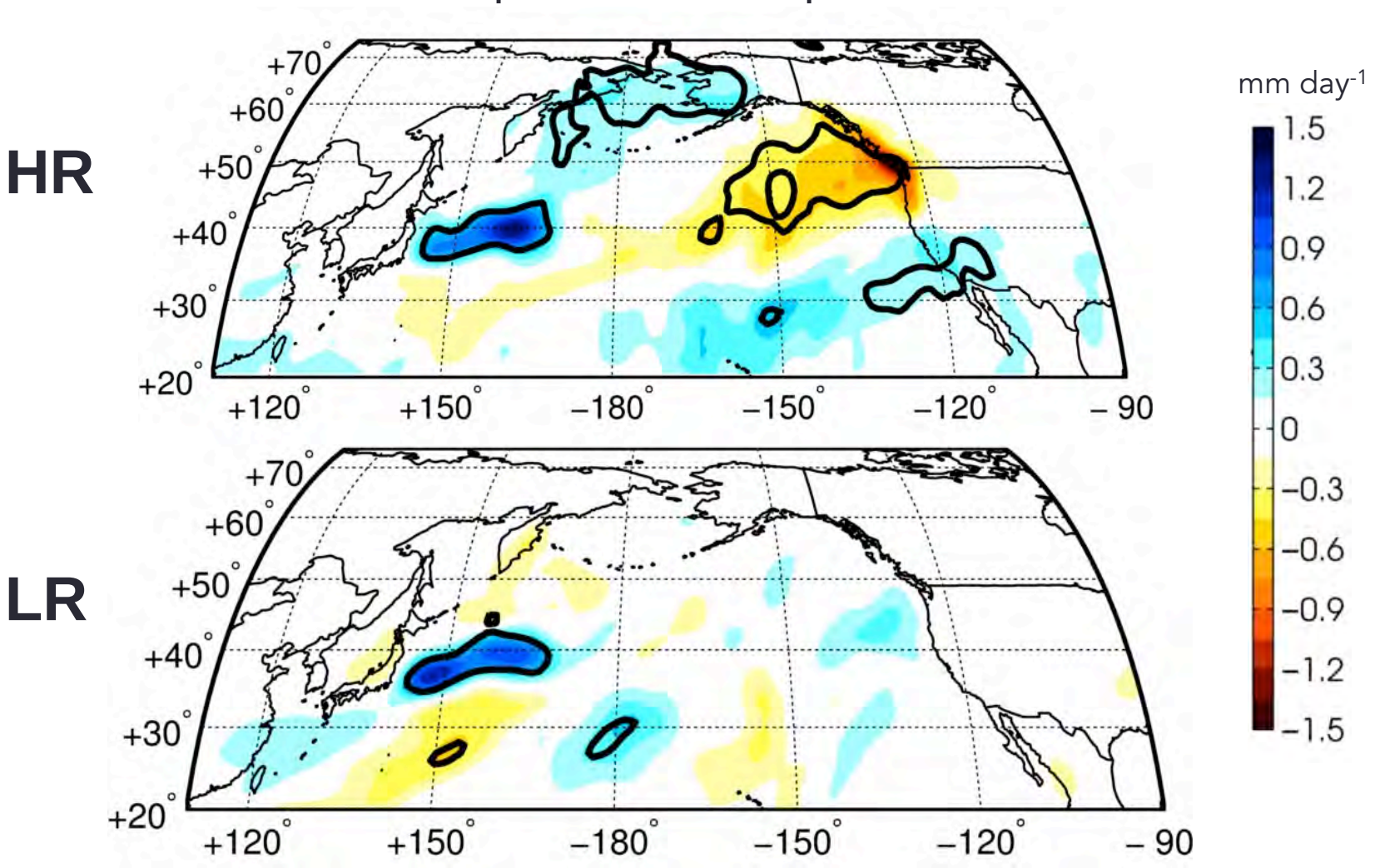


Remote response



Sensible impact

Precipitation response



Summary Slide

- The PDO is not a physical mode but rather is the sum of several physical processes
  - North Pacific SST *integrates* effects of extratropical weather noise and of ENSO via the atmospheric bridge
  - Re-emergence brings back ENSO-induced anomalies in succeeding winters (no summer/fall PDO)
  - Variations in the KOE provide more persistent SST anomalies and may provide a large part (most?) of the predictable atmospheric response

Some Implications

- Consequences for analysis: Need to differentiate PDO-forced signal from PDO-correlated signal
  - KOE anomalies may provide "decadal" forcing
  - What other "climate integrators" redden ENSO?
    - Hydrological (soil moisture anomalies, snowpack)
    - Paleoclimate proxies
    - Ecosystems?
- "Regimes" may have limited predictability
  - Regime changes randomly driven, due to superposition of different red noise processes
- We need to be careful when we reduce North Pacific decadal variability to a single index