Observational and Modeling Evidence of Reduced Decadal Predictability in the Tropical Pacific

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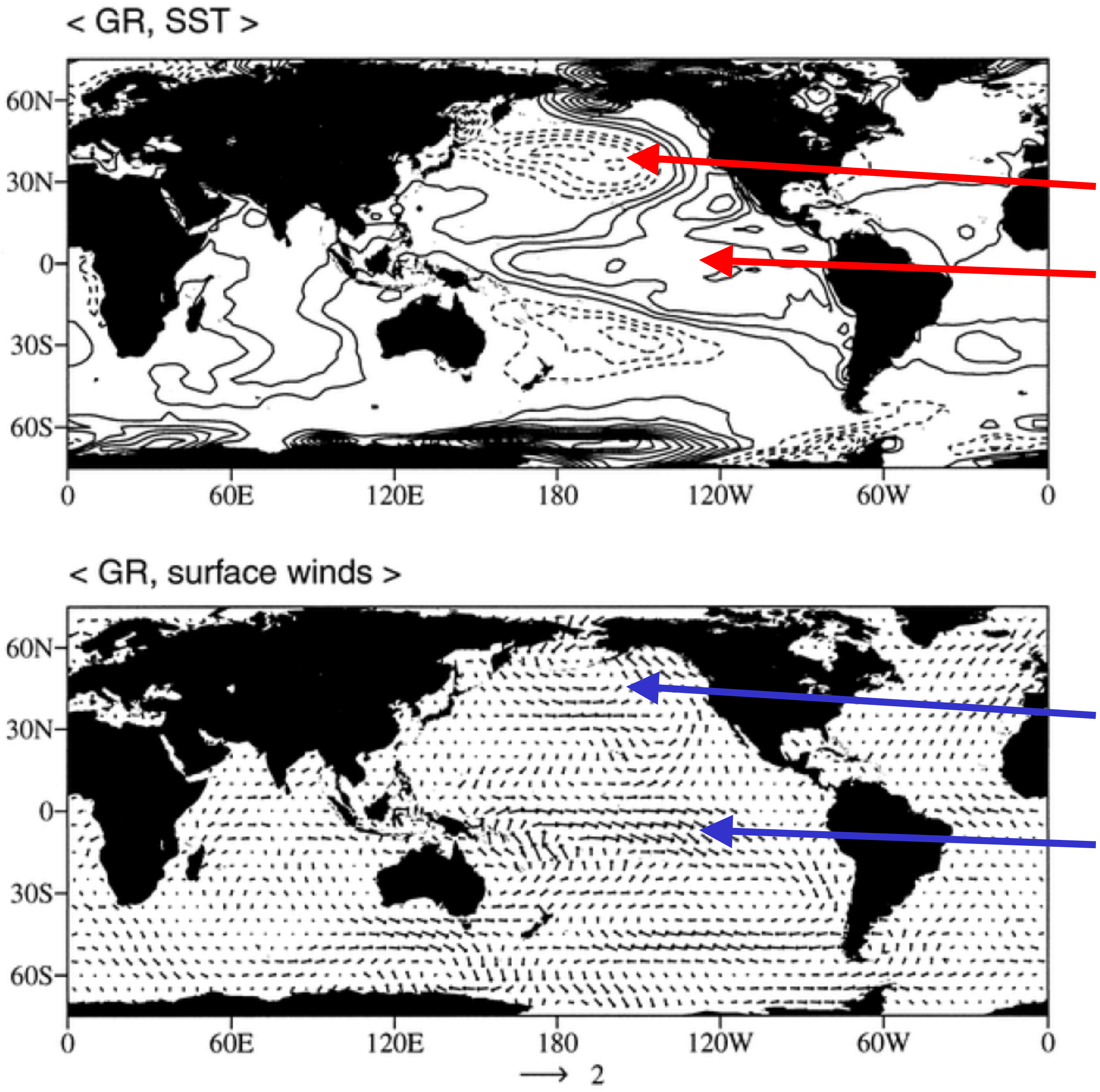
Outline

1. What is Pacific Decadal Variability (PDV)?
2. Importance of PDV for global climate variability.
3. Review of mechanisms that generate PDV.
4. **New theory: role of ocean dynamics different from ENSO.**
5. **Attempt to falsify theory using T(z) observations.**
6. Implications for decadal predictability in the Pacific basin.

Pacific Decal Variability



Cold North Pacific

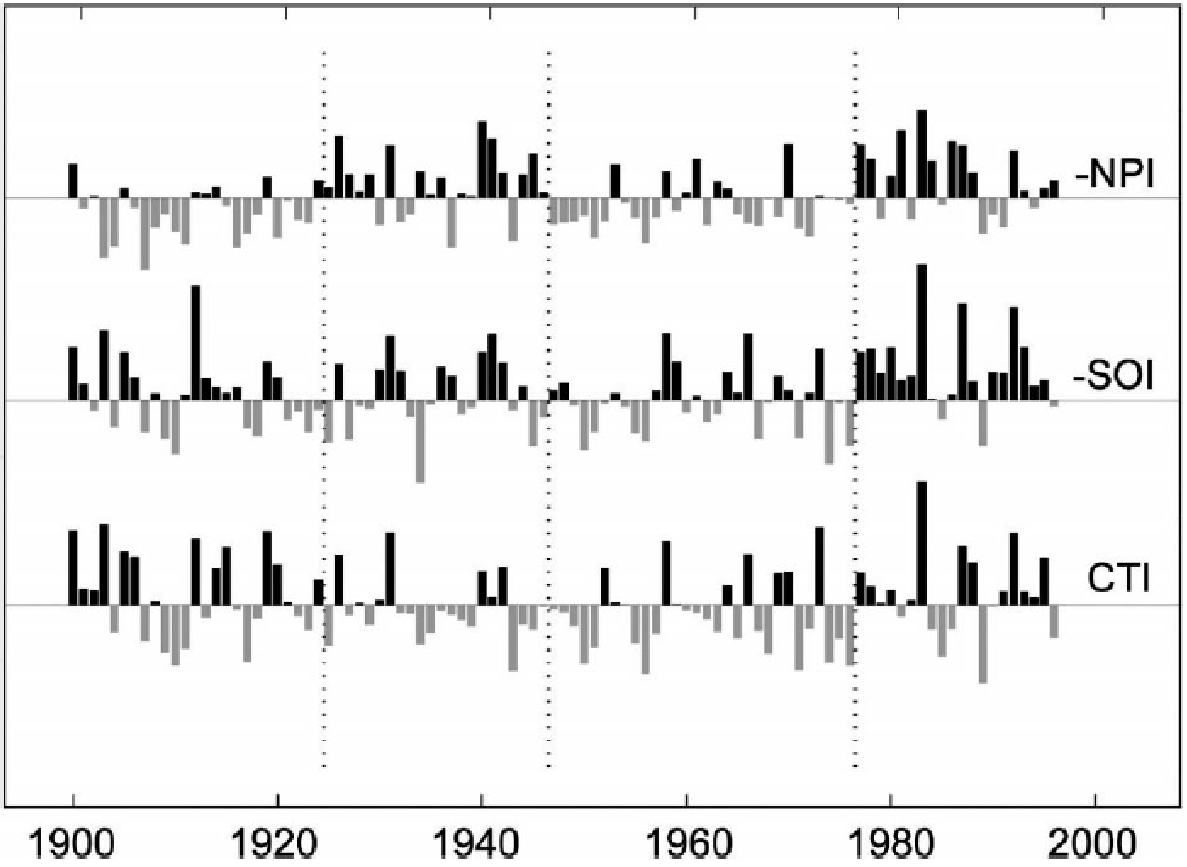
Warm tropical Pacific

Deeper (stronger) Aleutian low

Weaker trade winds

Garreaud and Battisti 1999

Pacific Decal Variability



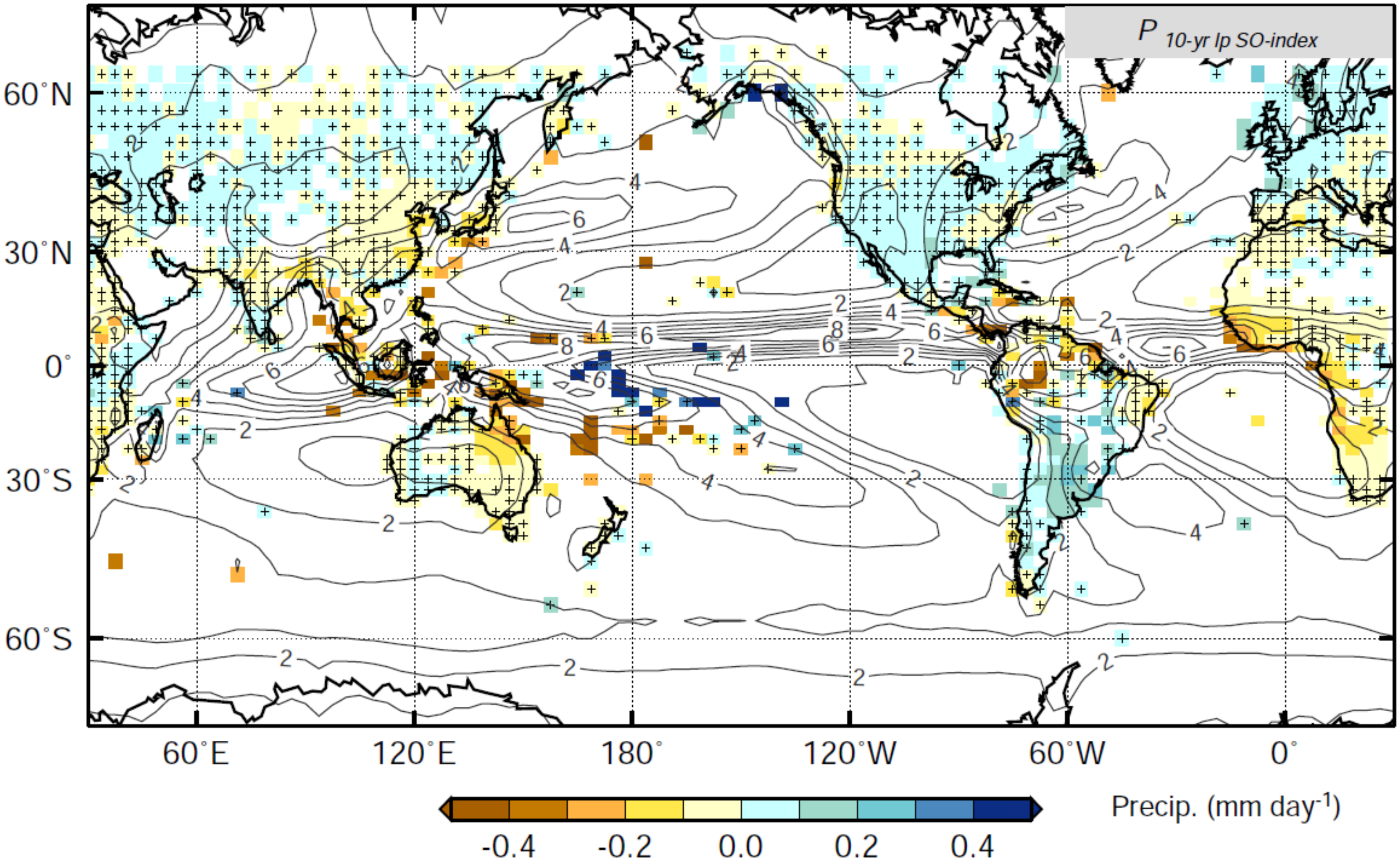
strong
Aleutian low
weak

weak
Trade winds
strong

warm
Cold tongue
cold

Deser et al. 2004

Precipitation changes associated with PDV



How is PDV generated?

- Ocean-atmosphere interactions in the North Pacific

  Barnet et al 1999; Pierce et al. 2000

- Tropical-extratropical interactions (atmospheric bridge – ocean tunnel)

  Gu and Philander 1997; Wang and Weisberg 1998; McPhaden and Zhang 2002; Liu et al, 2002

- Internal tropical dynamics analogous to ENSO

  Knutson and Manabe 1998; Jin 2001; Zhang and Busalacchi 2005; Hasegawa and Hanawa 2003; Hasegawa et al. 2007

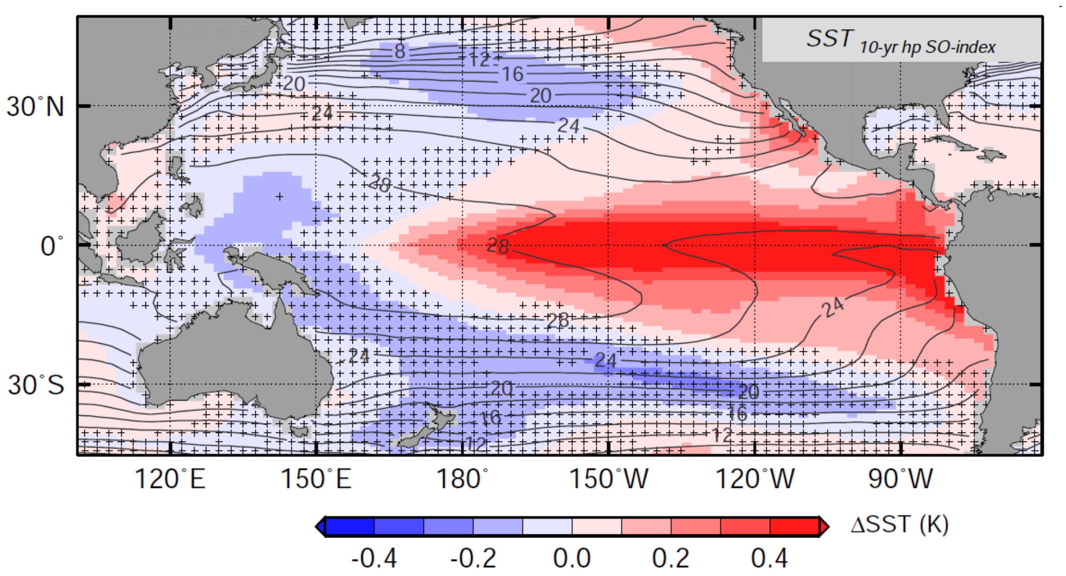
- Rectification of ENSO

  Newman et al. 2003, Rodgers et al. 2004; Vimont 2005; An et al. 2007

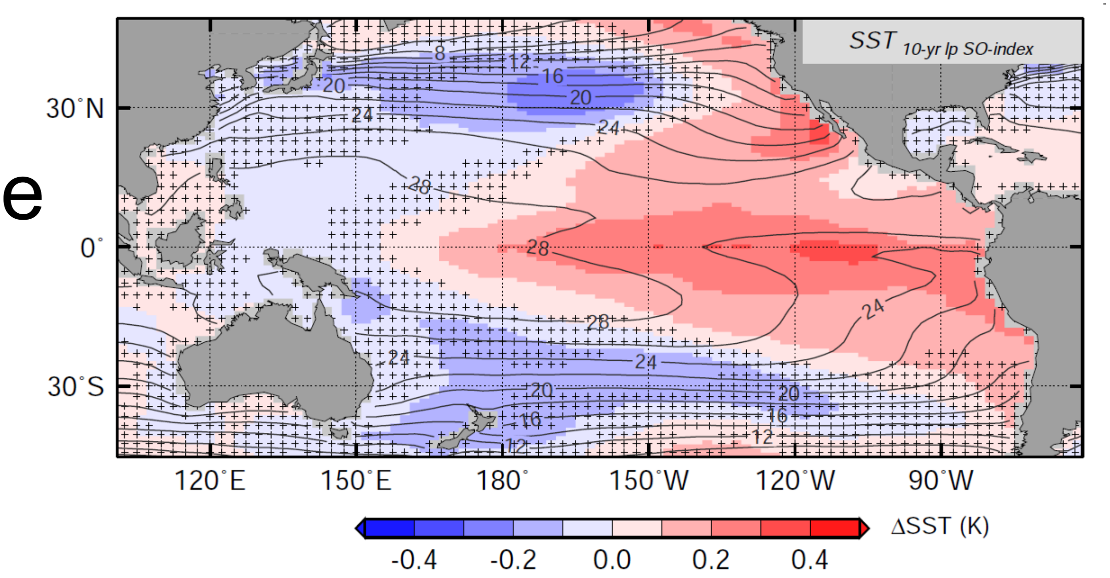
SST anomalies driven by equatorial thermocline

PDV is ENSO-like (in the surface)

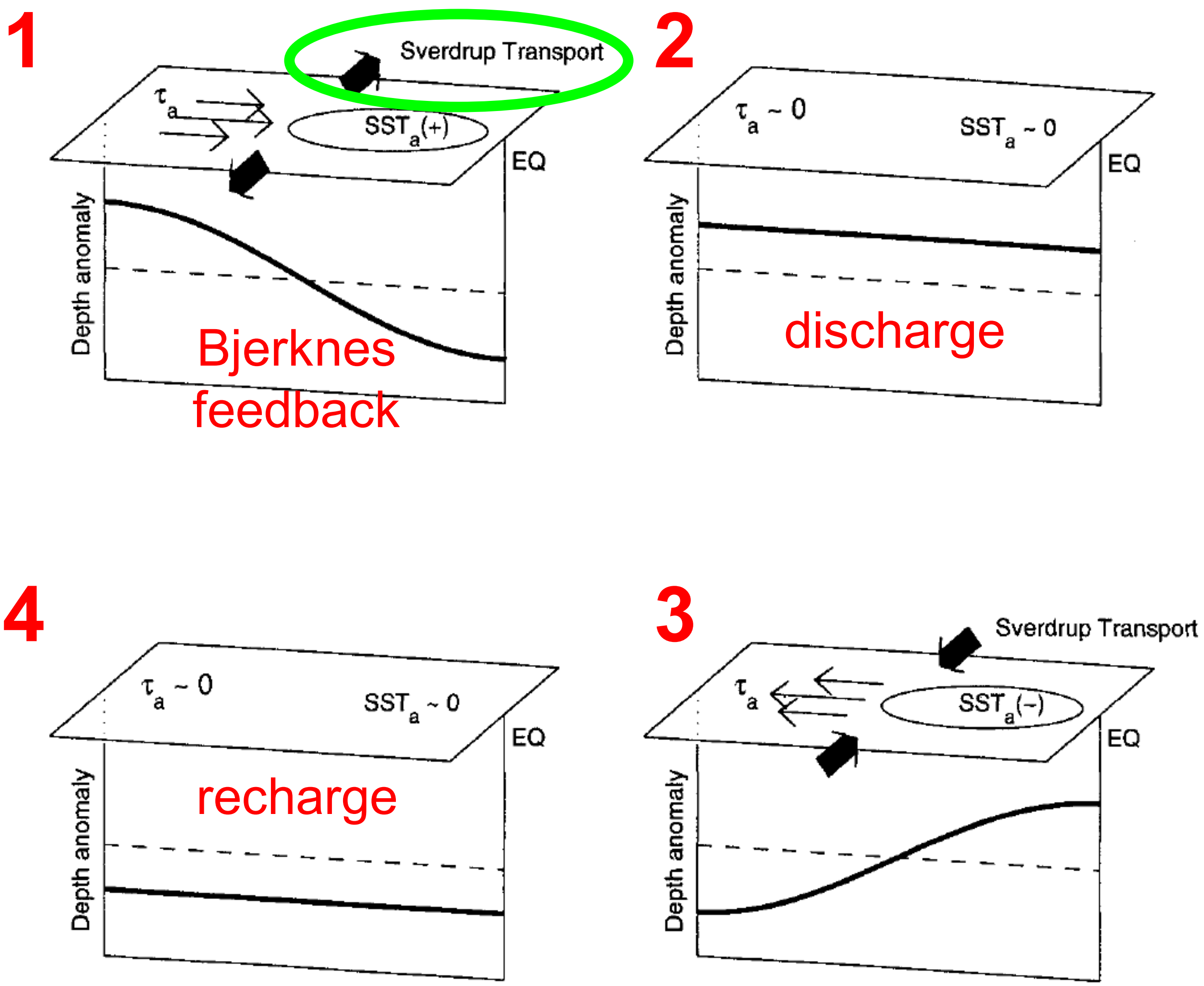
ENSO



ENSO-like PDV

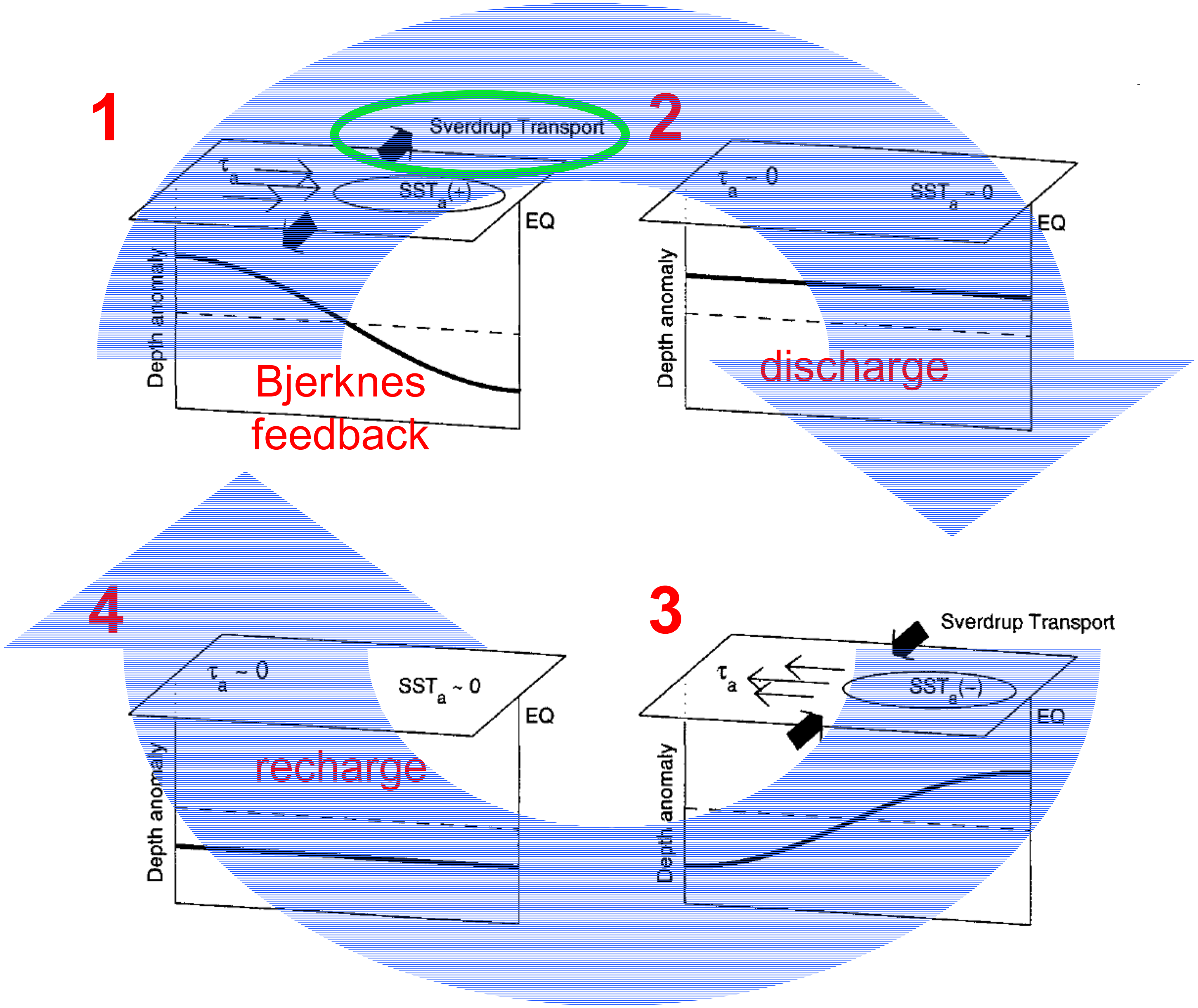


ENSO mechanism: Recharge Oscillator



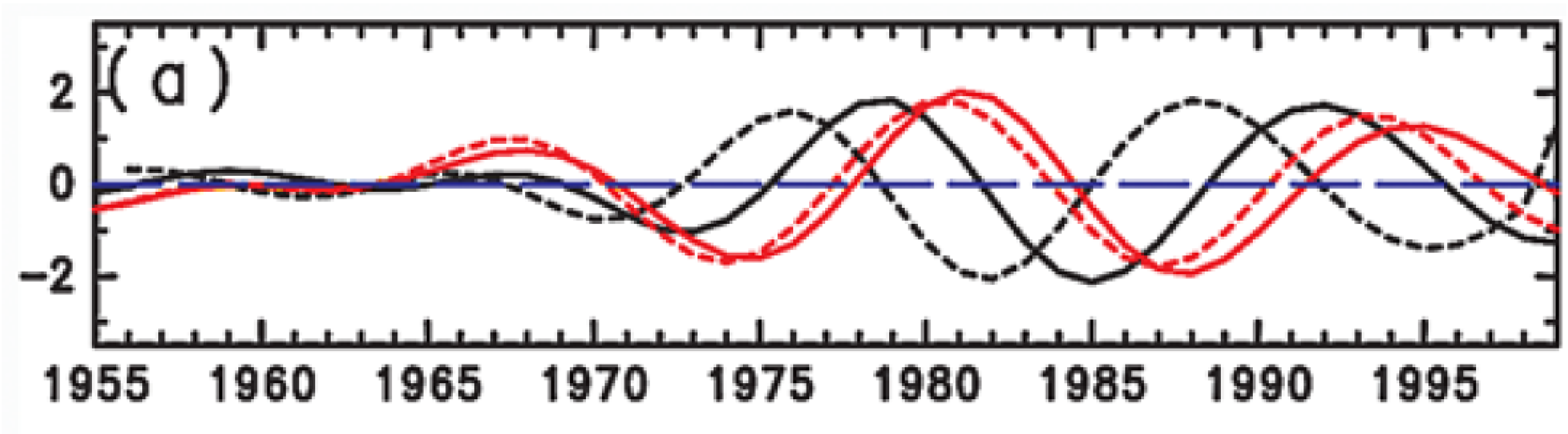
Jin 1997

ENSO mechanism: Recharge Oscillator



Jin 1997

ENSO-like subsurface decadal variability



– zonal mean OHC

– Nino 3

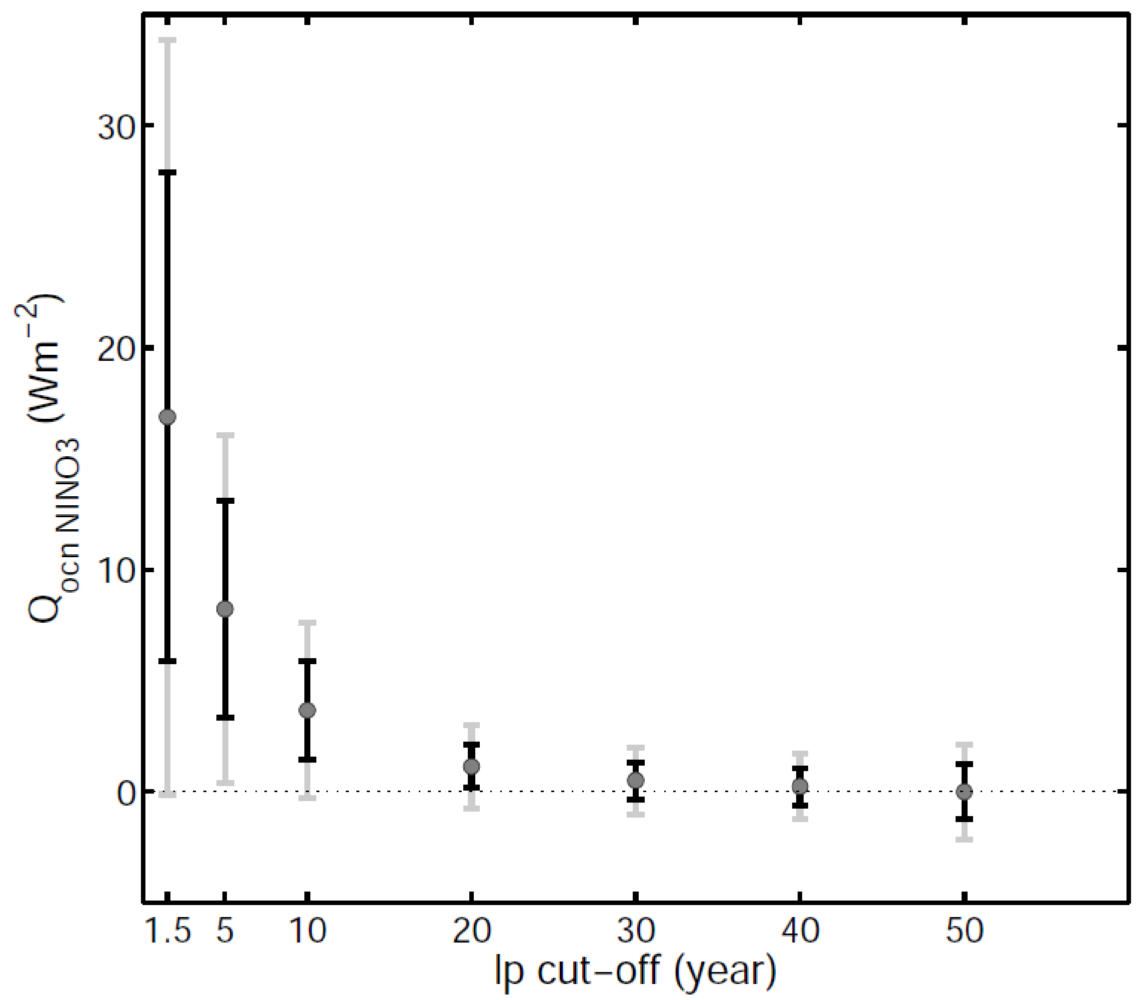
- Decadal OHC leads Nino-3 SST by 3 years.
- Caveat: OHC, D20, or sea level are not the best proxies for thermocline depth (Z_{TC}).

Hasegawa and Hanawa 2003

New theory for PDV

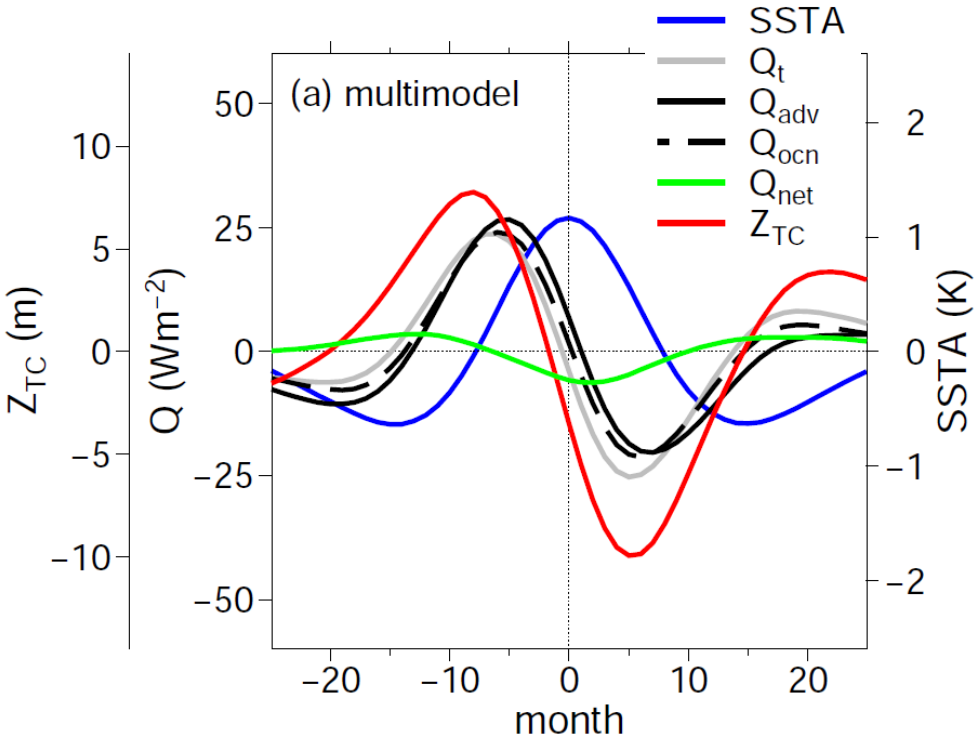
1. Motivation: rethink how fundamental is ocean dynamics in generating PDV.
2. PDV mechanism in coupled models:
   - Surface Bjerknes Mode (SBM).
3. Evidence of the SBM in observations.
   - XBT and Argo data to estimate decadal changes in thermocline depth.
   - Surface drifters / TAO to estimate decadal changes in equatorial currents and upwelling.

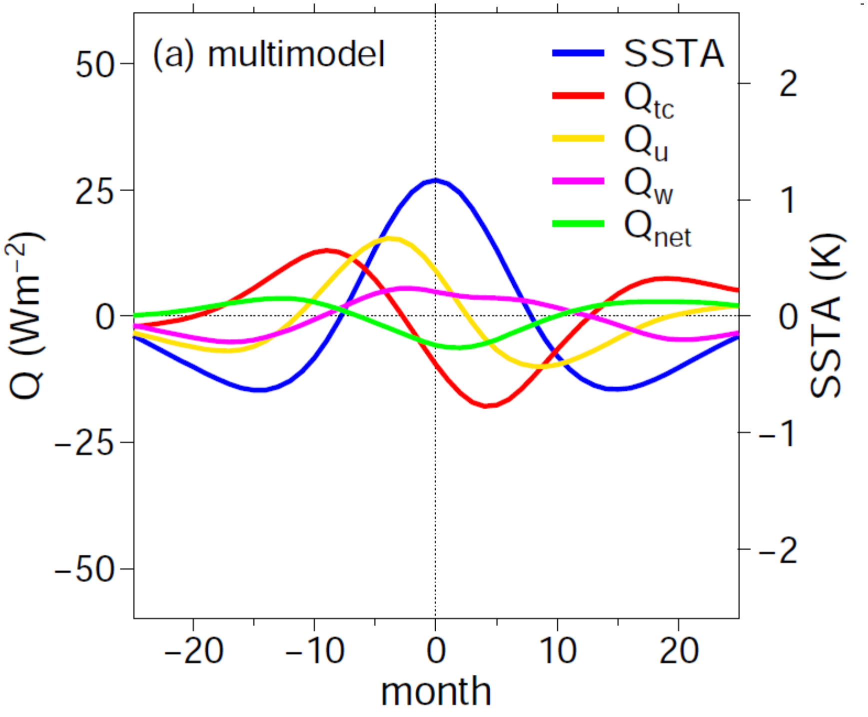
The Bjerknes feedback is time-scale dependent



Clement et al. 2011

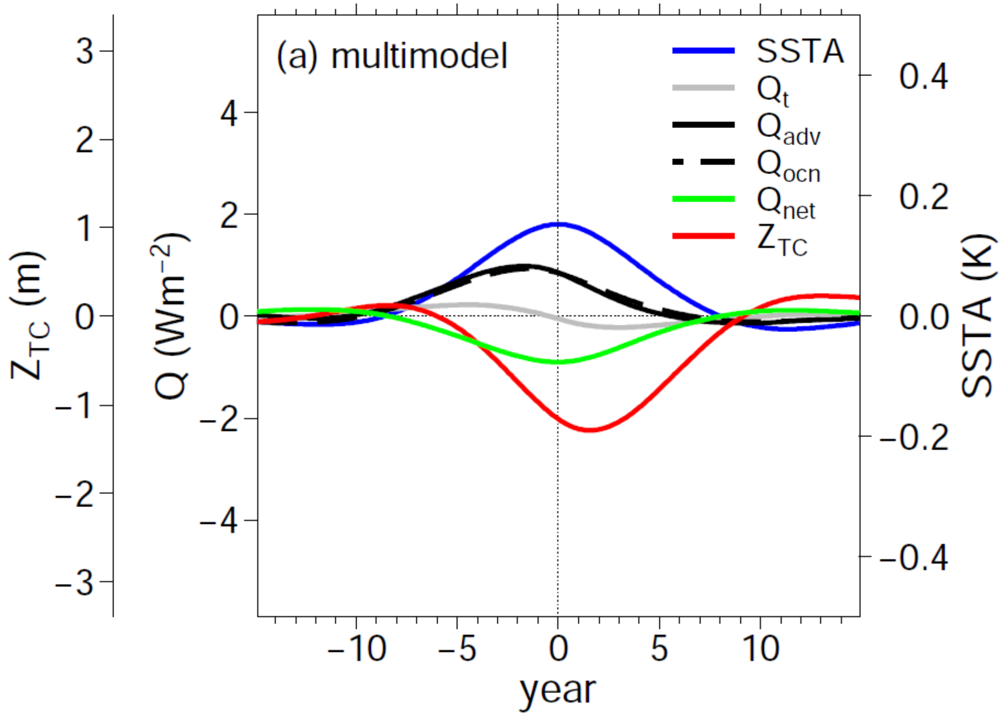
ENSO in coupled climate models

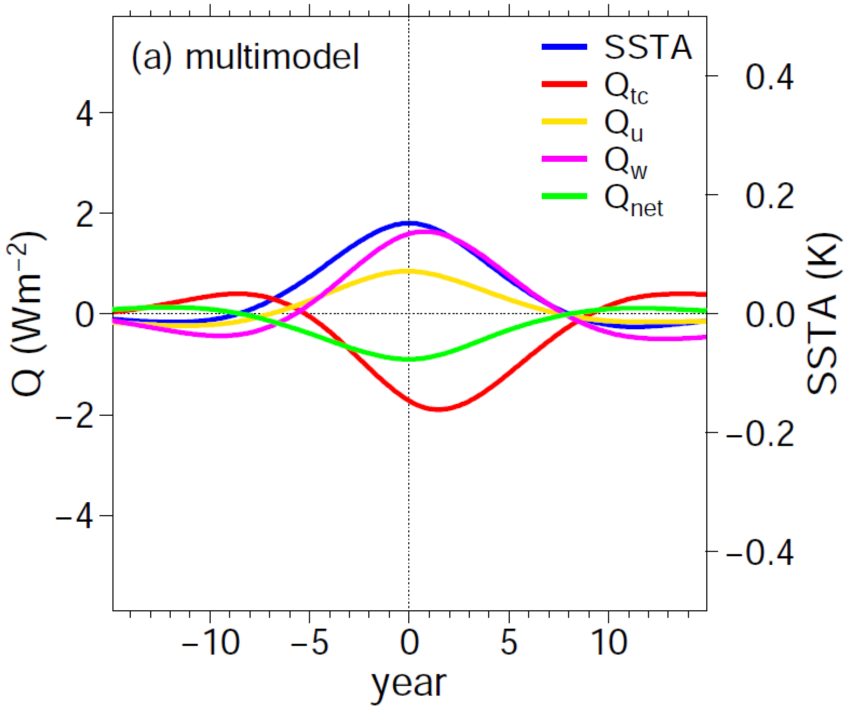




- Deepening of thermocline (recharge) initiates the development of ENSO events.
- Zonal advection contributes once the winds weaken.
- Lesser role for upwelling.
- Themocline shoaling (discharge) drives the transition from warm to cold phase.

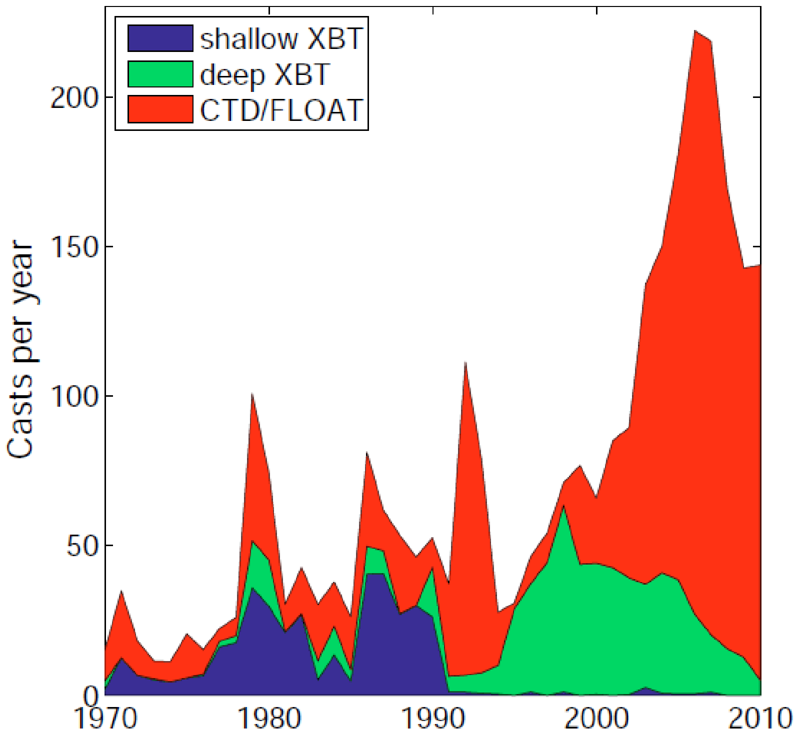
PDV in coupled climate models





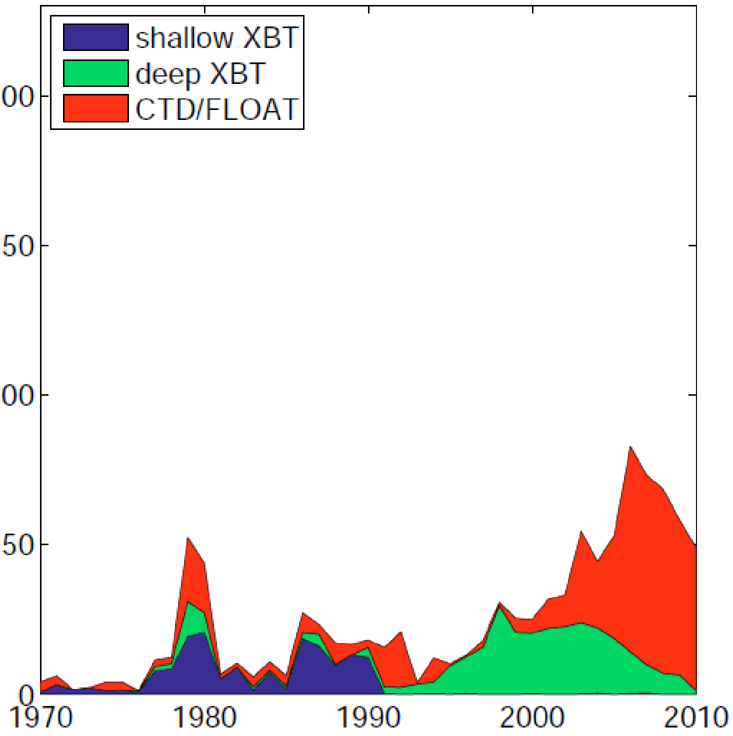
- Zonal advection and upwelling are positive feedbacks on decadal timescales.
- Thermocline is a negative feedback on decadal timescales.
- Atmospheric damping more effective on decadal time scales.

Available temperature profiles during 1970-2010



140ºE - 80ºW 10ºS - 10ºN

Equatorial Pacific

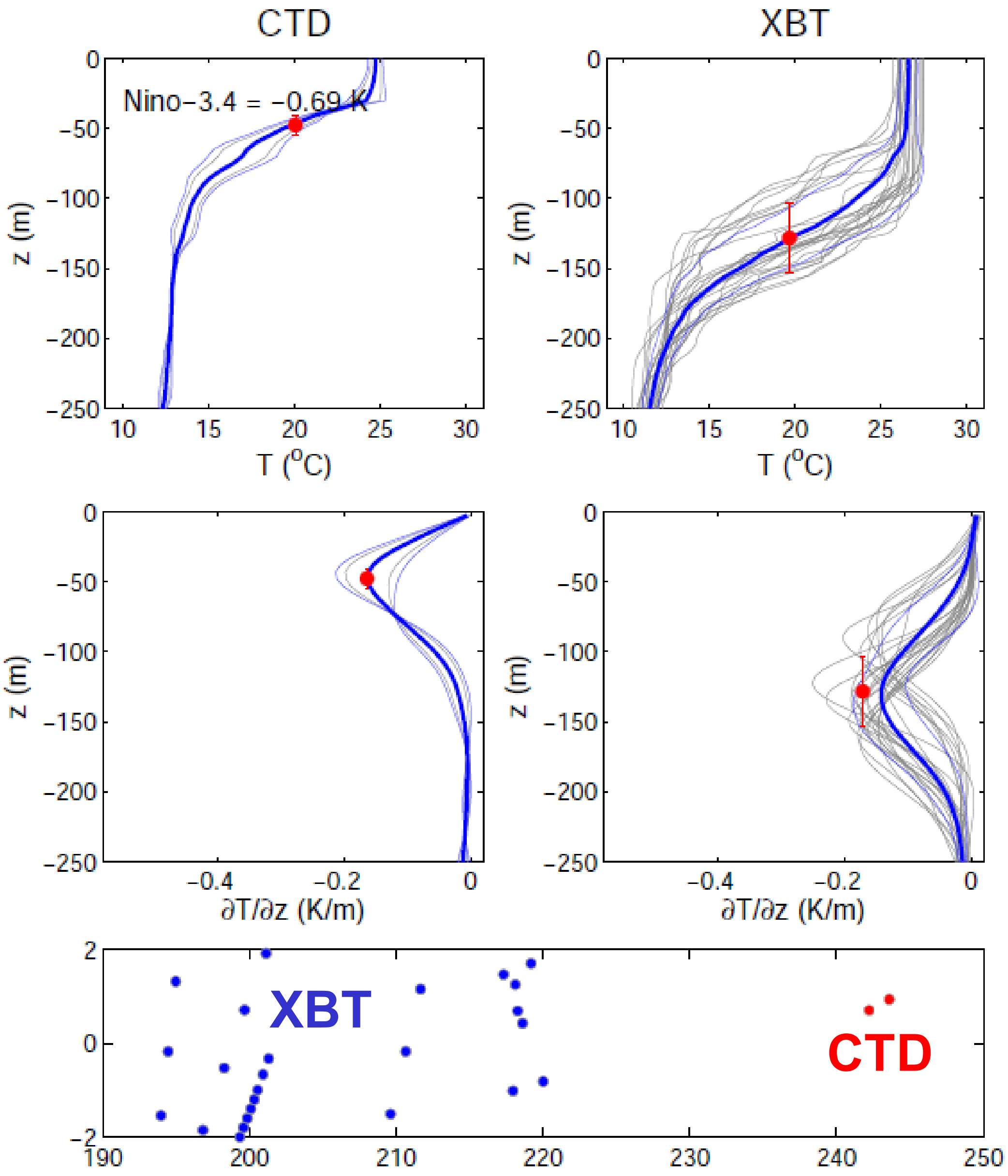


170ºW - 110ºW 5ºS - 5ºN

Nino-3.4

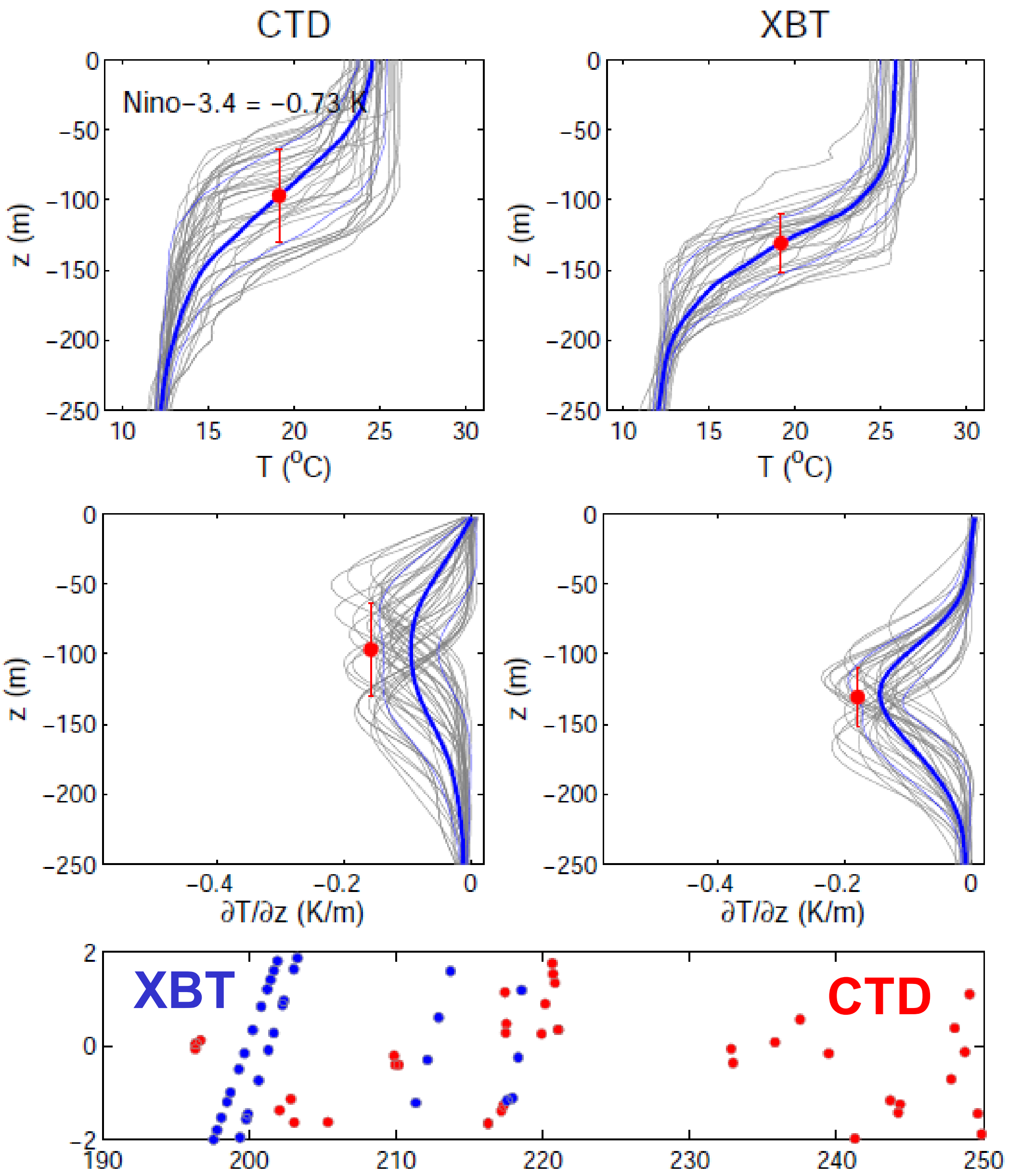
Estimating thermocline depth (Z_{TC})

Jun 1999

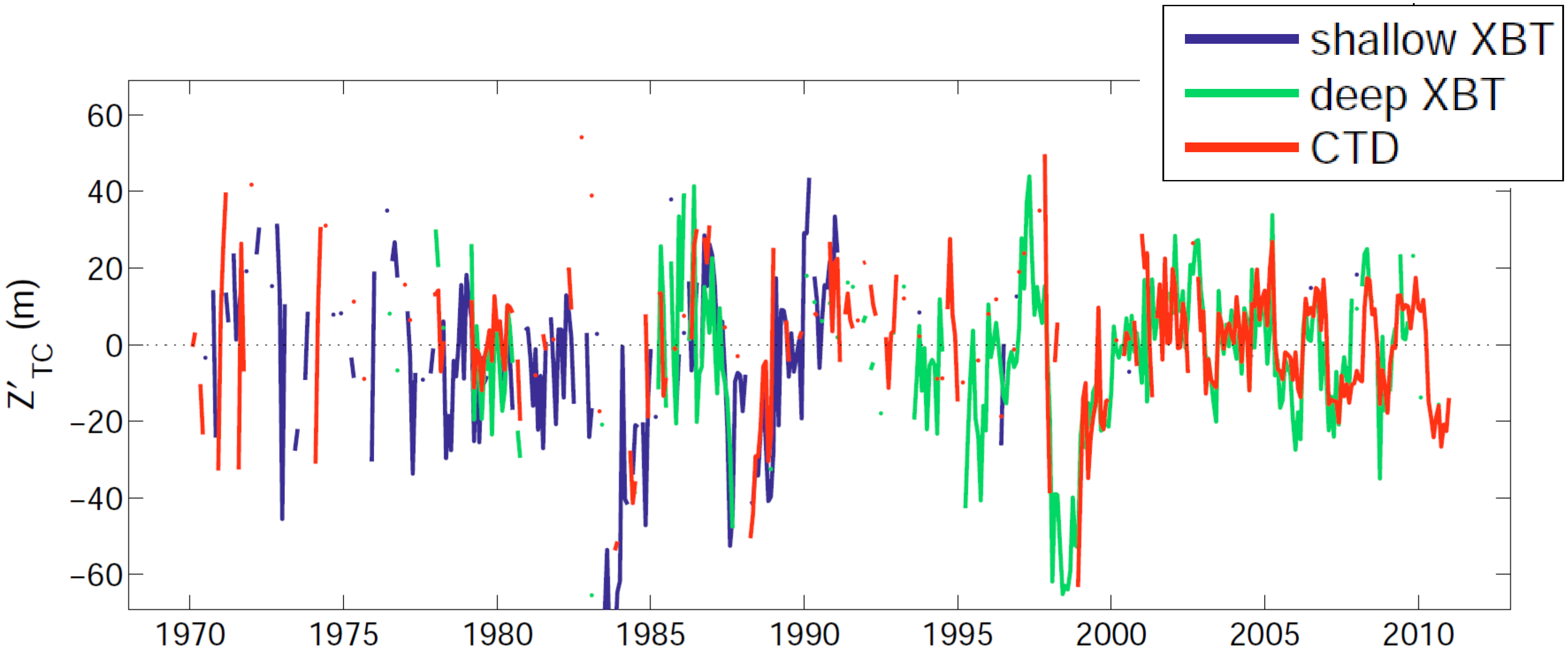


Estimating thermocline depth (Z_{TC})

Jan 2006



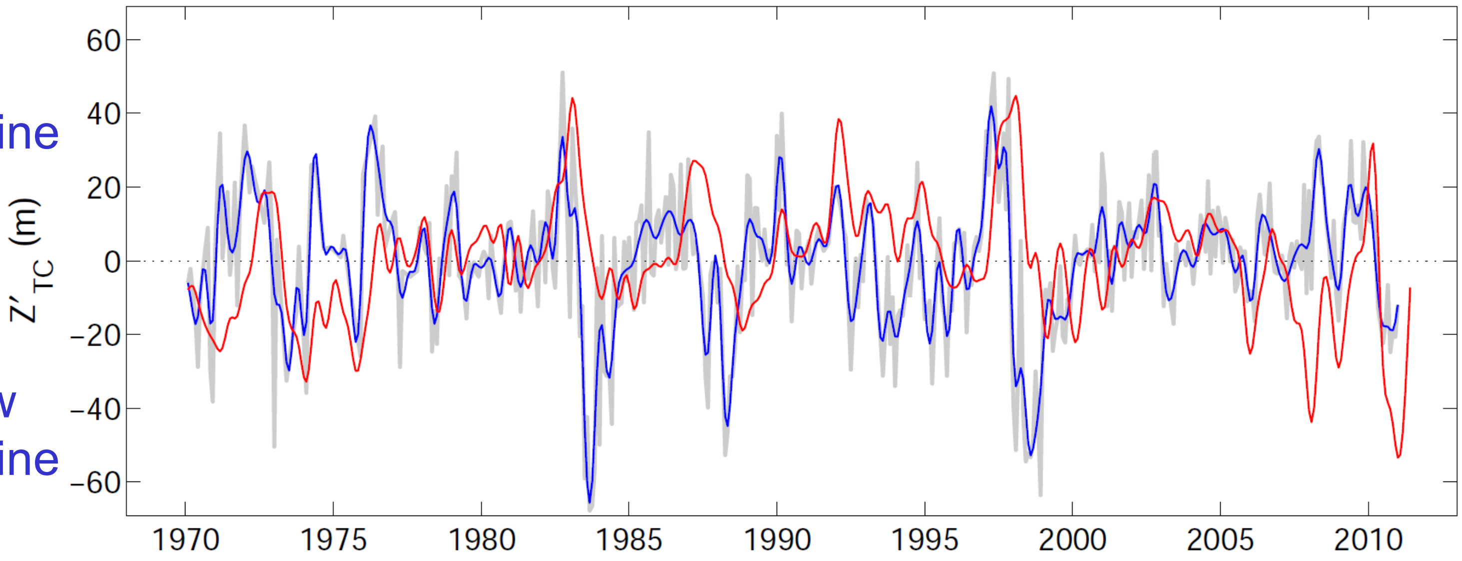
Estimating thermocline depth (Z_{TC})



Variability of thermocline and winds

deep thermocline

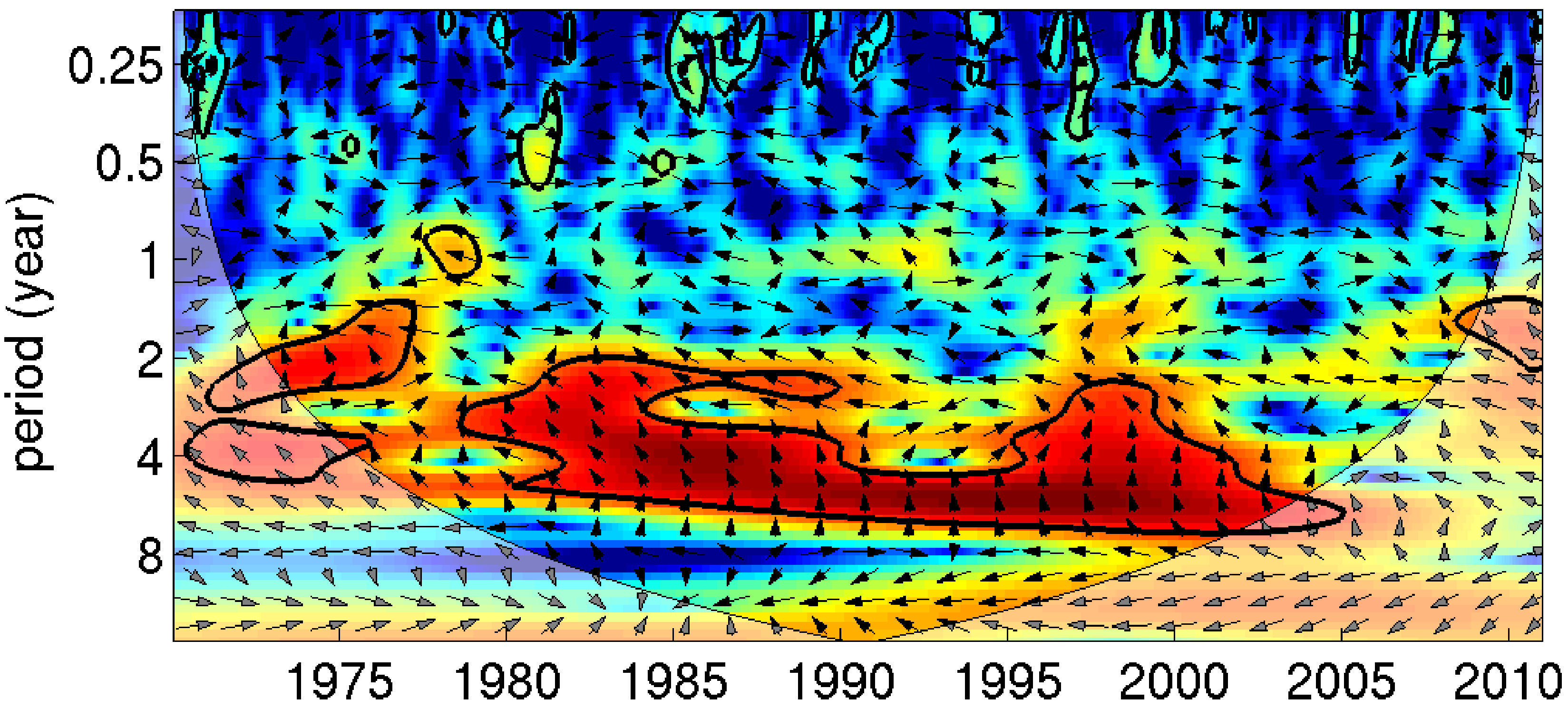
shallow thermocline



weak winds

strong winds

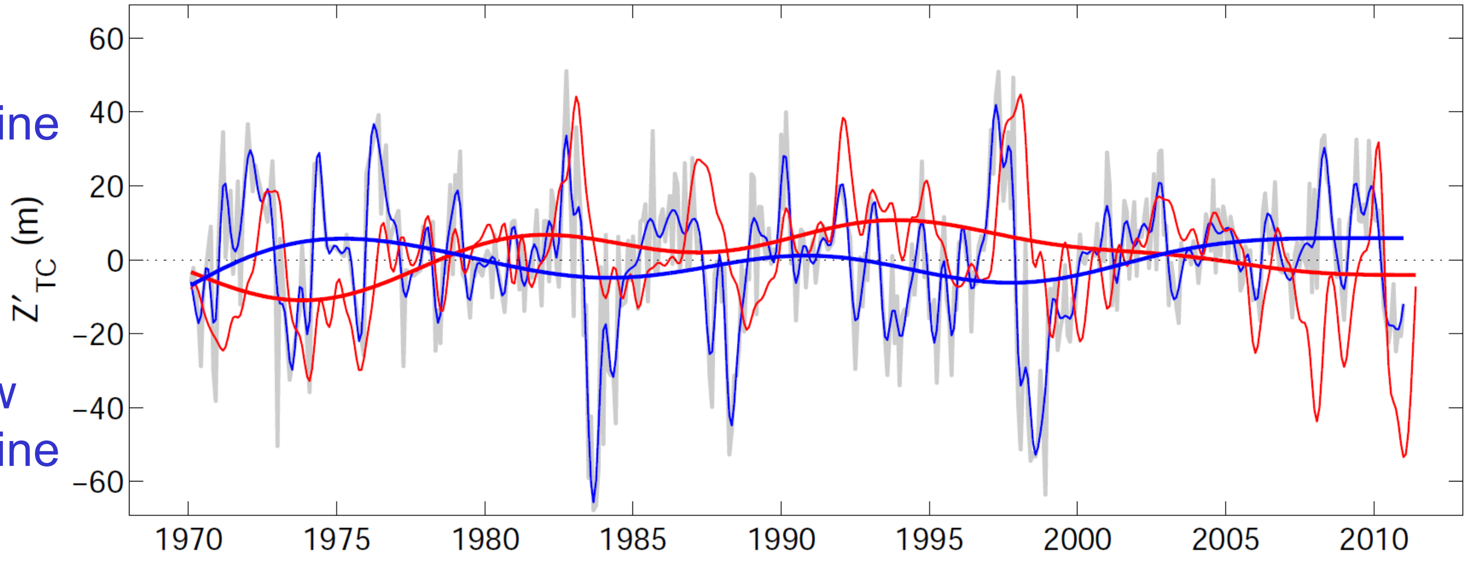
Interannual variability of thermocline and winds



↑ Z_{TC} leads -SOI by ¼ cycle

→ Z_{TC} and -SOI are in phase

Decadal variability of thermocline and winds



deep
thermocline

shallow
thermocline

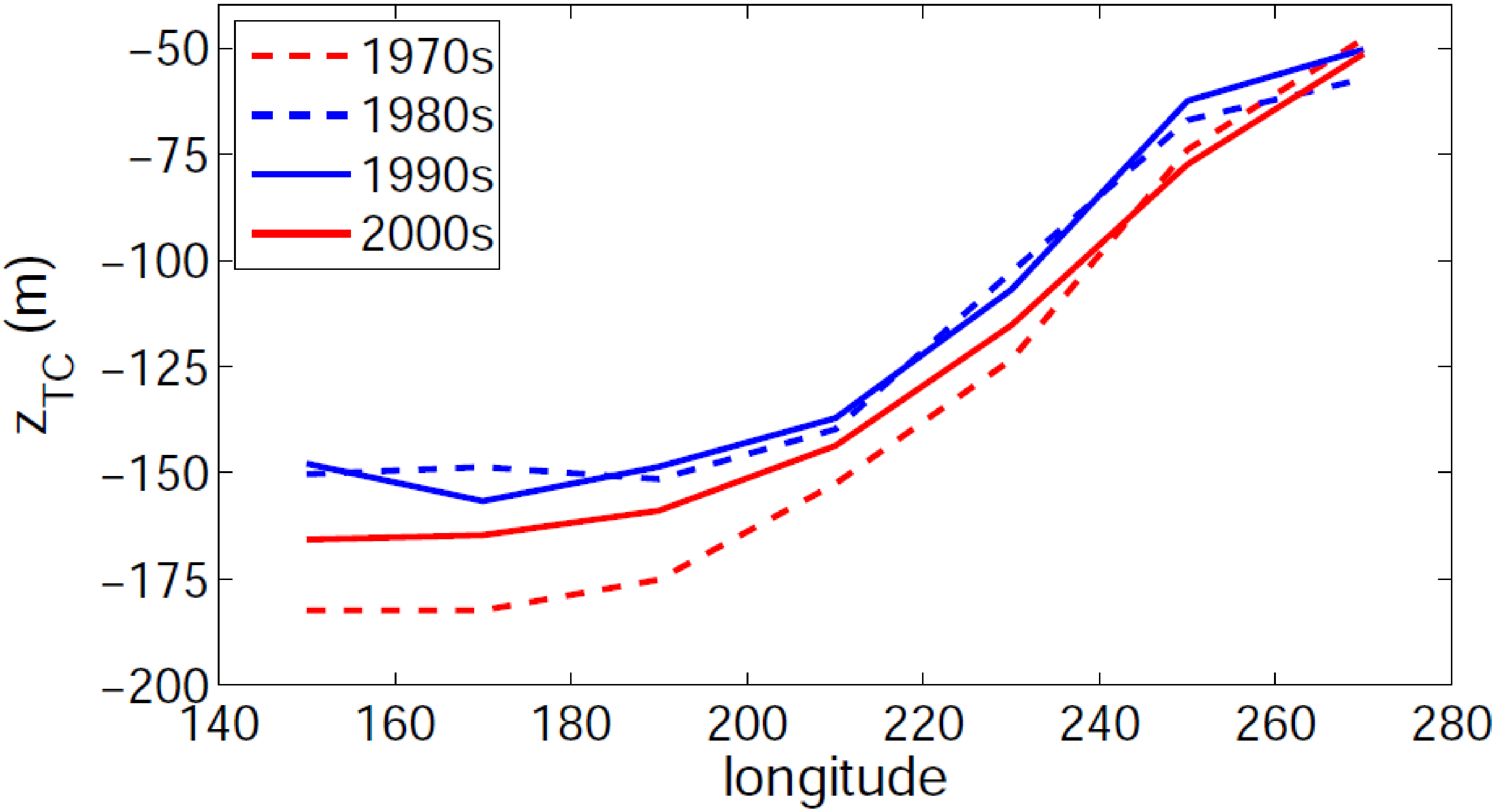
weak
winds

strong
winds

— Nino-3.4 Z_{TC}

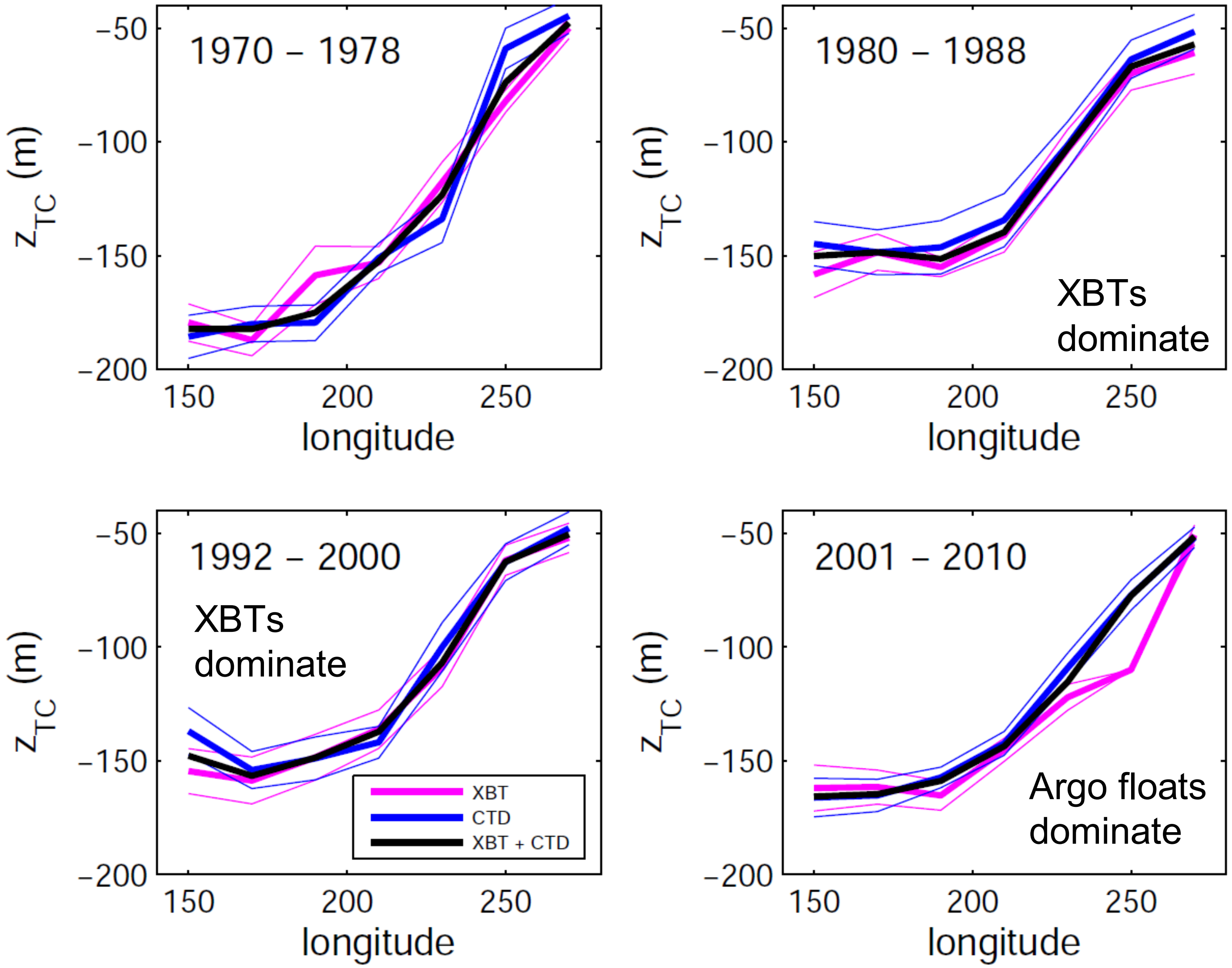
— negative SOI

Decadal variability of thermocline and winds

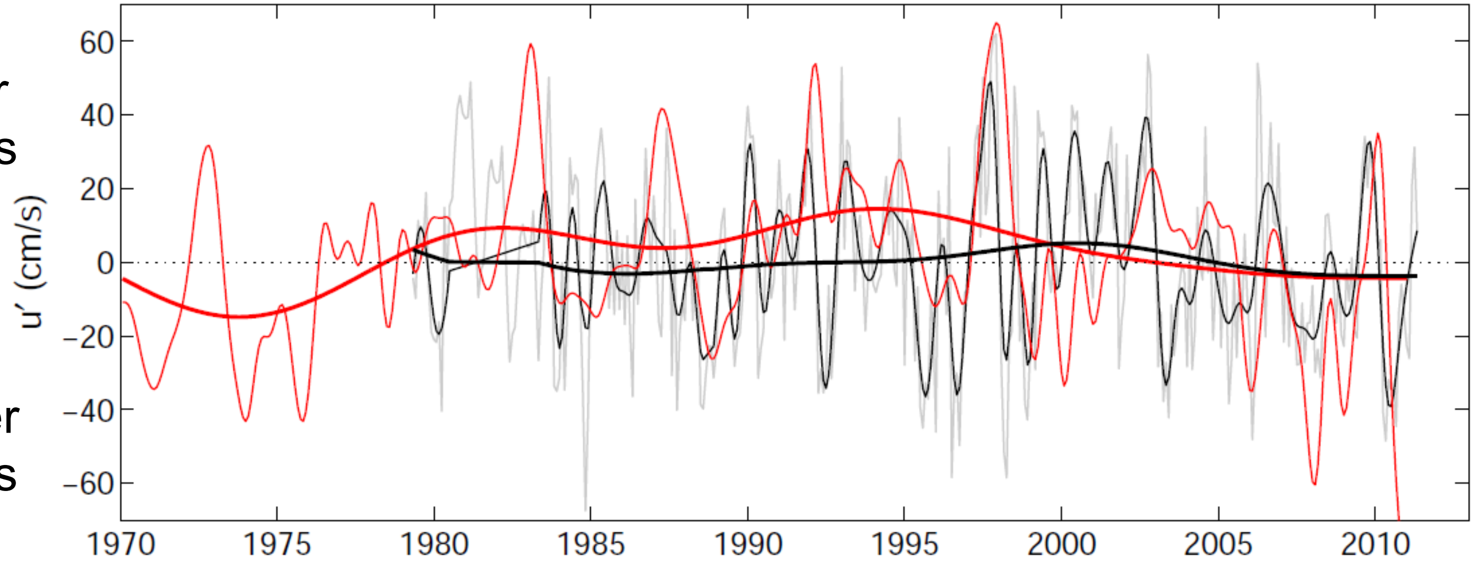


- deep thermocline during decades with stronger winds.
- shallow thermocline during decades with weaker winds.

Z_{TC} estimates using XBT and CTD separately



Zonal currents



weaker currents

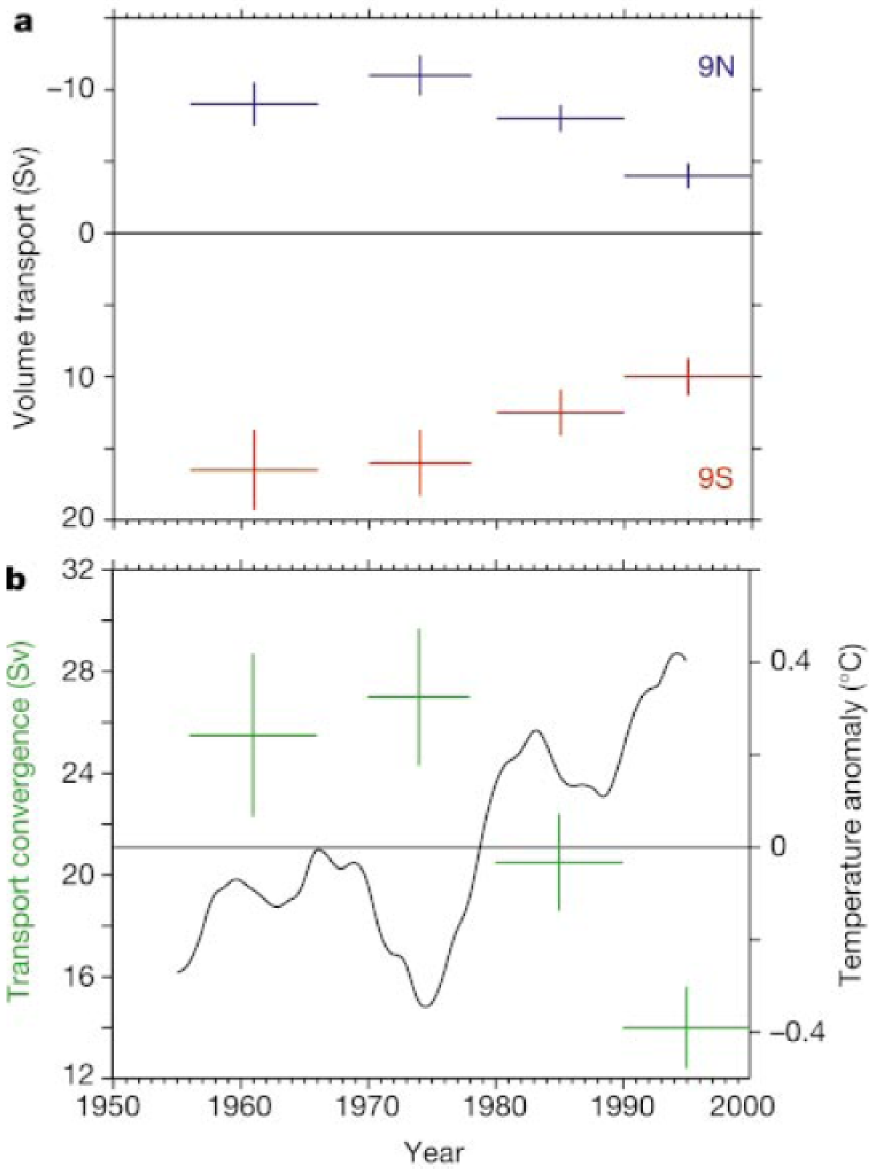
stronger currents

weak winds

strong winds

- weaker currents during El Nino events.
- however, the decadal changes in zonal currents do not follow the SOi/trade winds.

Weaker upwelling after the 70s shift

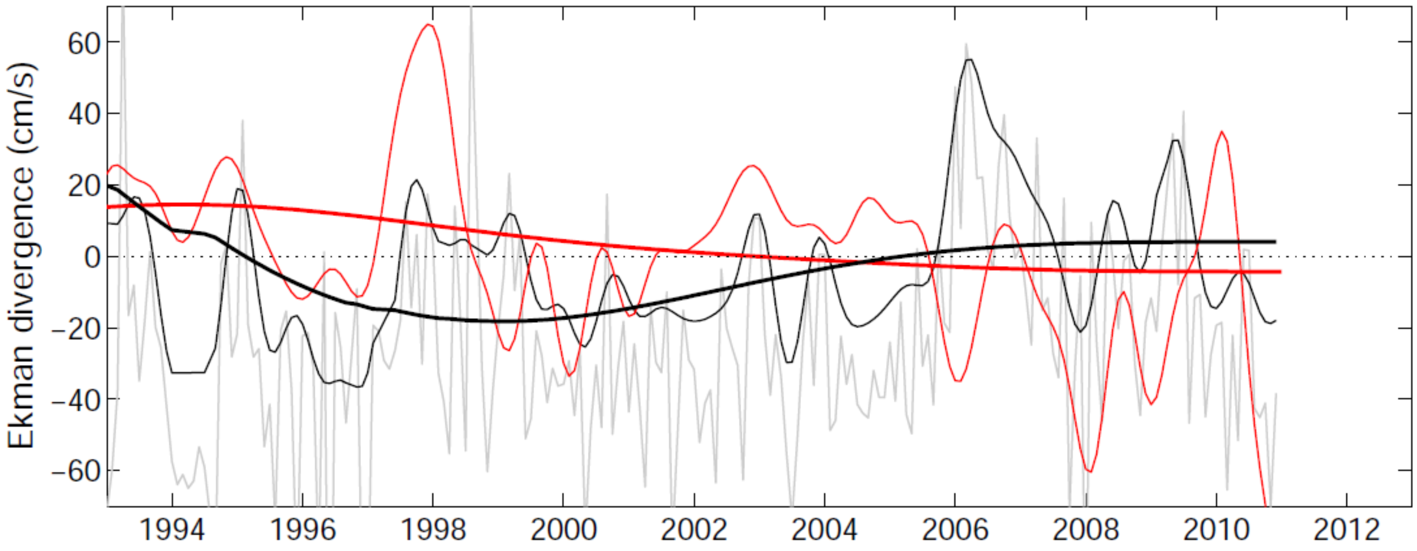


- MP&Z infer changes in upwelling from the divergence/convergence of upper ocean meridional transport.
- Transports are estimated using hydrographic sections.

Figure 2 Meridional transports in the pycnocline and smoothed sea surface temperatures over the past 50 years. **a**, Mean zonally integrated meridional transports in the pycnocline relative to 900 dbar along 9° N and 9° S, computed for 1956–65, 1970–77, 1980–89 and 1990–99. Values are integrated in the Northern Hemisphere from the eastern boundary to 145° E in density classes between 22 and 26 kg m^{-3}, and in the Southern Hemisphere from the eastern boundary to 160° E in density classes between 22.5 and 26.2 kg m^{-3}. Transports are in units of sverdrups (1 Sv = 10^6 m^3 s^{-1}) which is the volumetric equivalent of mass for a constant reference density. Error bars are for one standard error. **b**, Mean meridional transport convergence (in Sv) in the pycnocline across 9° N and 9° S. Convergence is calculated as the difference between Southern Hemisphere minus Northern Hemisphere transports in **a**. Also plotted in **b** are areally averaged sea surface temperature anomalies in the eastern and central equatorial Pacific (9° N–9° S, 90° W–180° W) where equatorial upwelling is most intense[31]. The temperature time series is derived from monthly analyses[50] smoothed twice with a 5-year running mean to filter out the seasonal cycle and year-to-year oscillations associated with ENSO. Anomalies are relative to 1950–99 averages.

McPhaden and Zhang 2002

Has upwelling strengthened in the 2000s?



stronger upwelling

weaker upwelling

weak winds

strong winds

- Ekman divergence estimated from using drifters.
- Ekman divergence is difficult to estimate from TAO obs.
  - only moorings on the equator have ADCPs. off-equatorial v obs are needed to compute Ekman divergence/upwelling.
- no consistent relationship between SOi and upwelling on interannual timescales.
  - weird, not even during the 97 Nino? Maybe during La Ninas?

Conclusions

Models and theory

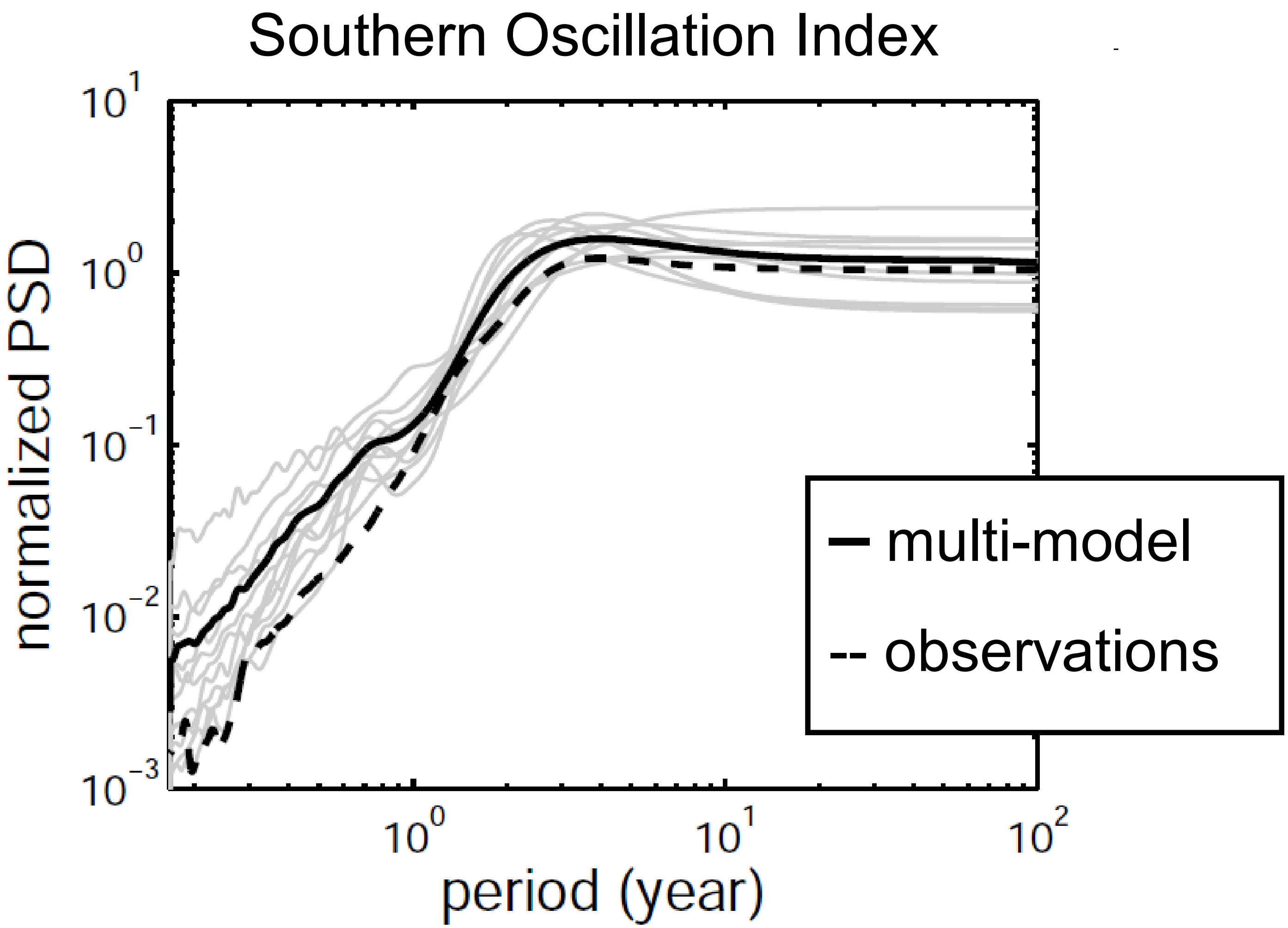
- Models and theory indicate that PDV is not ENSO-like.
- Predictability of PDV maybe severely limited because the thermocline is NOT a precursor of SST anomalies on decadal timescales.

Observations

- XBT/CTD/Argo: negative (positive) thermocline feedback on decadal (interannual) timescales.
- TAO: positive zonal advection feedback on interannual timescales, but not evident for decadal timescales ☹.
- Drifters: positive upwelling feedback on decadal timescales?

Extra slides

Spectra of Pacific Variability in Models and Obs



Clement et al. 2011

Decadal variability of OHC in the tropical Pacific

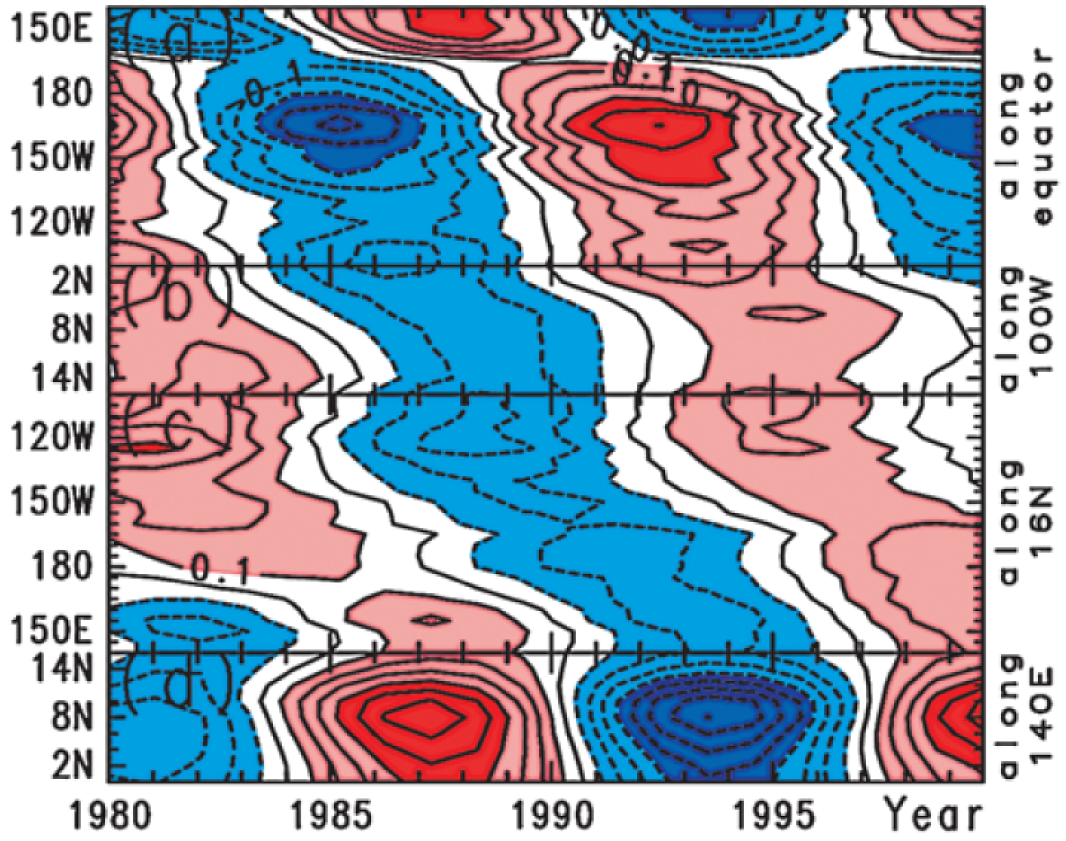


Figure 3. Time series of decadal-scale OHC anomalies on the rectangular path (circuit) around the northern tropical Pacific from 1980 to 1999. (a) Along the equator from the western boundary (140°E) to the eastern boundary (100°W). (b) Along the eastern boundary from the equator to 16°N. (c) Along the 16°N line from the eastern boundary to the western boundary. (d) Along the western boundary from 16°N to the equator. Units in °C. Counter interval is 0.05°C and negative values are represented by the broken lines. The values from 0.1°C to 0.2°C (from −0.2°C to −0.1°C) are represented by light red (blue) color, and values greater than 0.2°C (less than −0.2°C) are represented by dark red (blue) color.

This figure **does not** show reflection of off-equatorial OHC anomalies in the western boundary.

This figure **does** show that equatorial OHC anomalies (KWs) reflect in the eastern boundary

Hasegawa and Hanawa 2003