ENSO Mechanisms

Outline

- Bjerknes feedback
- Other theories

Walker Circulation: Normal Condition

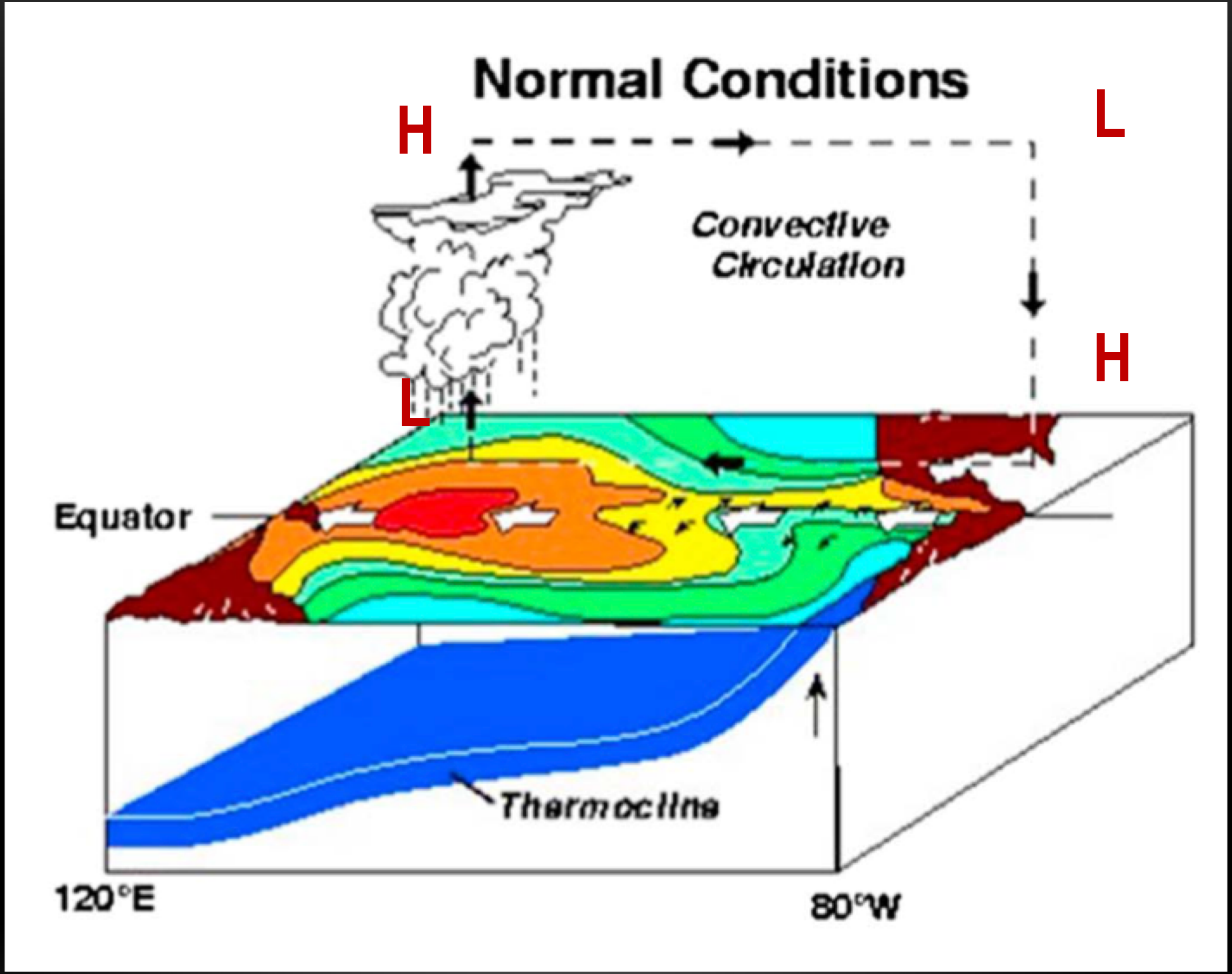


Figure courtesy of the Pacific Marine Environmental Laboratory/National Oceanic and Atmospheric Administration. Also see Fig. 1 in Yeh et al. 2018 https://doi.org/ 10.1002/2017RG000568

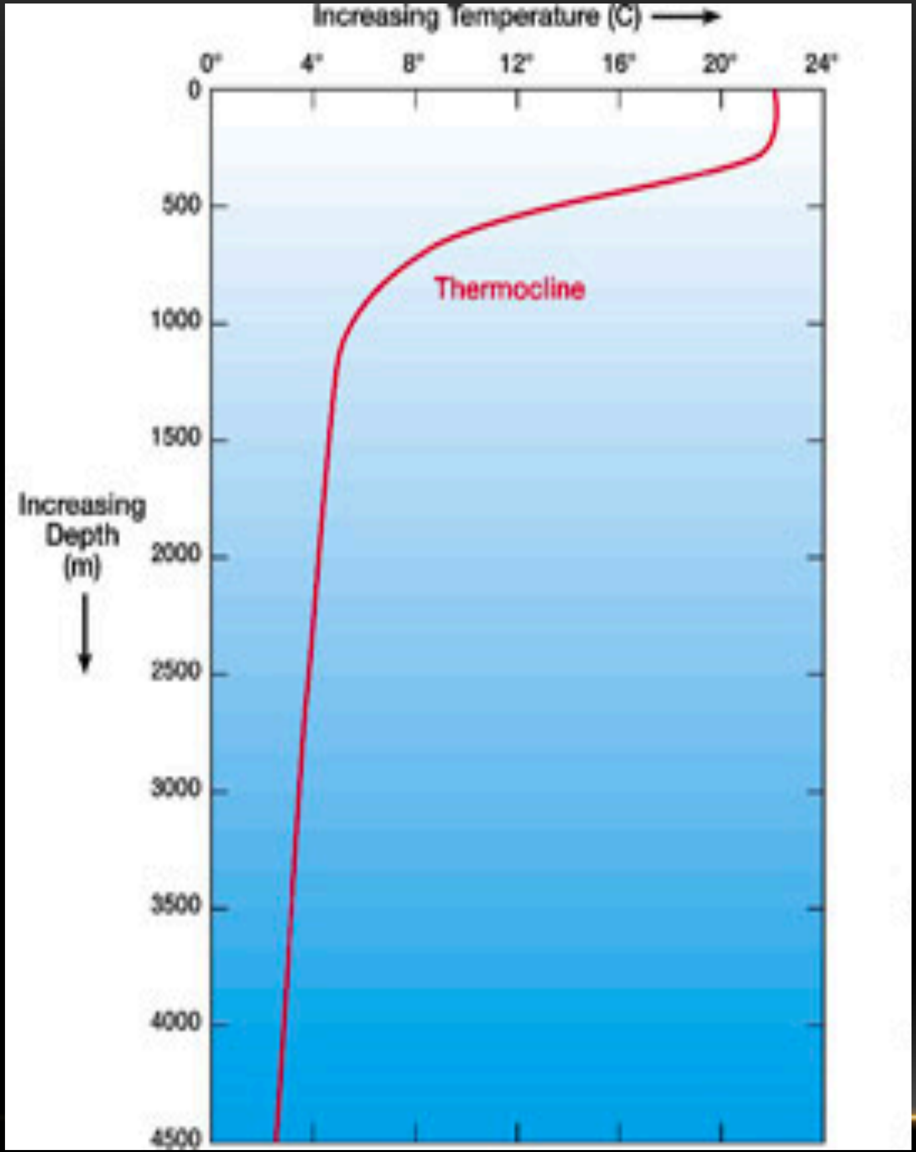


Figure credit: UCAR – Windows to the Universe.

Thermocline

- The thermocline separates the upper mixed layer from the calm deep water below.
- The thermocline is characterized by strong vertical gradient of T.
- The thermocline is normally about 100 m deeper in the equatorial western Pacific than in the equatorial eastern Pacific

Bjerknes feedback: positive air-sea interaction

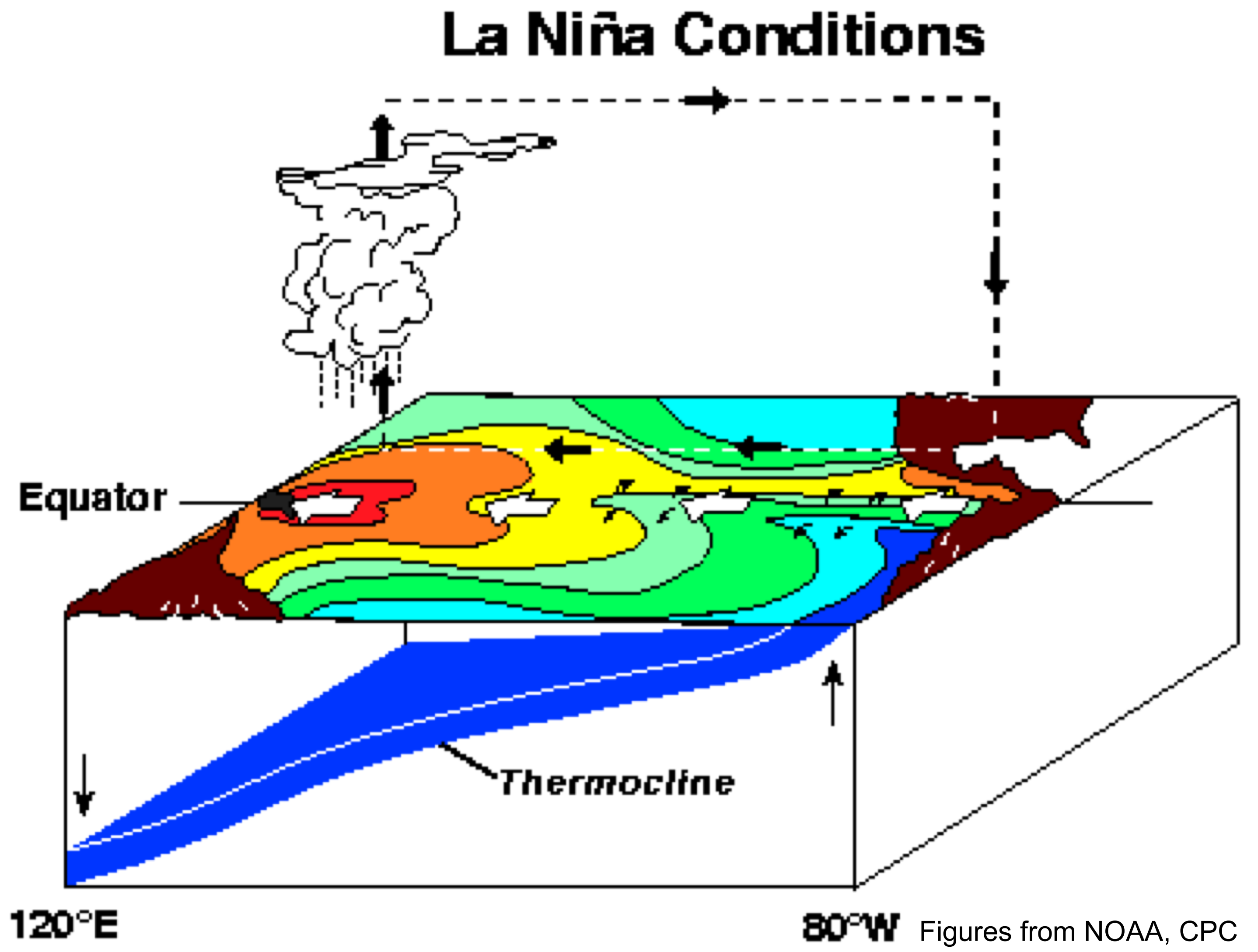
- SST
- SST and SLP gradients
- Walker Circ.
- Surface zonal wind
- SST

- anomalous cooling in the eastern tropical Pacific (i.e., La Niña) →
- enhance the zonal SST and SLP gradients across the Pacific basin →
- a stronger Walker Cell →
- enhanced surface easterly →
- further amplify the east-west SST gradient through the effects of oceanic advection, upwelling and thermocline displacement.

La Nina Condition

Can you describe the key changes in the coupled atmosphere-ocean system?

- Enhanced east-west SST gradient
- A stronger Walker circulation
- Shallow thermocline over the East Pac and a steeper thermocline slope

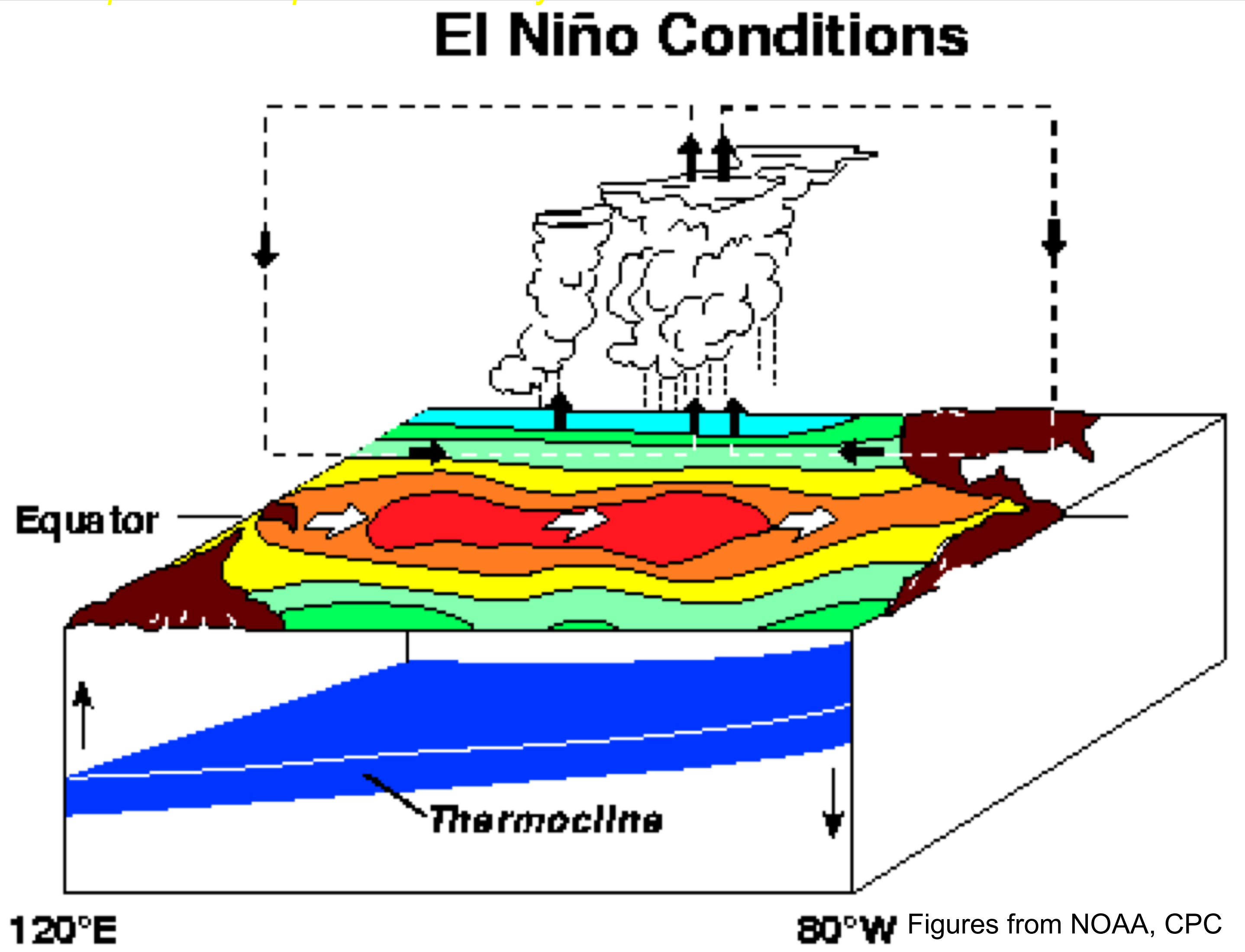


Figures from NOAA, CPC

El Nino Condition

Can you describe the key changes in the coupled atmosphere-ocean system?

- Reduced east-west SST gradient
- Convection shift toward the Central Pacific
- A weaker Walker Circ. with reduced low-level easterly and upper-level westerly.
- Reduced thermocline slope



Figures from NOAA, CPC

El Nino Composite: 850-hPa Zonal Wind Anomalies

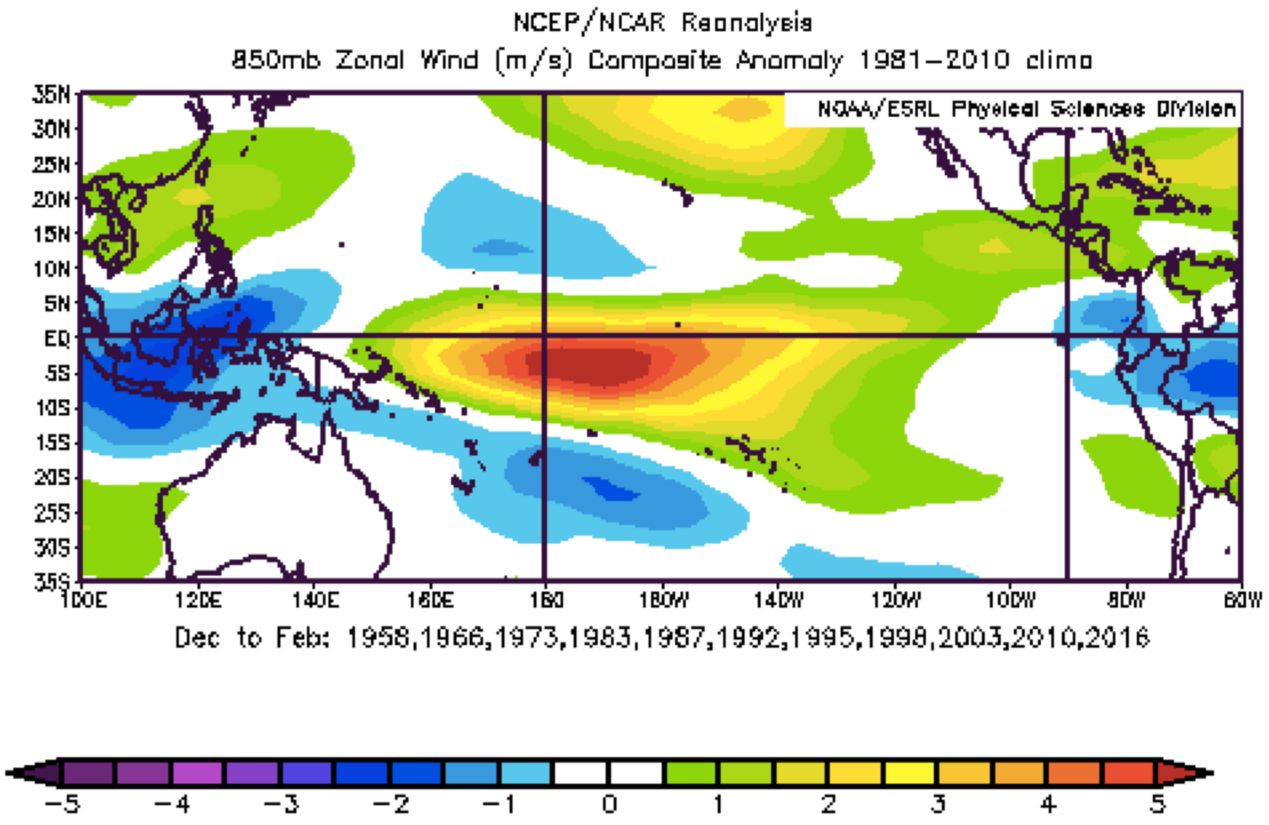


Figure produced at https://psl.noaa.gov/cgi-bin/data/composites/printpage.pl

The total flow may become westerly; westerly burst occurs on the synoptic time scale.

El Nino Composite: 250-hPa Zonal Wind Anomalies

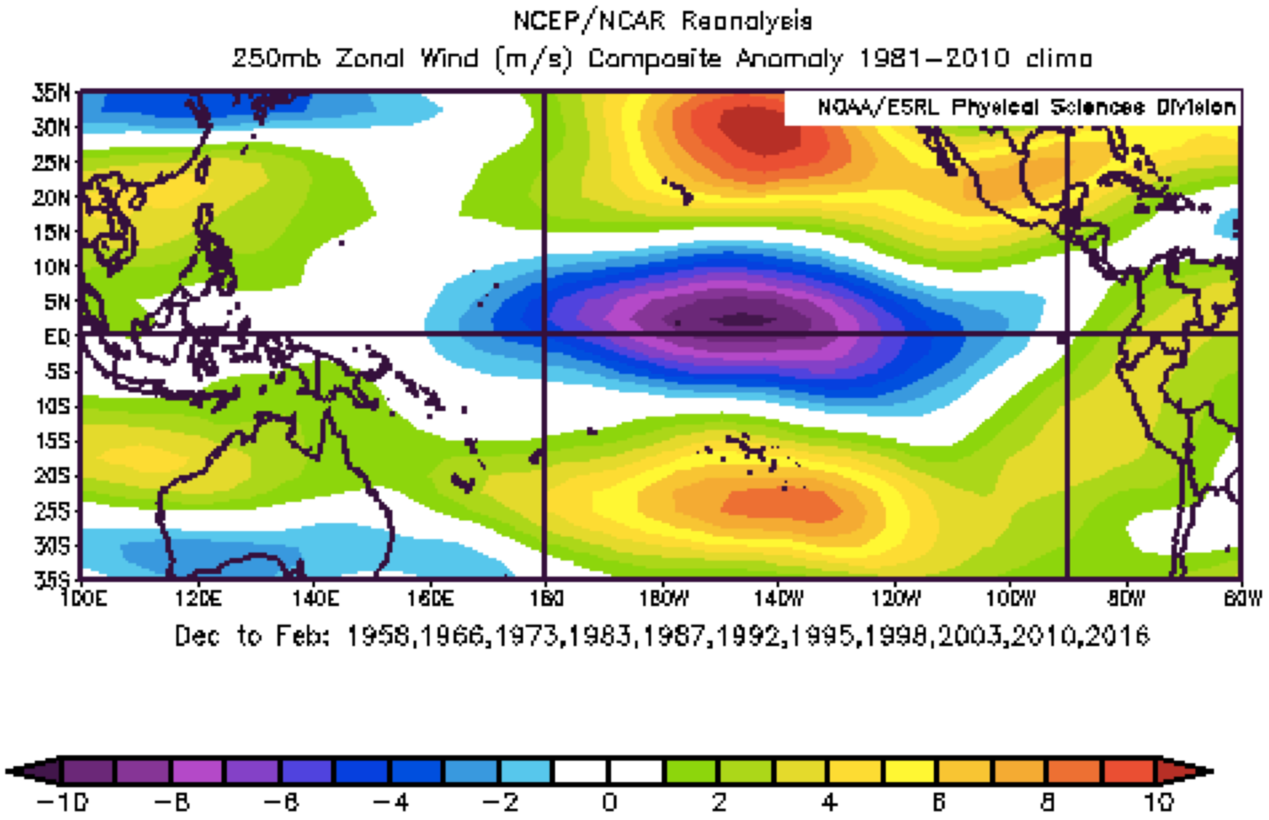


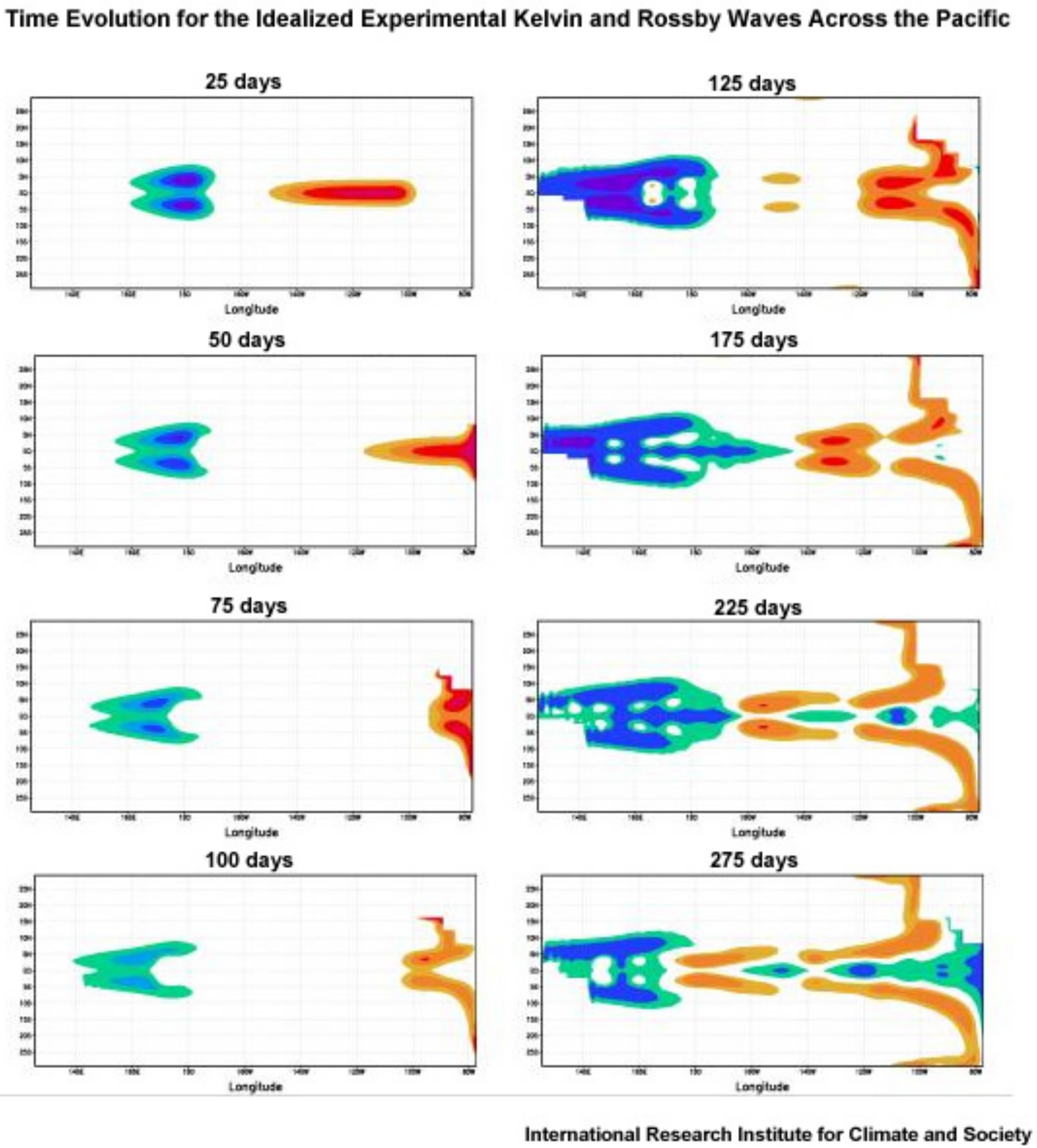
Figure produced at https://psl.noaa.gov/cgi-bin/data/composites/printpage.pl

What does the Bjerknes feedback fail to explain?

- What limits the amplitude of the perturbations?
  - Availability of moisture
  - SST reduced by evaporation
  - Strong zonal advection may reduce SSTA
- It is just a positive feedback process. What induces the phase transition of ENSO (cold to warm or warm to cold)?
- What determines the lifetime of an ENSO event?

Other Theories: Delayed oscillator theory

- The wave reflection at the western boundary of the Pacific ocean provides a negative feedback for the coupled system to oscillate.
- The time that it takes for waves to propagate across the Pacific sets the duration of an ENSO event (Suarez and Schopf 1988; Battisti and Hirst 1989; Cane et al. 1990).



Other Theories: Recharge-discharge oscillator

- During the warm phase of ENSO, the ocean dynamic response to the westerly wind anomalies results in the discharge of equatorial heat content, an anomalously shallow thermocline and the transition to the cold phase.
- The converse occurs during the cold phase of the ENSO.
- The discharge and recharge of equatorial heat content cause the coupled system to oscillate (Jin 1997).

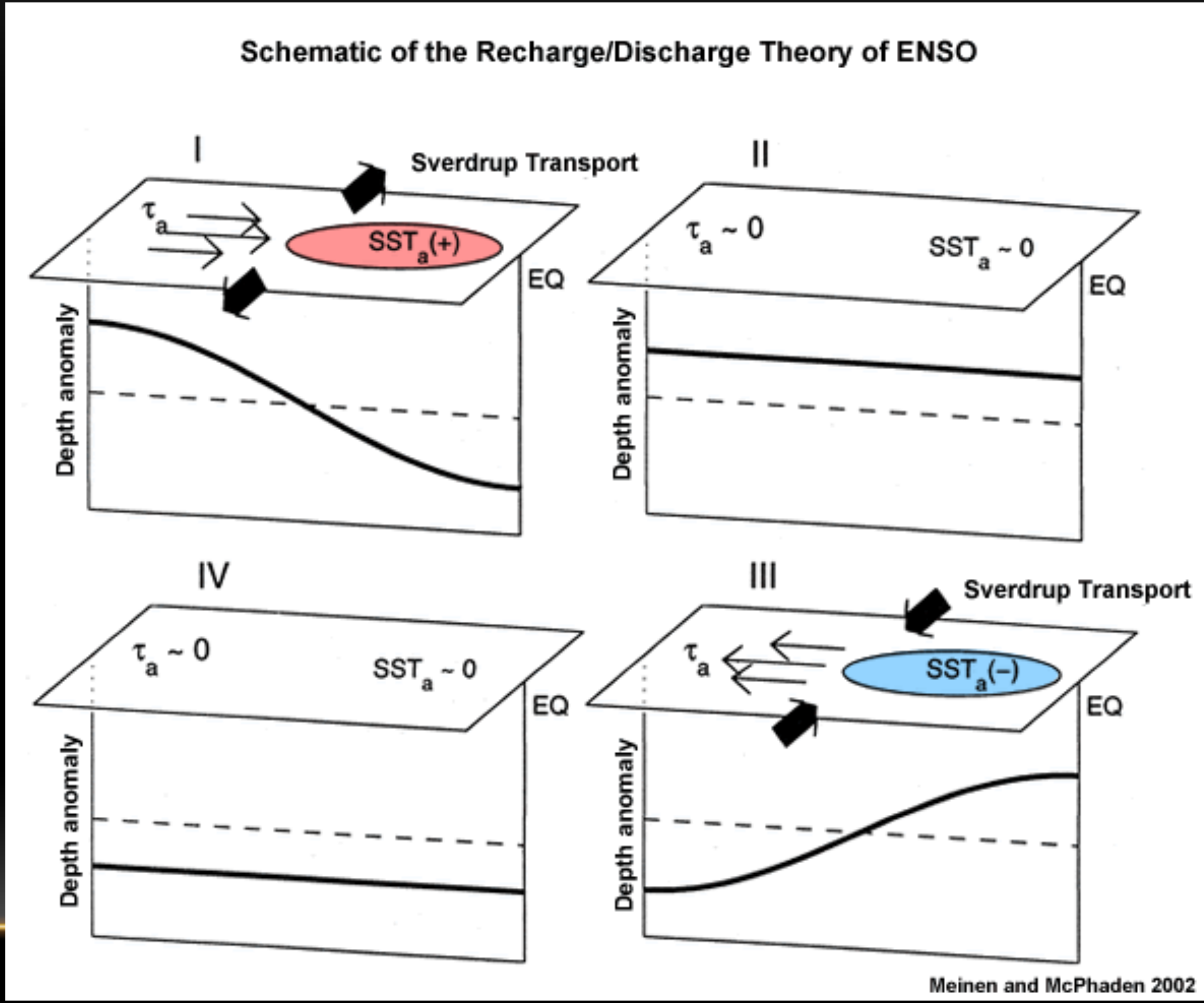
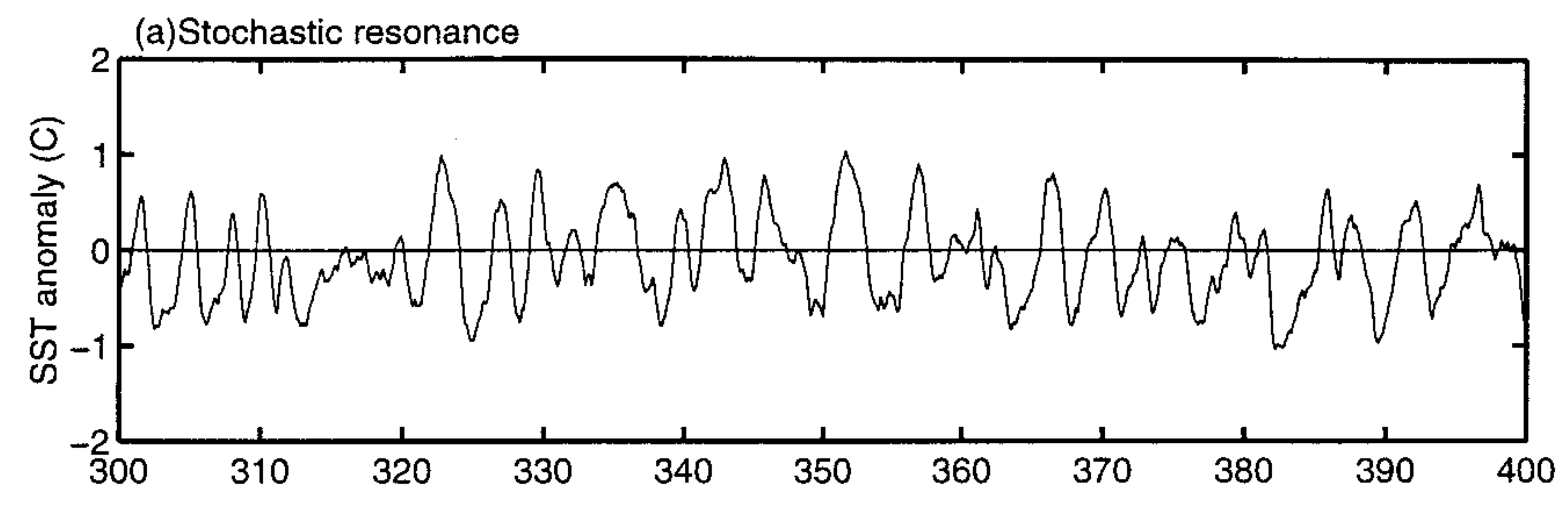


Figure https://www.pmel.noaa.gov/pubs/outstand/mein2119/images/fig_01.gif

Other Theories: Linear Stochastic Theory

- ENSO can be characterized as a stable (or weakly damped) mode triggered by stochastic atmospheric/oceanic forcing (e.g., Lau 1985; Neelin et al. 1998; Philander and Fedorov, 2003): analogous to "a damped pendulum subject to moderate blows at random times"
- Disturbances external to the coupled system are the source of random forcing that drive ENSO, including the MJO, westerly wind bursts (Gebbie et al., 2007), and tropical waves (An 2008)
- It explains the irregular behavior of ENSO variability and limited predictability.



The SSTA time series derived from the stochastic response of the ENSO model to a white noise forcing in the stable regime (Wang et al. 1999 © American Meteorological Society. Used with permission)

References

- NOAA CPC ENSO Cycle: https://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensocycle/enso_cycle.shtml
- Wang, B., A. Barcilon, and Z. Fang, 1999: Stochastic Dynamics of El Nino-Southern Oscillation. J. Atmos. Sci., 56, 5-20.