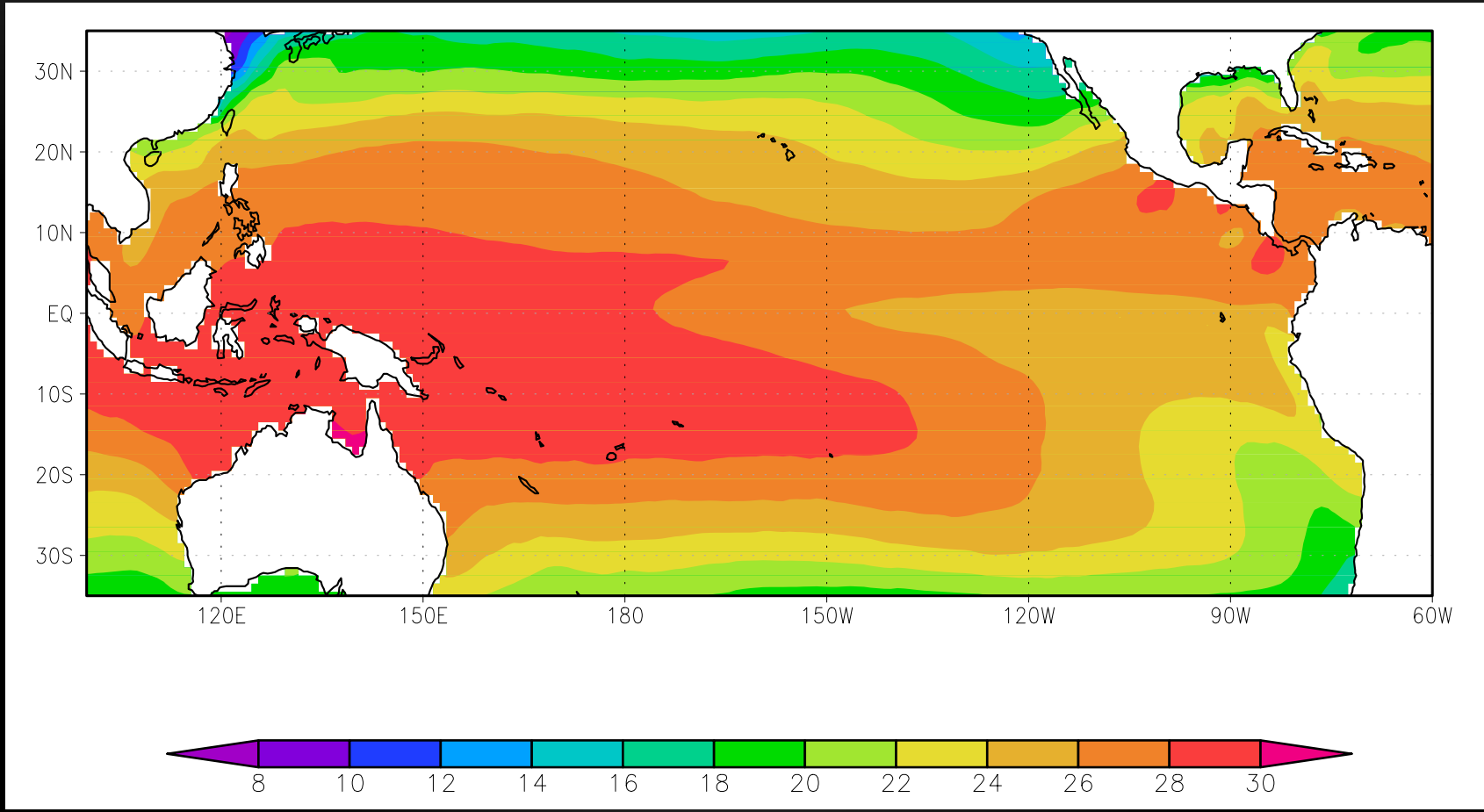
Module 4: Interannual Variability and Prediction

Outline

- El Niño–Southern Oscillation (ENSO): definition, indices, characteristics
- ENSO mechanisms: including the Bjerknes feedback
- ENSO teleconnection and impacts on climate and weather
- Prediction of the ENSO
- The North Atlantic Oscillation (NAO): characteristics
- Impacts of the NAO
- Atmospheric teleconnections

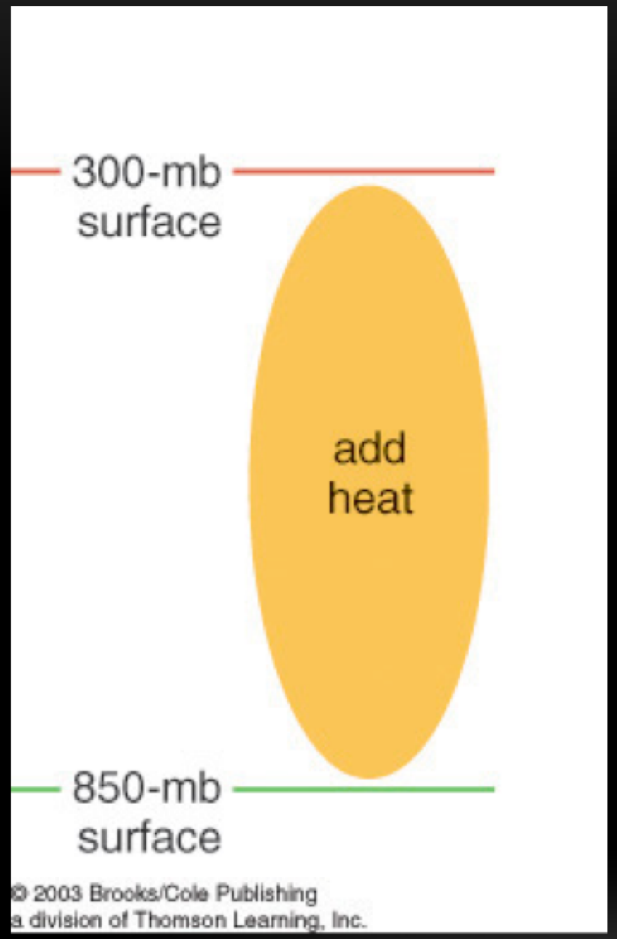
What is the ENSO?

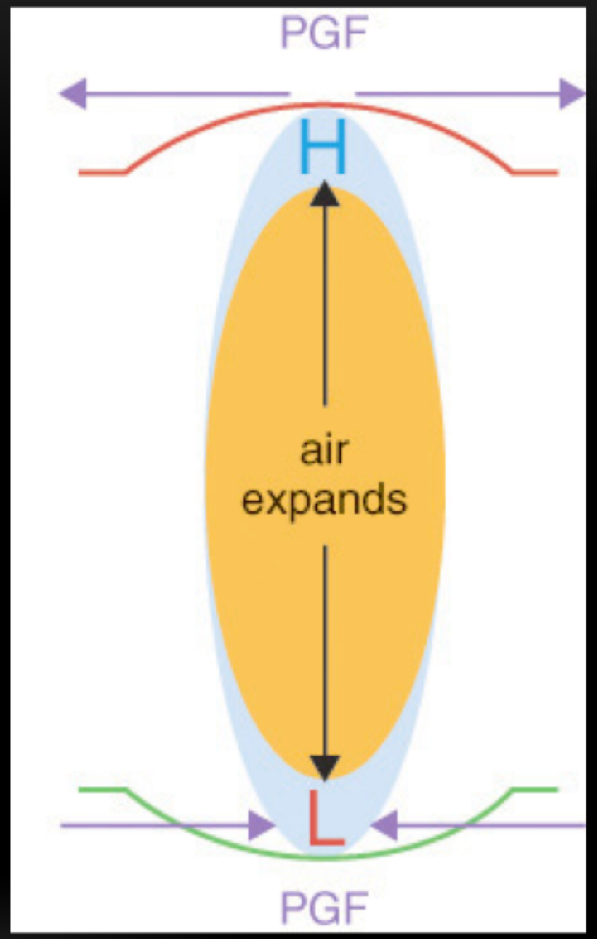
Long-term Mean SST (Jan)



- SST over the equatorial western Pacific is much higher than that over the equatorial eastern Pacific
- *What vertical circulation do you expect given the east-west asymmetric SST distribution?*

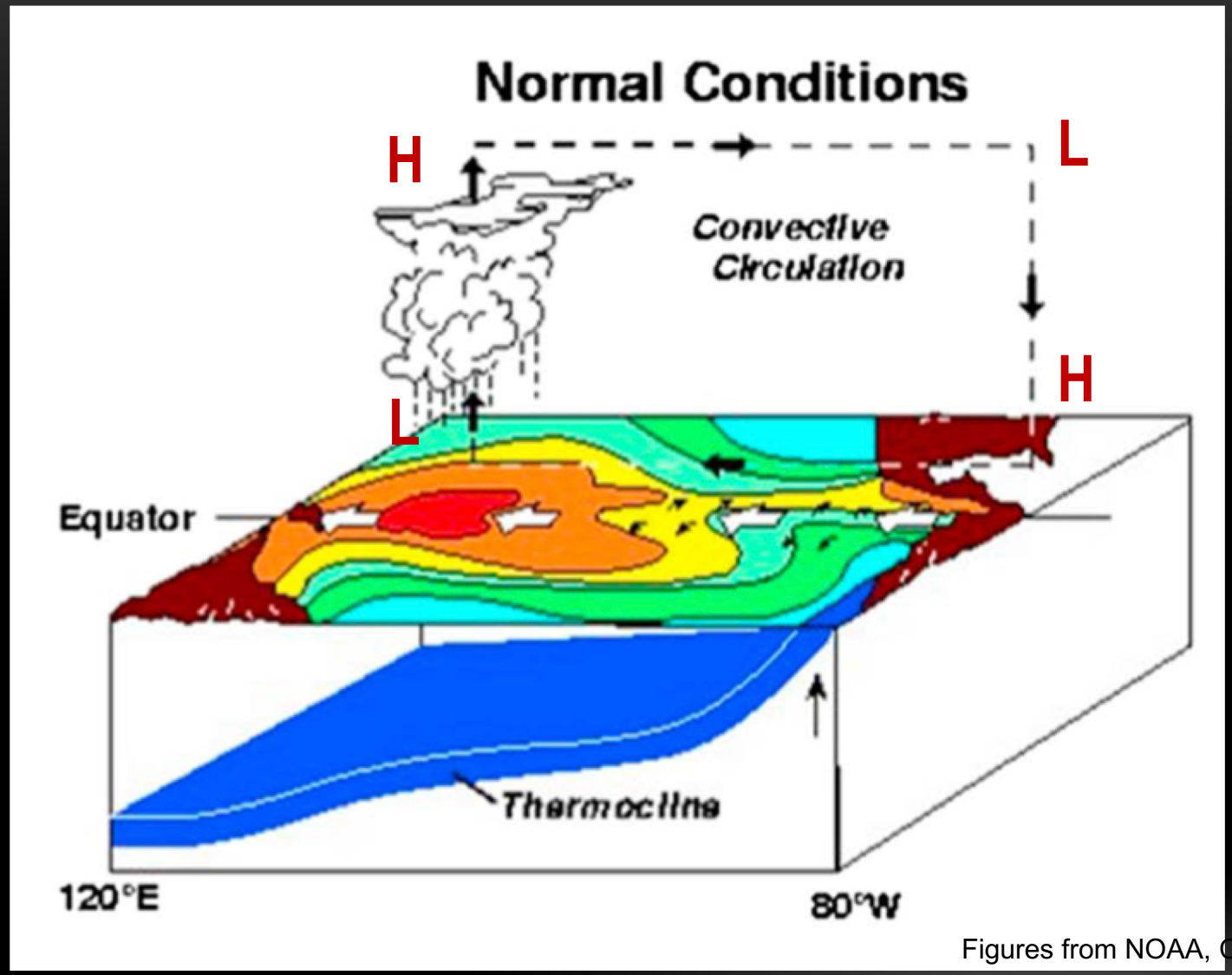
Hydrostatic Balance





- The hydrostatic balance implies that column warming will lead to high (low) pressure anomalies in the upper (lower) troposphere.
- This is a simplified view: the tropical response to a steady forcing is best described by the Matsuno-Gill model

The Walker Circulation over the Pacific

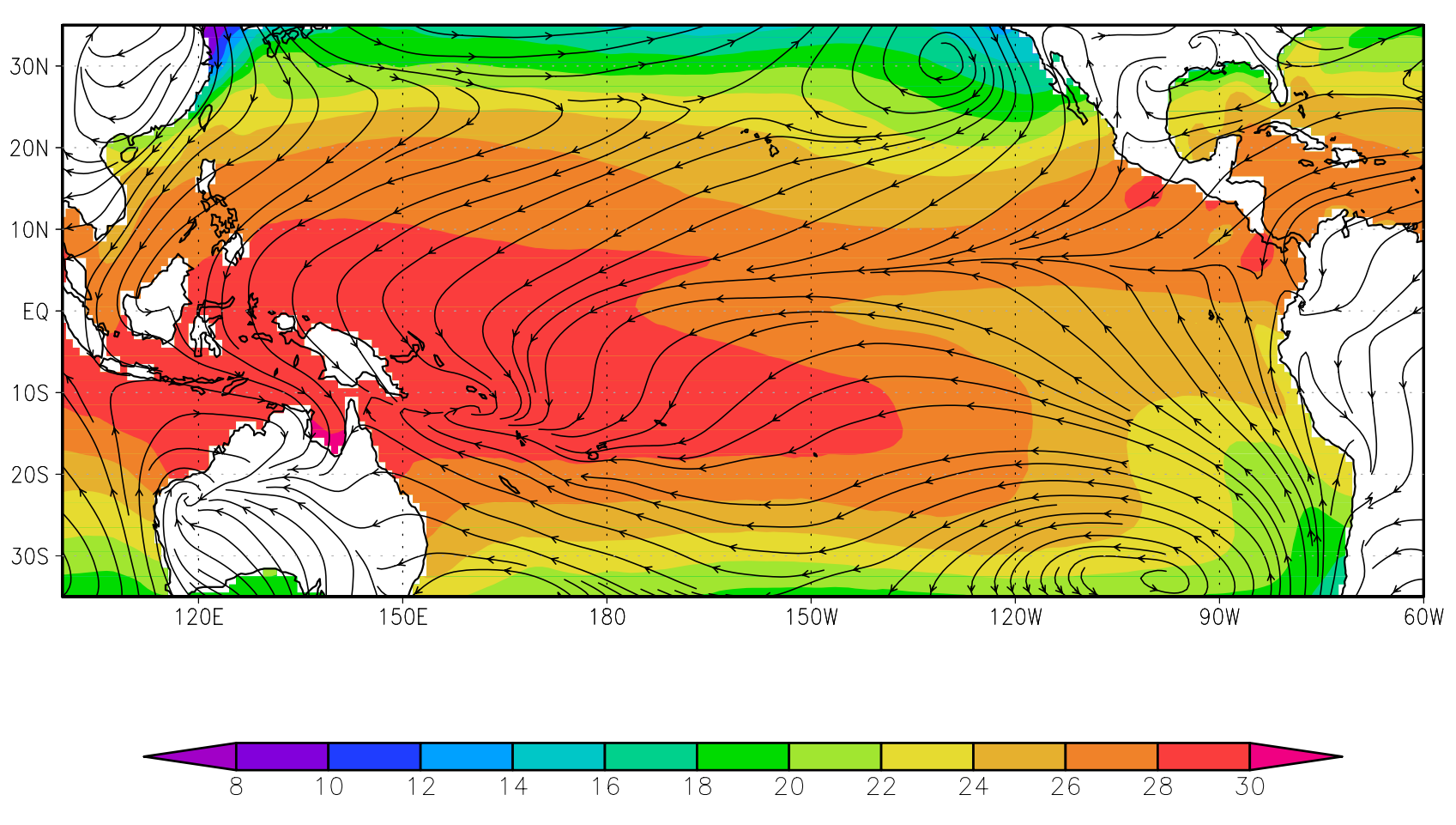


Figures from NOAA, CPC

- The sea level pressure is lower over the western Pacific where SST is warmer and higher over the eastern Pacific where SST is cooler.
- Wind is directed from the western Pacific to the eastern in the upper troposphere and is reversed in the lower troposphere.
- The warmer SST in the western Pacific is corresponding to a deeper thermocline or a deeper layer of warm water.
- In contrast, there is upwelling and relatively cool SST in the EP.

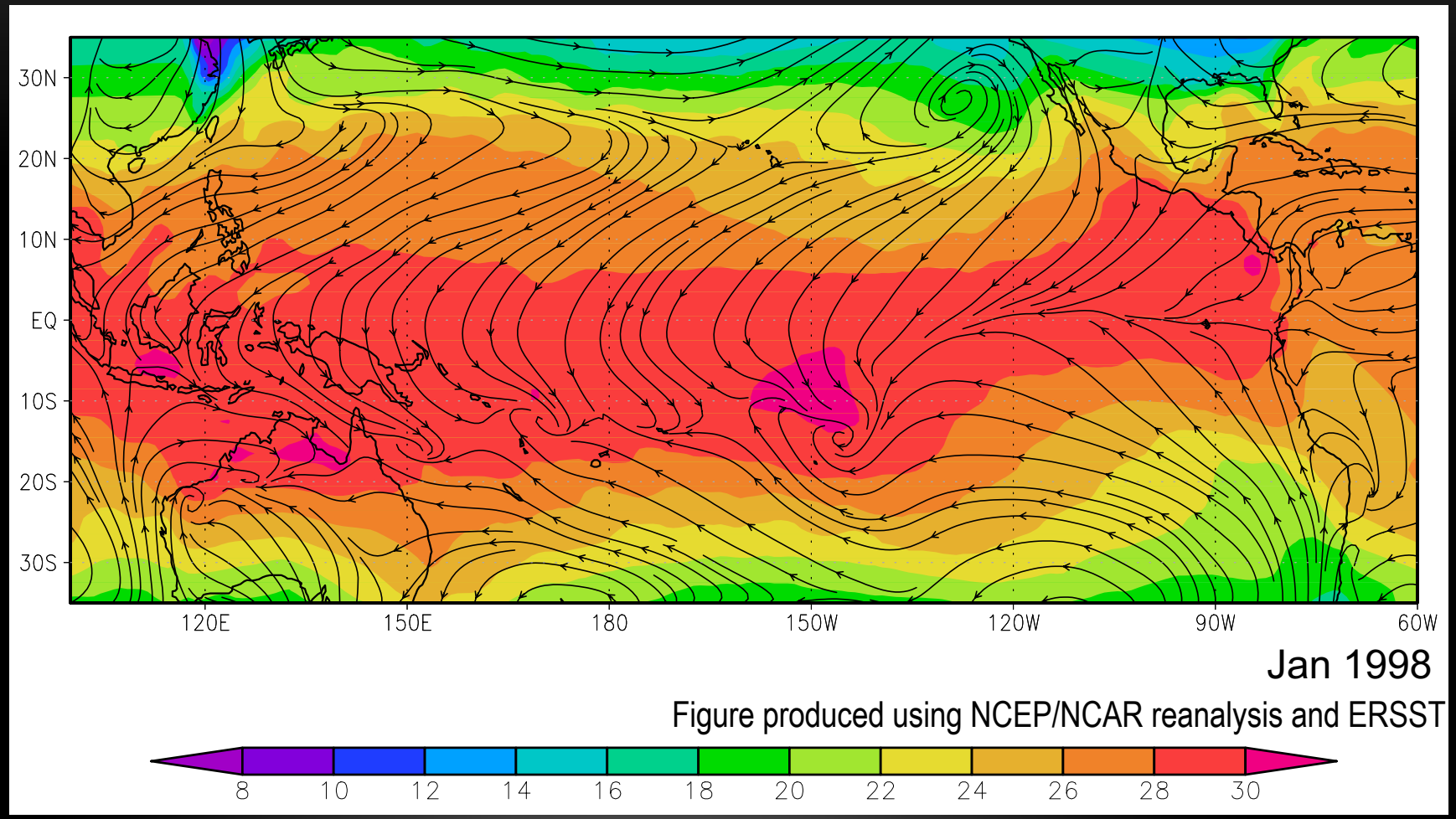
Figure courtesy of the Pacific Marine Environmental Laboratory/National Oceanic and Atmospheric Administration. Also see Fig. 1 in Yeh et al. 2018 https://doi.org/ 10.1002/2017RG000568

Long-term Mean SST and Low-level Wind



The low-level wind is directed from the eastern Pacific cold tongue toward the western Pacific warm pool in the tropics.

In some years… (say Jan 1998)



In some years, like 1998, the SST in the eastern Pacific is anomalously warm, and the low-level easterly is weakened or even reversed into a westerly flow – SST and atmospheric circulation are coupled!

El Niño and La Niña

- El Niño: A significant increase in sea surface temperature over the eastern and central equatorial Pacific that occurs at irregular intervals, generally ranging between two and seven years (the AMS glossary). This phenomenon typically peaks in boreal winter near Christmas, hence the name El Niño (Spanish for "the boy child").
- La Niña: La Niña is the counterpart to the El Niño "warm event," and its spatial and temporal evolution in the equatorial Pacific is, to a considerable extent, the mirror image of El Niño, although La Niña events tend to be somewhat less regular in their behavior and duration. (the AMS glossary).

https://glossary.ametsoc.org/wiki/El_ni%C3%B1o
https://glossary.ametsoc.org/wiki/La_ni%C3%B1a

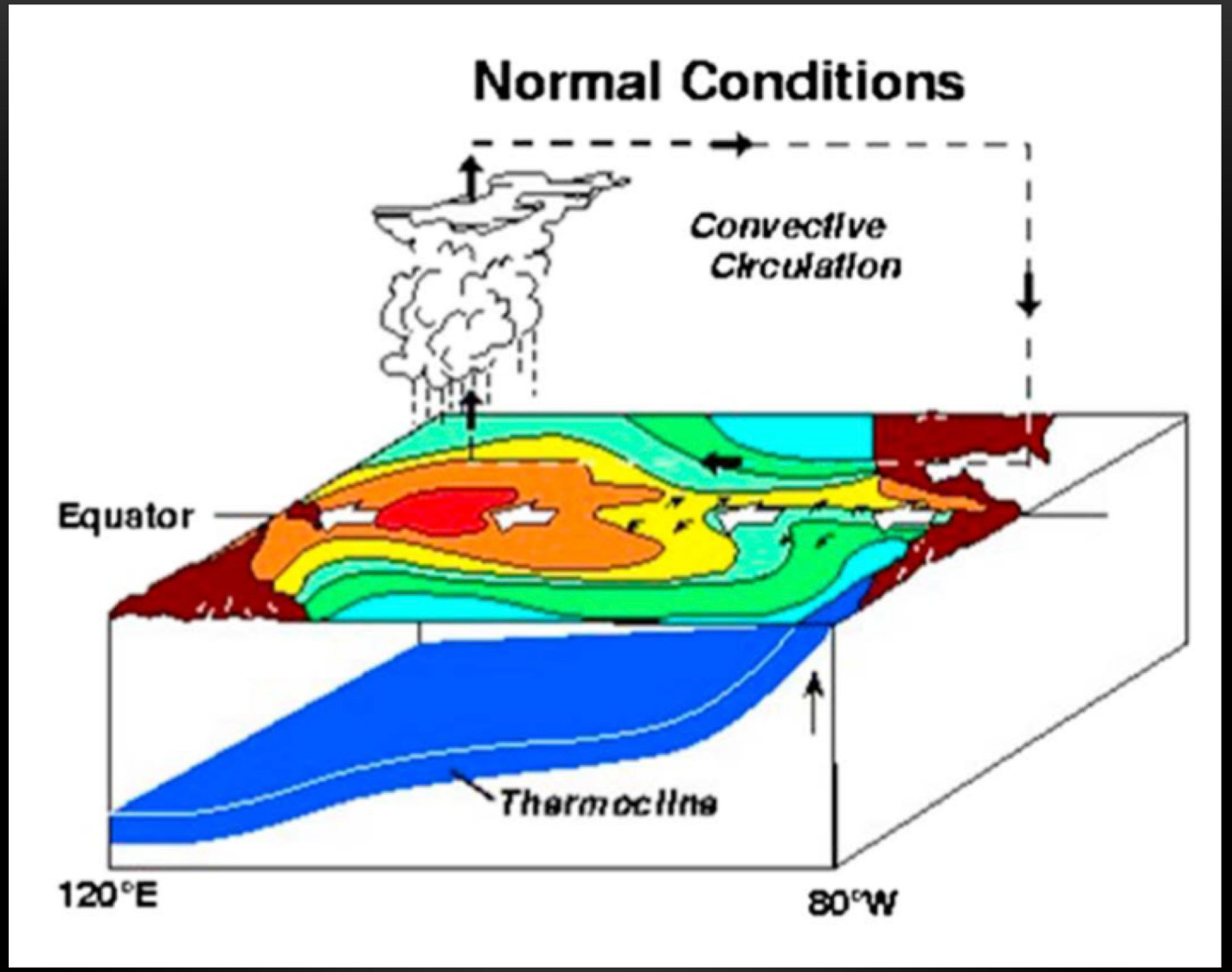
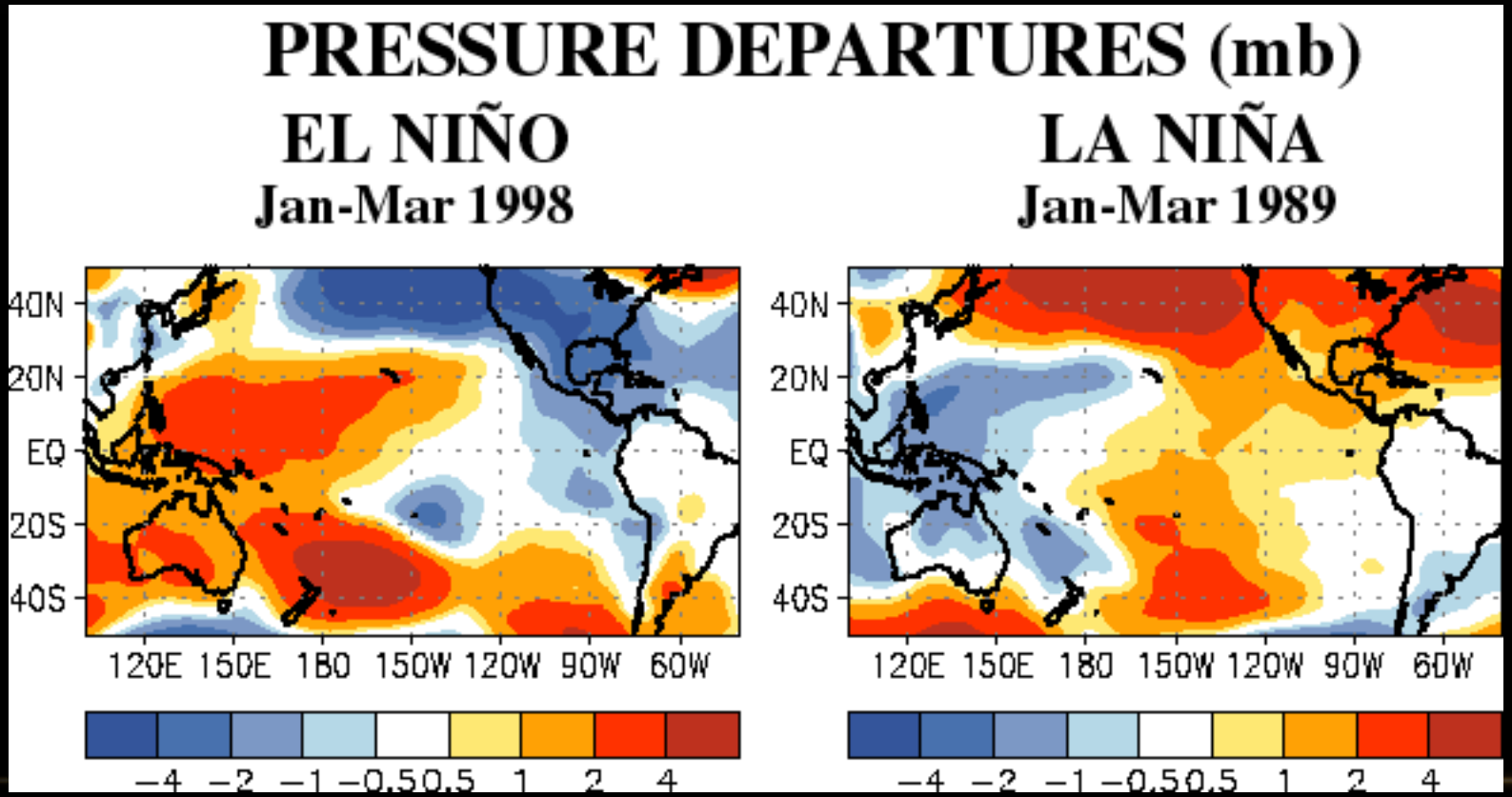


Figure courtesy of the Pacific Marine Environmental Laboratory/National Oceanic and Atmospheric Administration. Also see Fig. 1 in Yeh et al. 2018 https://doi.org/10.1002/2017RG000568

Now let's look at the atmospheric conditions: fluctuations of SST are accompanied by larger-scale fluctuations of SLP. The associated SLP fluctuations are known as the Southern Oscillation.

Southern Oscillation

- Southern Oscillation is coined by Walker and Bliss (1932) to refer to the east-west seesaw pattern in SLP.
- SOI = SLP (Tahiti) – SLP (Darwin) or SLP(east) minus SLP(west)



- Is SOI positive or negative when there is warming in the East Pacific?

Figure from NOAA, CPC

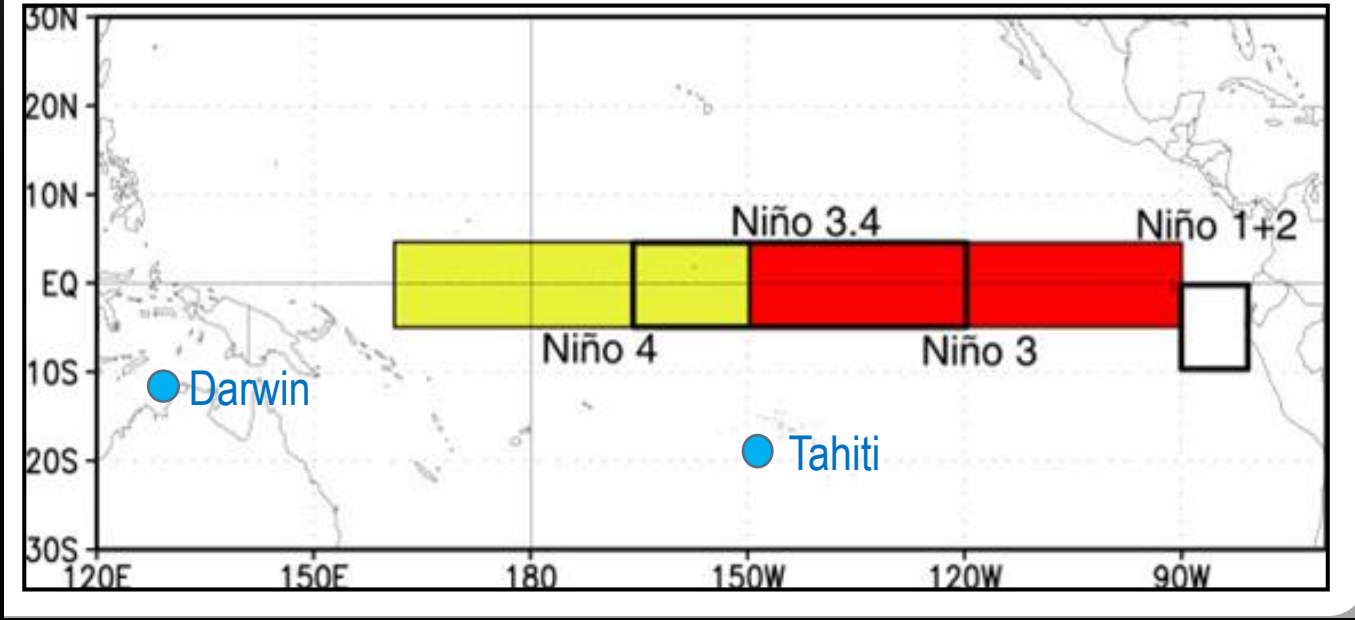
What is ENSO?

- Bjerknes (1966, 1969) pointed out that El Niño and the Southern Oscillation (SO) are strongly coupled to each other. Prior to the late 1960s they had been viewed as two unrelated phenomena.
- Acronym for El Niño–Southern Oscillation, coined in the early 1980s in recognition of the intimate linkage between El Niño events and the Southern Oscillation. The global ocean–atmosphere phenomenon to which this term applies is sometimes referred to as the "ENSO cycle." (AMS Glossary: https://glossary.ametsoc.org/wiki/Enso)

Why is ENSO so important?

- Although ENSO is not the only phenomenon which informs seasonal-to-interannual prediction, it is generally regarded as the most important one. This importance stems from the combination of two factors:
  - Current forecast systems have some skill in predicting ENSO itself (e.g. Landsea and Knaff 2000; Jin et al. 2008; Tippett et al. 2012; Barnston et al. 2012)
  - ENSO strongly influences other aspects of the climate system in relatively predictable ways

ENSO Indices



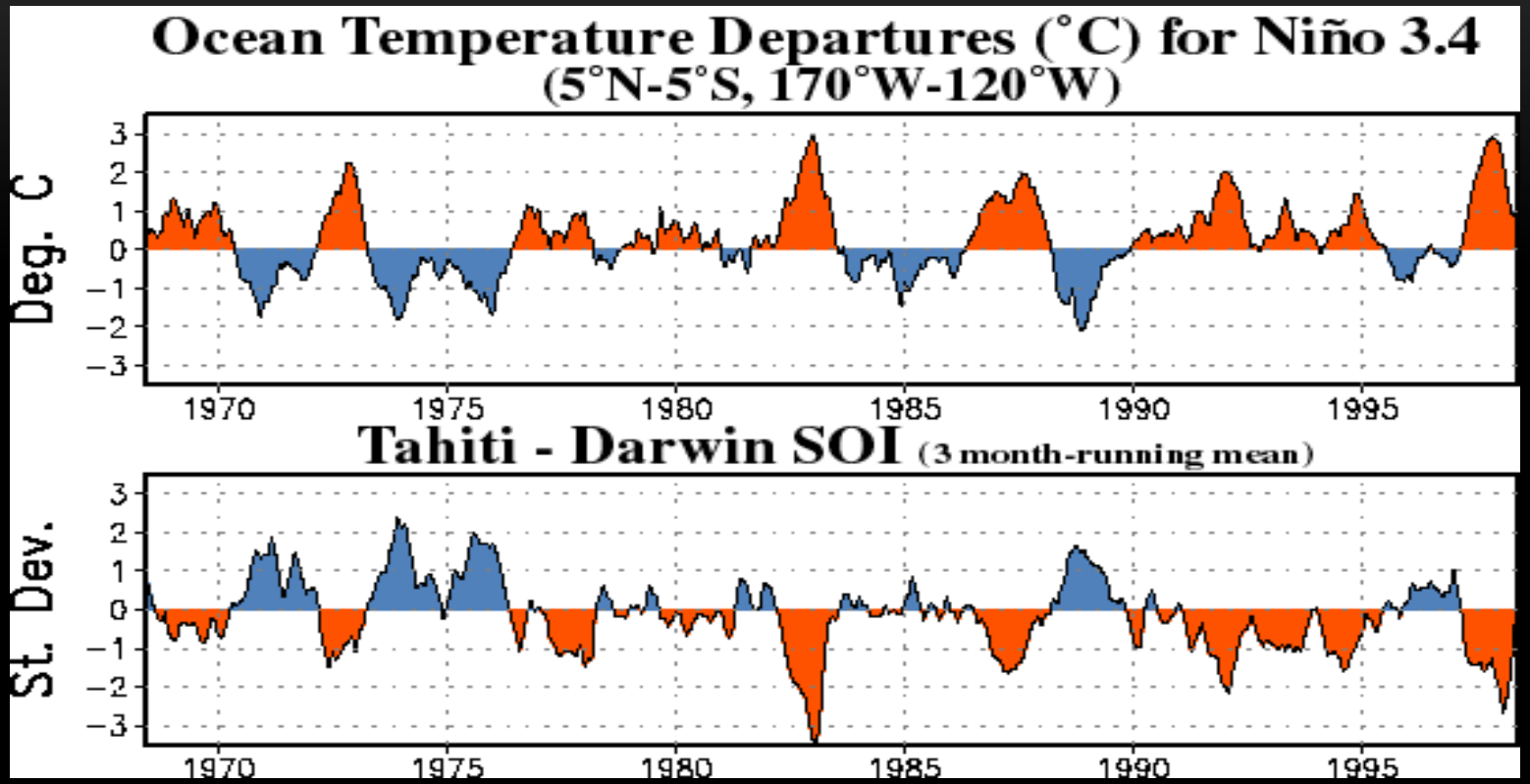
- SST Indices: Nino3, Nino4, Nino3.4
  - Nino1 (80W-90W, 5S-10S); Nino 2 (80W-90W, 0S-5S); Nino3 (150W-90W, 5S-5N); Nino4 (150W-160E, 5S-5N)
  - Nino3.4 (170W-120W, 5S-5N): tropical convection is more sensitive to the SST variability in the Niño-3.4 than in the Niño-3 region; SST variability and the background SST gradient are stronger in the Nino 3.4 region than the Nino-4 region
- SLP index: SOI = SLP (Tahiti) – SLP (Darwin)

Adapted figure from the NOAA CPC

Other ENSO Indices

- Multivariate ENSO Index (MEI):
  - the MEI is calculated as the first unrotated Principal Component (PC) of six observed fields over the tropical Pacific: sea-level pressure (SLP), zonal (U) and meridional (V) components of the surface wind, sea surface temperature (SST), surface air temperature (A), and total cloudiness fraction of the sky.
- Bivariate ENSO Time Series (BEST) Index:
  - combined SOI and Nino3.4
- Oceanic Niño Index (ONI): the three-month running mean SST anomalies in the Nino3.4 region
- ENSO longitude index (ELI): an index that tracks the average longitude of tropical Pacific deep convection. It is to account for the nonlinear response of deep convection to SST and characterize the diversity of ENSO in a single index (Williams and Patricola 2018).

Time Series



- Negative correlation between Nino 3.4 and SOI
- Period: 2-7 years, dominant period of about four years (there is also a decadal change)
- Not a regular cyclic oscillation: strong variations in period and amplitude
- El Nino tends to be stronger than La Nina
- Decadal change: more evident if using a longer time series.

Figure from https://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensocycle/soi.shtml

References

- NOAA CPC ENSO Cycle: https://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensocycle/enso_cycle.shtml