Midterm #1 Results

- Overall OK job.
- 17 takers: highest score is 105, slowest score is 52. Wide distribution below (1/3 above B; 1/3 on C, and 1/3 on D&F):

  score above 95: 3 students --A

  Score 90-94: 1 student -- A-

  Score 87-89: 1 student – B+

  Score 77-79: 1 student -- C+

  Score 70-76: 6 student -- C

  Score 60-69: 2 students -- D

  Score below 60: 3 students -- F
- You did better on Part I & II questions. Need to work on Part III & IV type of questions.

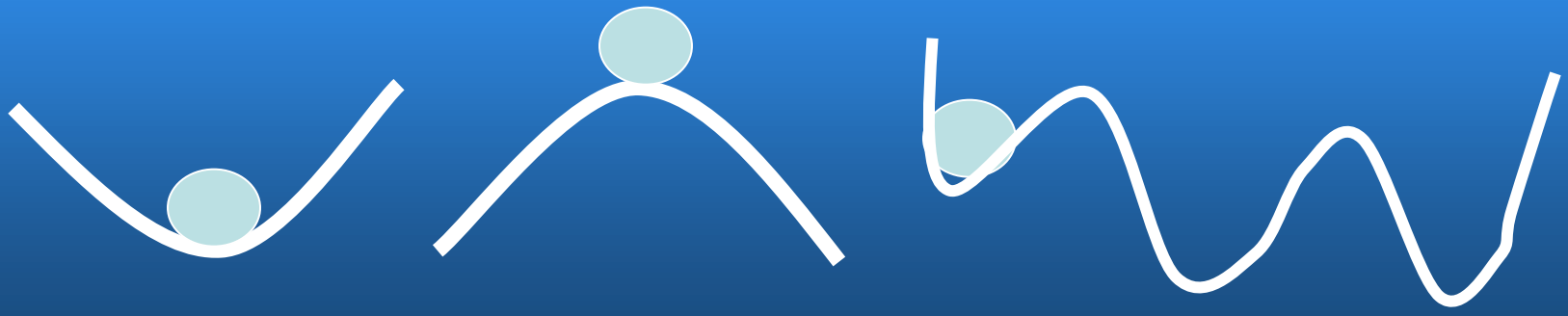
Complications in Climate Change

- **Direct Radiative effect:** is the effect that a particular gas (CO_2 or other greenhouse gases) has on the energy budget of the planet. CO_2 is the most important greenhouse gas in terms of direct radiative effect.
- **Indirect effect:** is the effect that one greenhouse gas might have on top of another gas. For example, water vapor is the most powerful of greenhouse gases because changes in water vapor content is caused by changes in atmospheric CO_2. Indirect effect are often results of “feedback loops”.

Systems

- **Open System:** Energy and Matter can be exchanged between systems
- **Closed System:** Exchange of Matter greatly restricted, but may allow exchange of energy
- **Isolated System:** No Energy or Matter can be transferred in or out of the system

- **Stable System:** resists change and reverts back to this state when disturbed
- **Unstable System:** Once disturbed the system cannot return to the original state
- **Metastable System:** Can have several stable states.

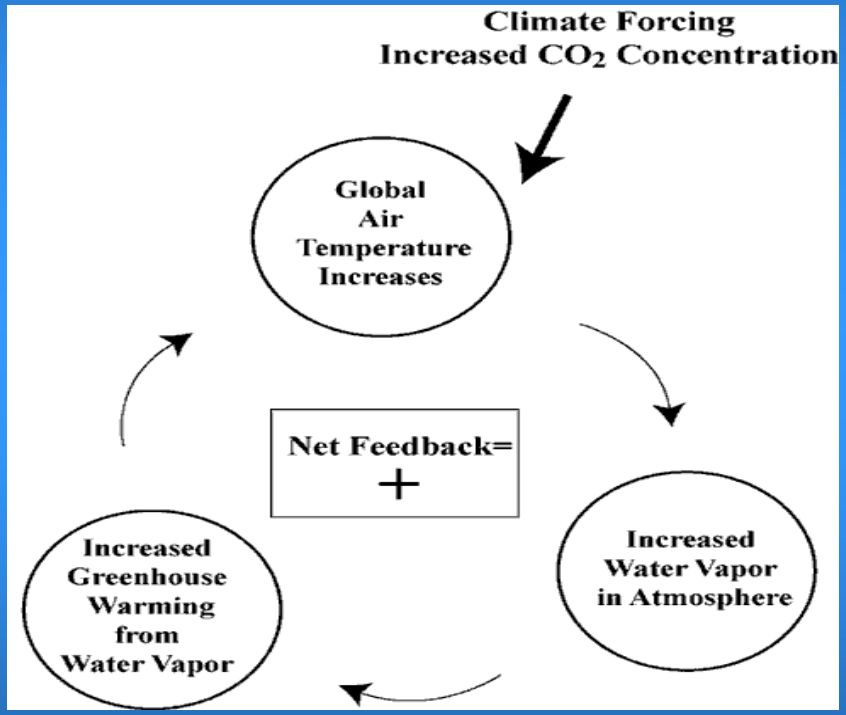


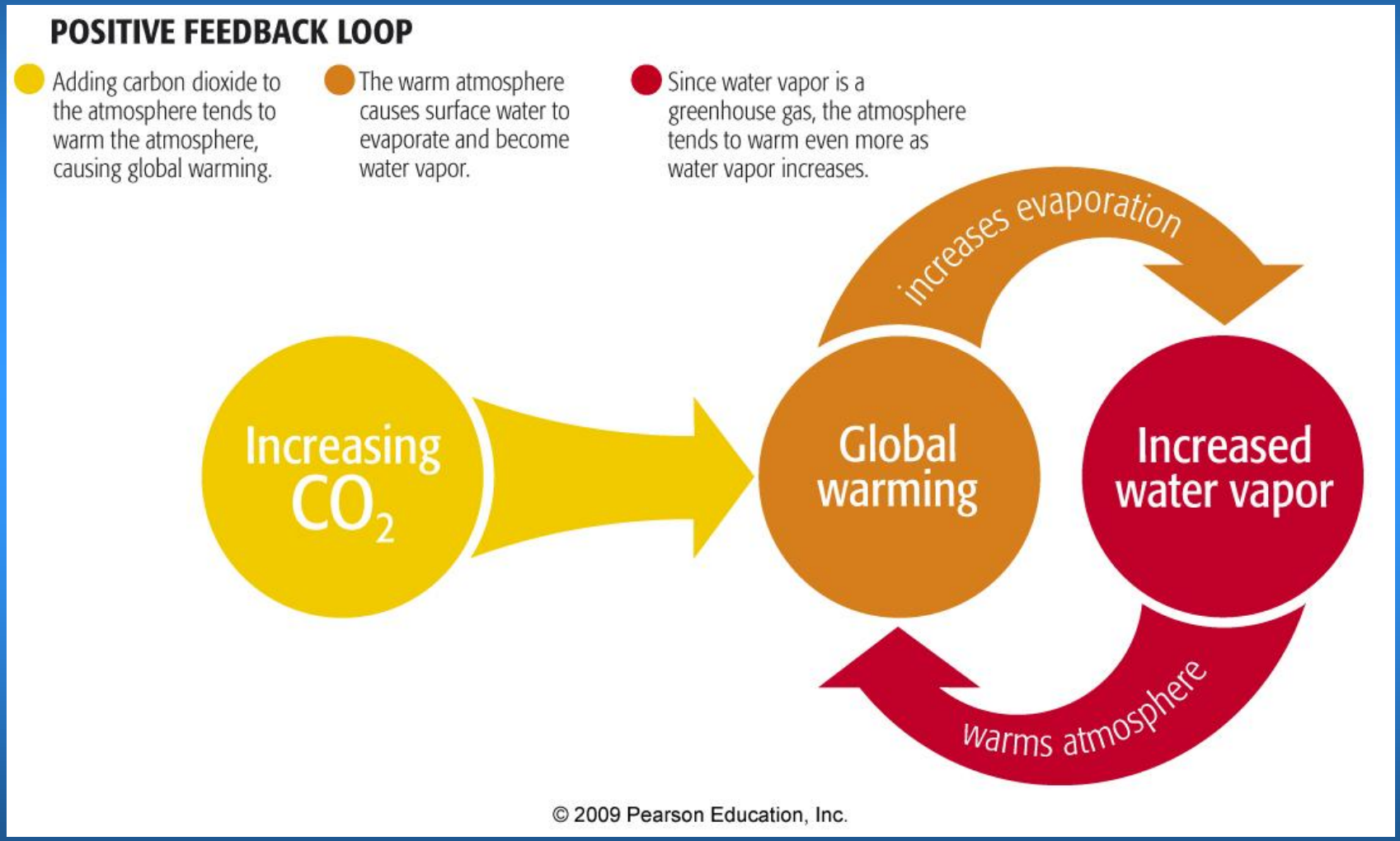
Feedback

- Processes in one system influences processes in another interconnected system by exchange of matter and energy. The exchange is called feedback.
- **Positive Feedback:** Change in one system causes similar change in the other system. Can cause runaway instability
- **Negative Feedback** means positive change in one system causes negative change in the other

Changing CO_2 induces Positive water vapor Feedback loop, which Amplify the original Warming by CO_2 only.

Positive feedback




POSITIVE FEEDBACK LOOP
Adding carbon dioxide to the atmosphere tends to warm the atmosphere, causing global warming.
The warm atmosphere causes surface water to evaporate and become water vapor.
Since water vapor is a greenhouse gas, the atmosphere tends to warm even more as water vapor increases.
increases evaporation
Increasing CO_2
Global warming
Increased water vapor
warms atmosphere
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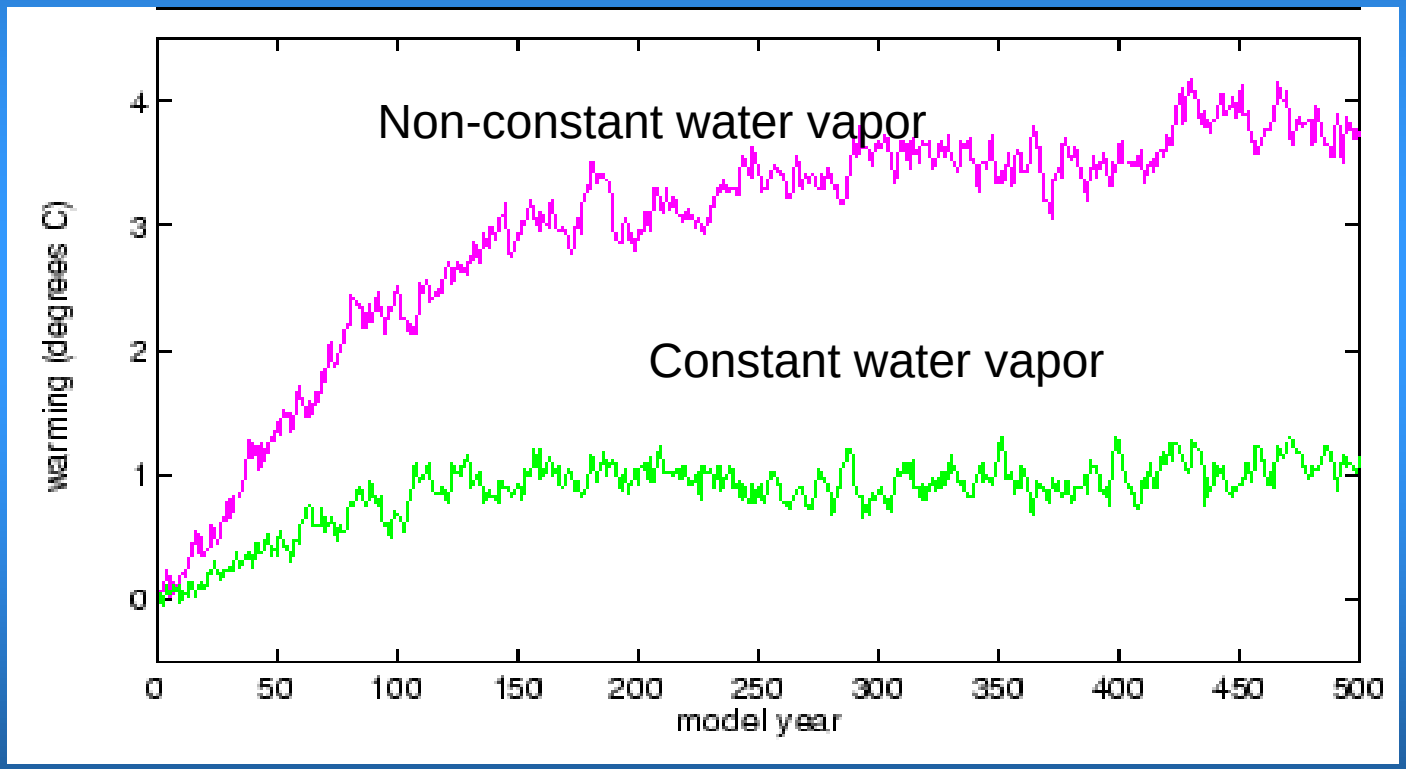
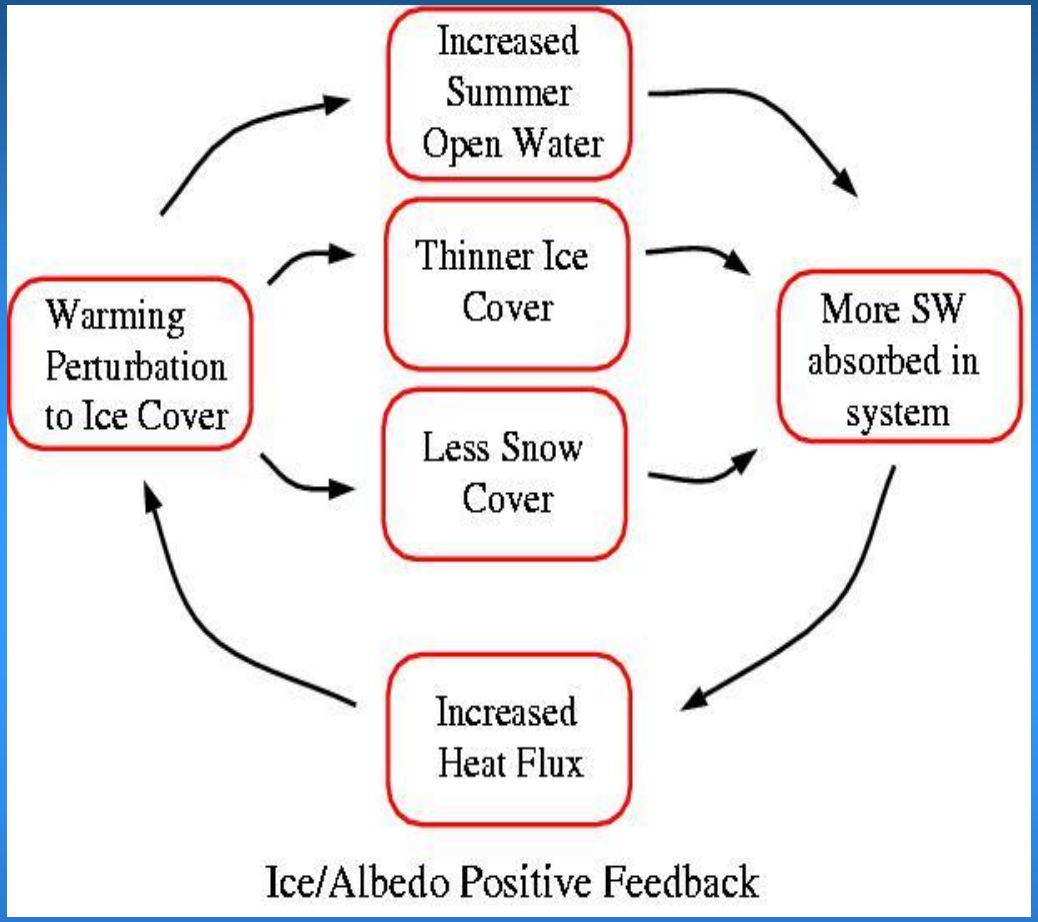
2 CO_2 experiments



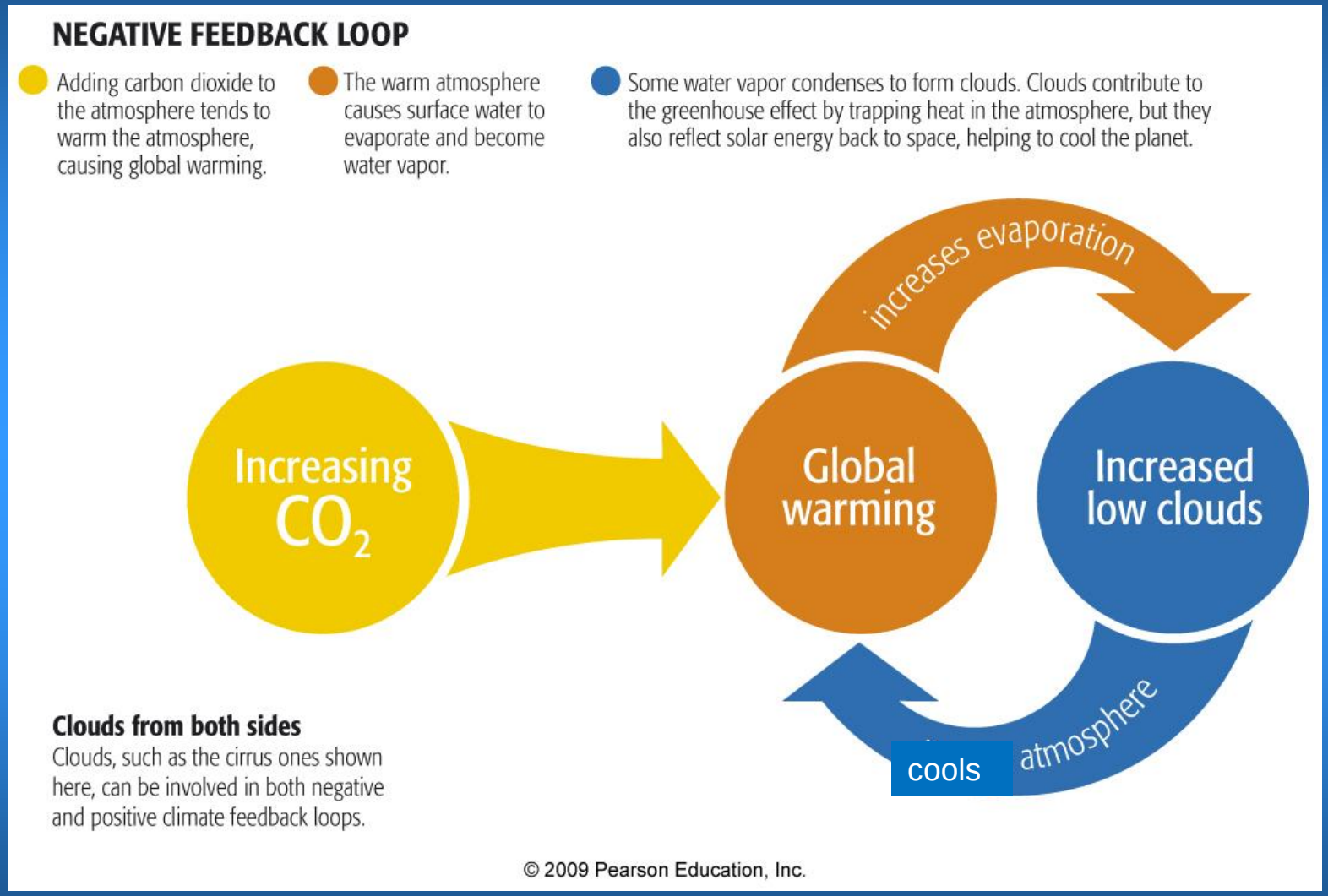
Ice albedo positive feedback



Can you give a negative feedback example based on your every day life?

What feedback is associated with cloud cover?

Cloud cover negative feedback: offsetting the original warming



Overall, positive feedbacks in the climate system outweigh negative feedbacks, so the expected warming from CO_2 buildup is greater than its direct radiative effect alone.

Climate variability

Low frequency climate variability:

sub-seasonal variation, seasonal variation, annual variation, and interannual variation.

Sub seasonal variability is normally caused by the Internal nonlinear dynamic process of atmosphere.

Longer than seasonal time scale variability is mainly controlled by anomalies in SST and air-sea interaction.

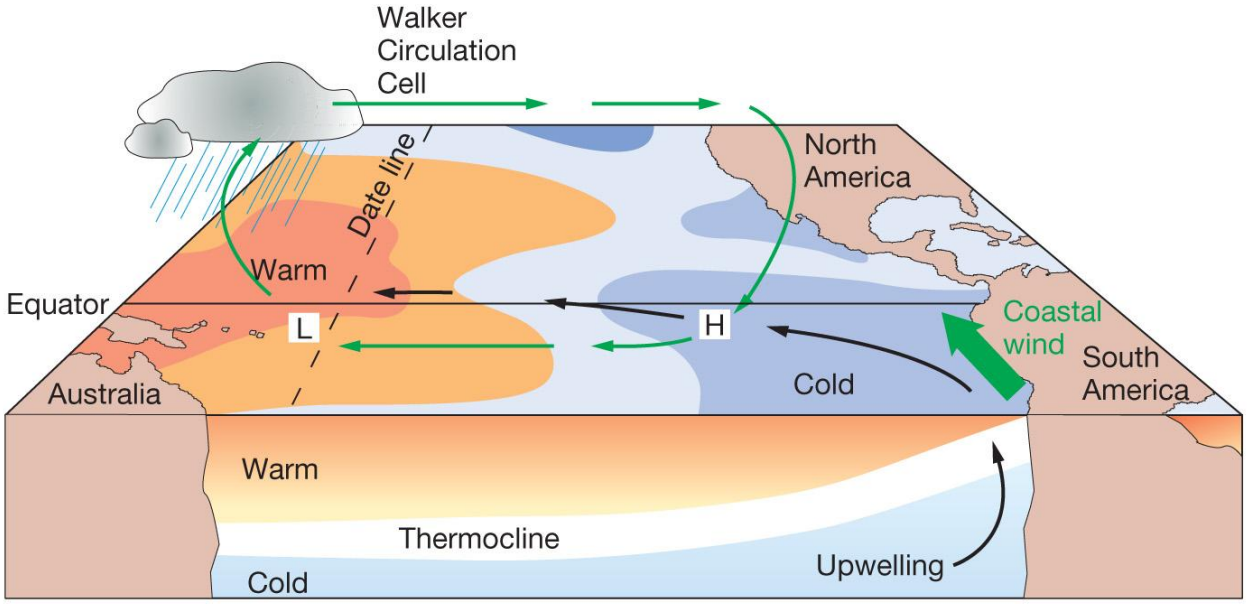
Two Long Time-Scale Climate Anomalies: ENSO and PDO

ENSO: Atmospheric-Ocean Connections in the Pacific Ocean

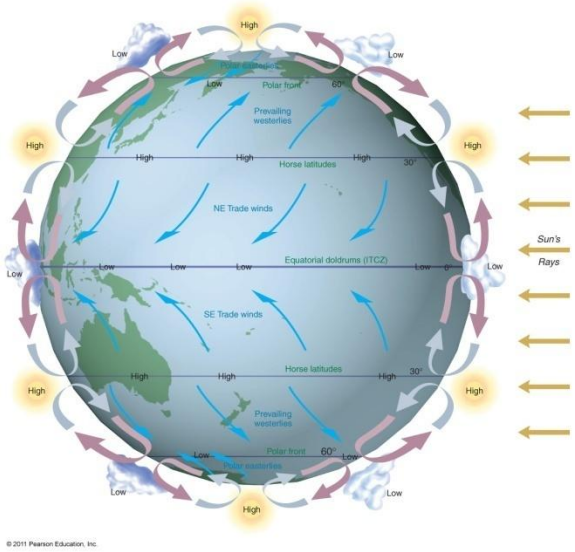
- Normal Conditions
- El Nino conditions
- La Nina condition

Normal Conditions

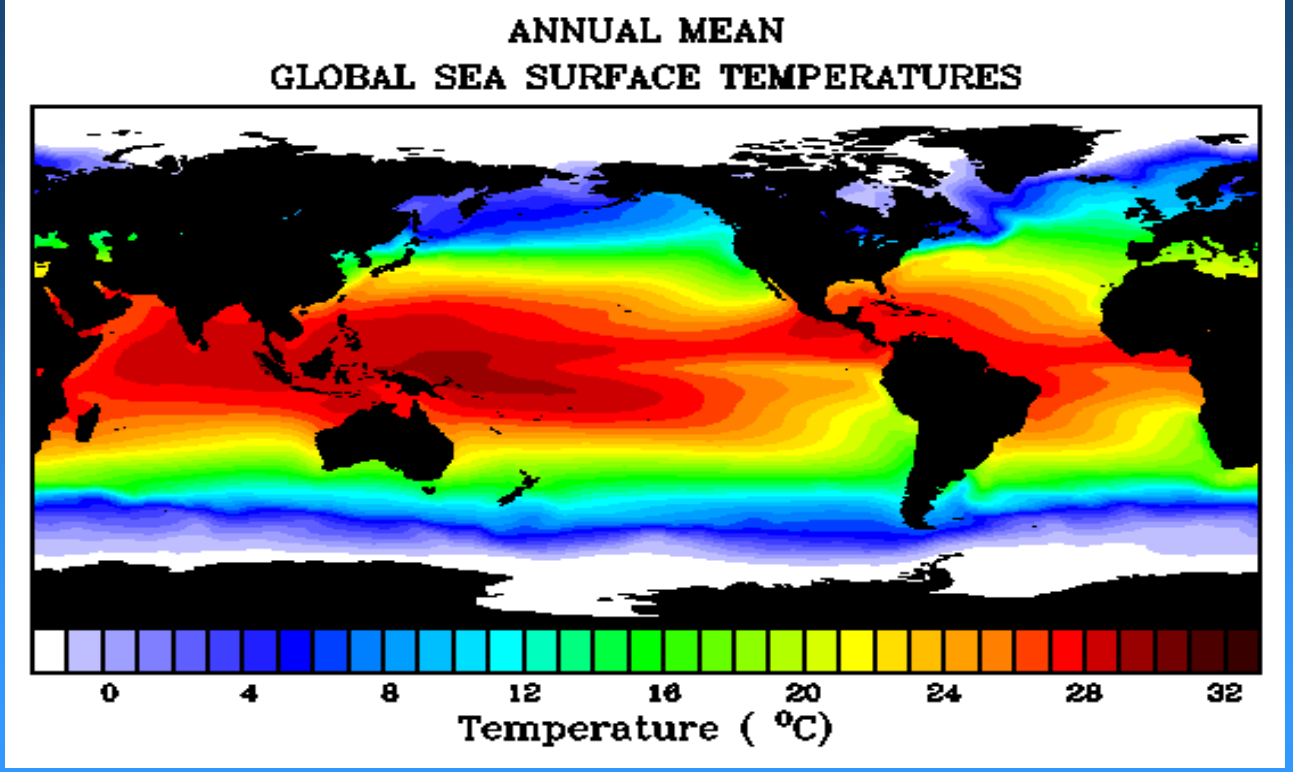
- Walker Circulation Cell
  - Air pressure across equatorial Pacific is higher in eastern Pacific
  - Strong southeast trade winds
  - Pacific warm pool on western side of ocean
  - Thermocline deeper on western side
  - Upwelling off the coast of Peru

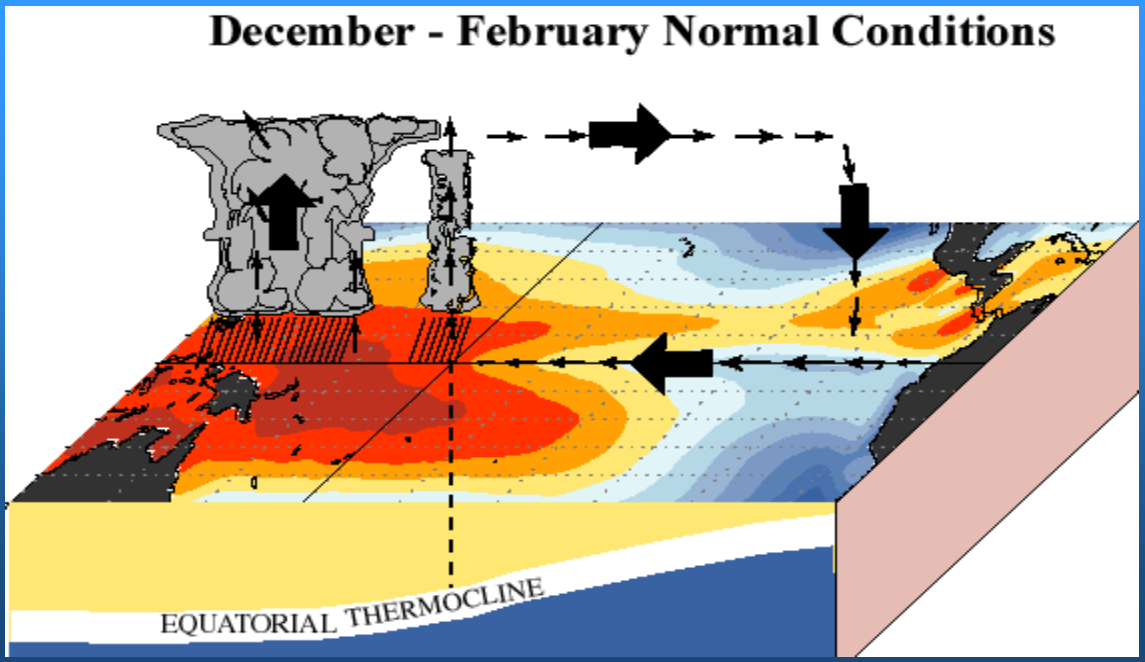


(a) Normal conditions



Walker circulation

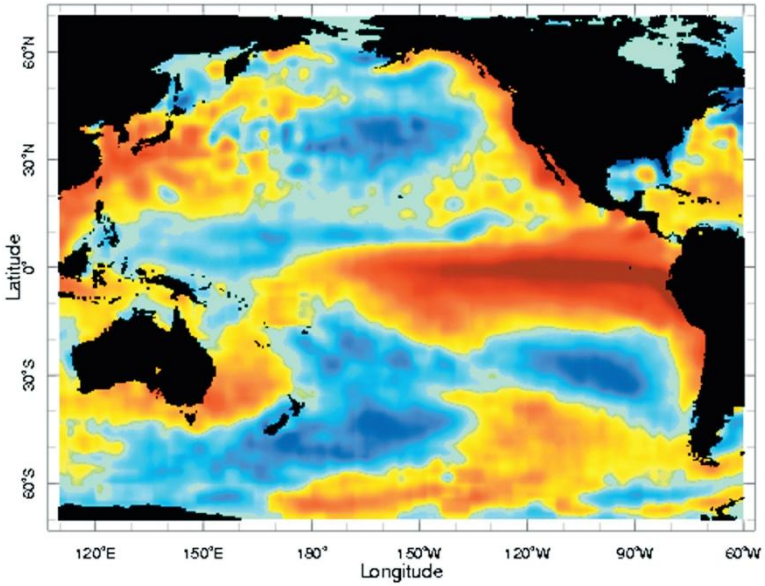


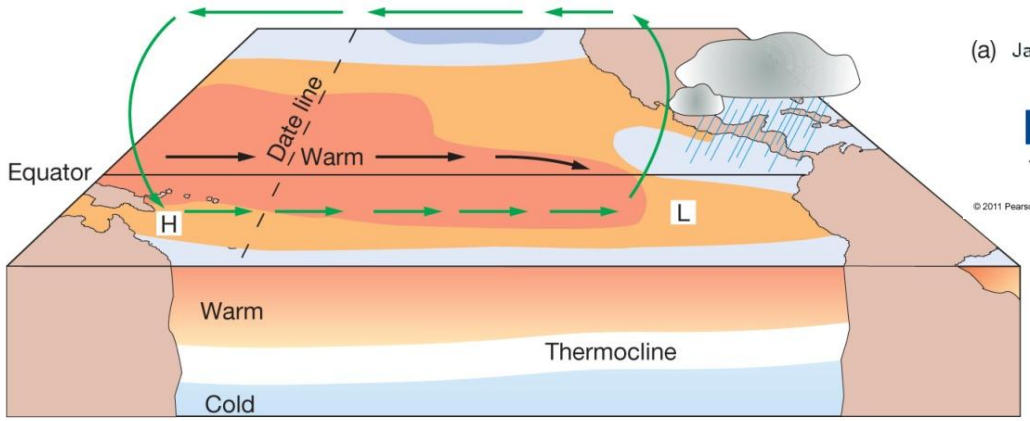


El Niño – Southern Oscillation (ENSO) Conditions

Walker Cell Circulation disrupted

- High pressure in eastern Pacific weakens
- Weaker trade winds
- Warm pool migrates eastward
- More hurricanes in East Pacific
- Thermocline deeper in eastern Pacific
- Downwelling
- Lower biological productivity
  - Peruvian fishing suffers



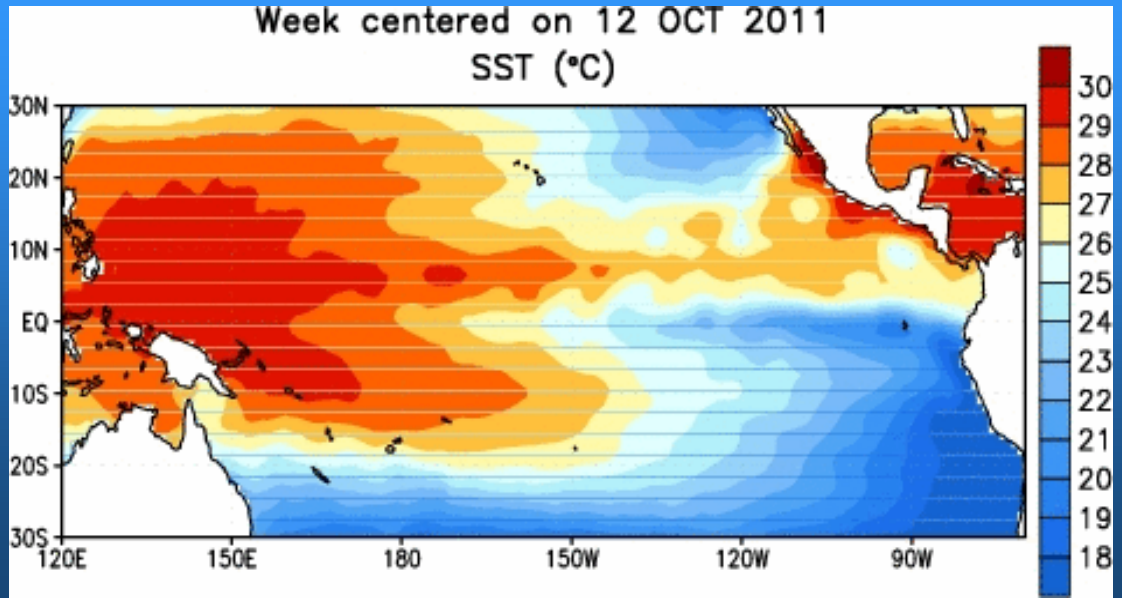


(b) El Niño conditions (strong)

El Niño Conditions

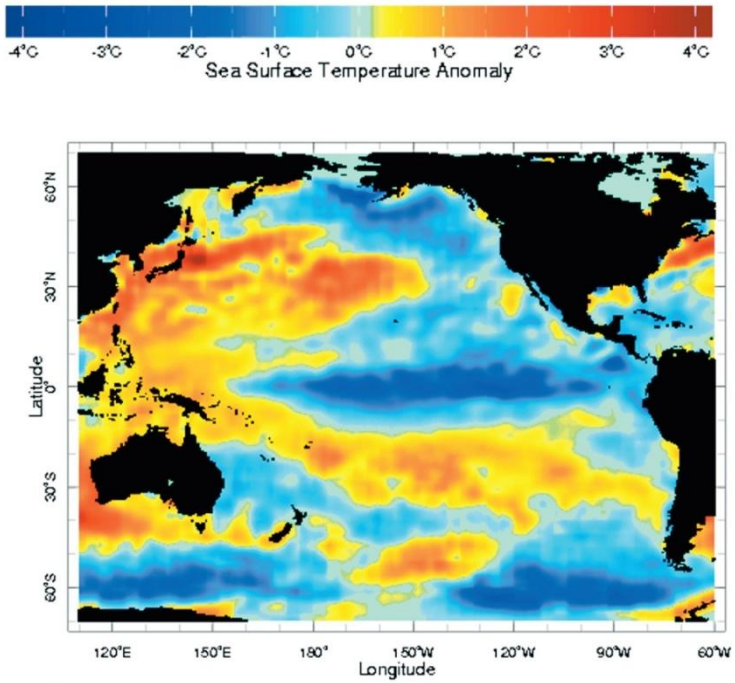
El Niño is characterized by unusually warm ocean temperatures in the Equatorial Pacific, as opposed to La Niña, which characterized by unusually cold ocean temperatures in the Equatorial Pacific. El Niño is an oscillation of the ocean-atmosphere system in the tropical Pacific having important consequences for weather and climate around the globe.

2011
El Niño

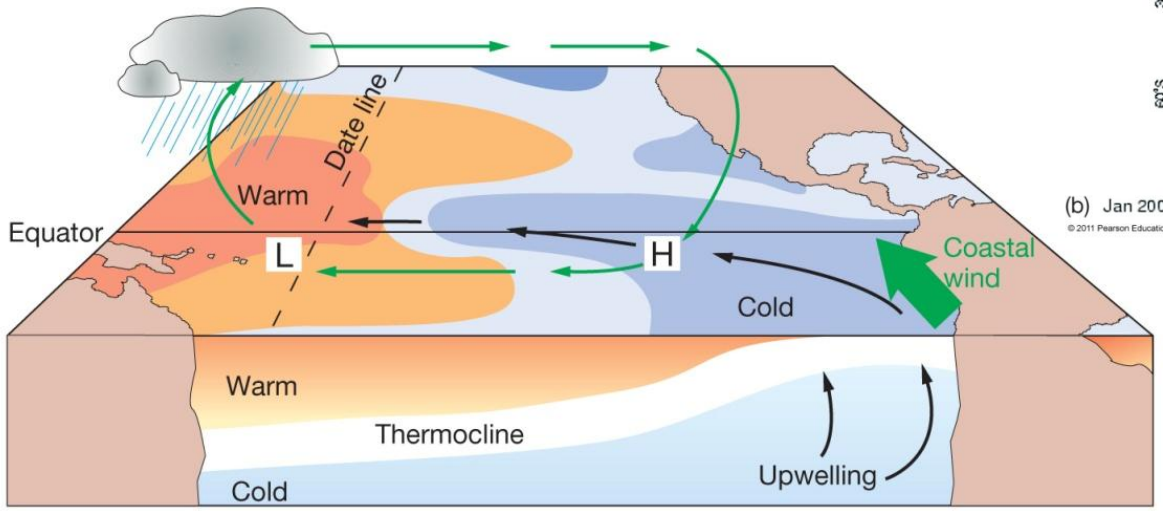


La Niña – ENSO Cool Phase

- Increased pressure difference across equatorial Pacific
- Stronger trade winds
- Stronger upwelling in eastern Pacific
- Shallower thermocline
- Cooler than normal seawater
- Higher biological productivity



(b) Jan 2000



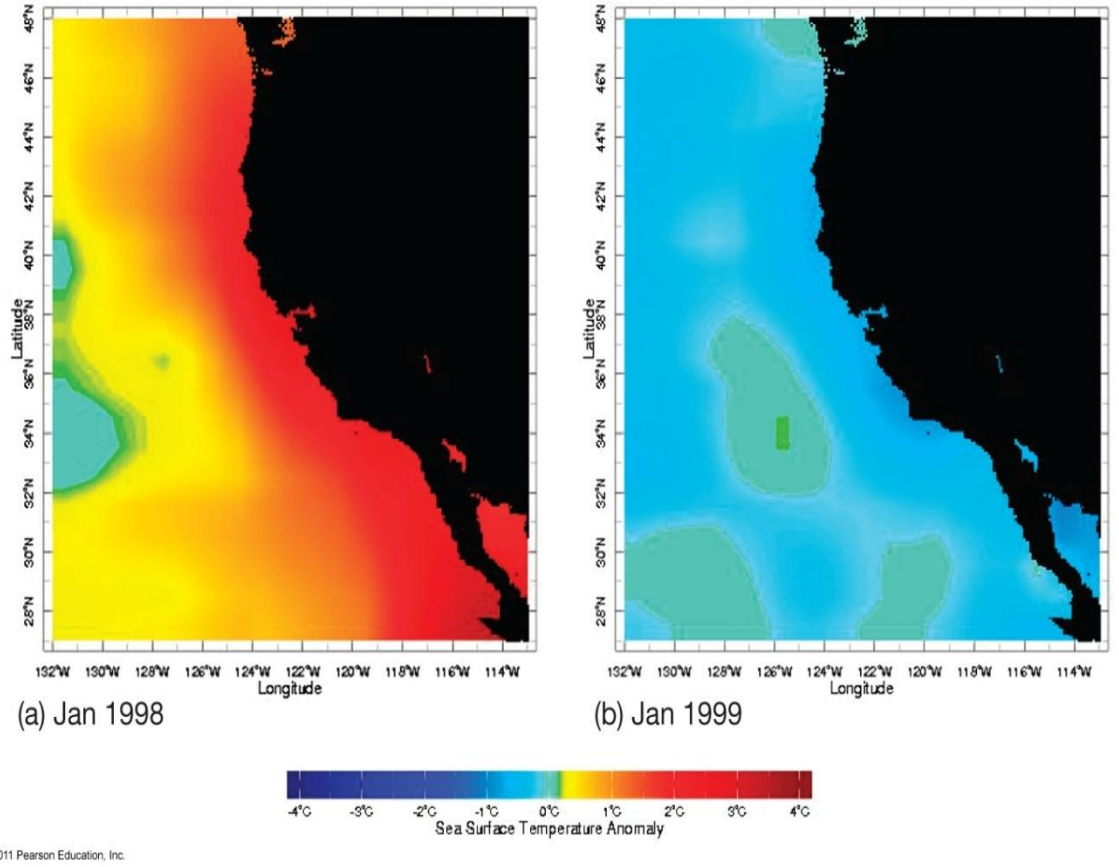
(c) La Niña conditions

Occurrence of ENSO Events

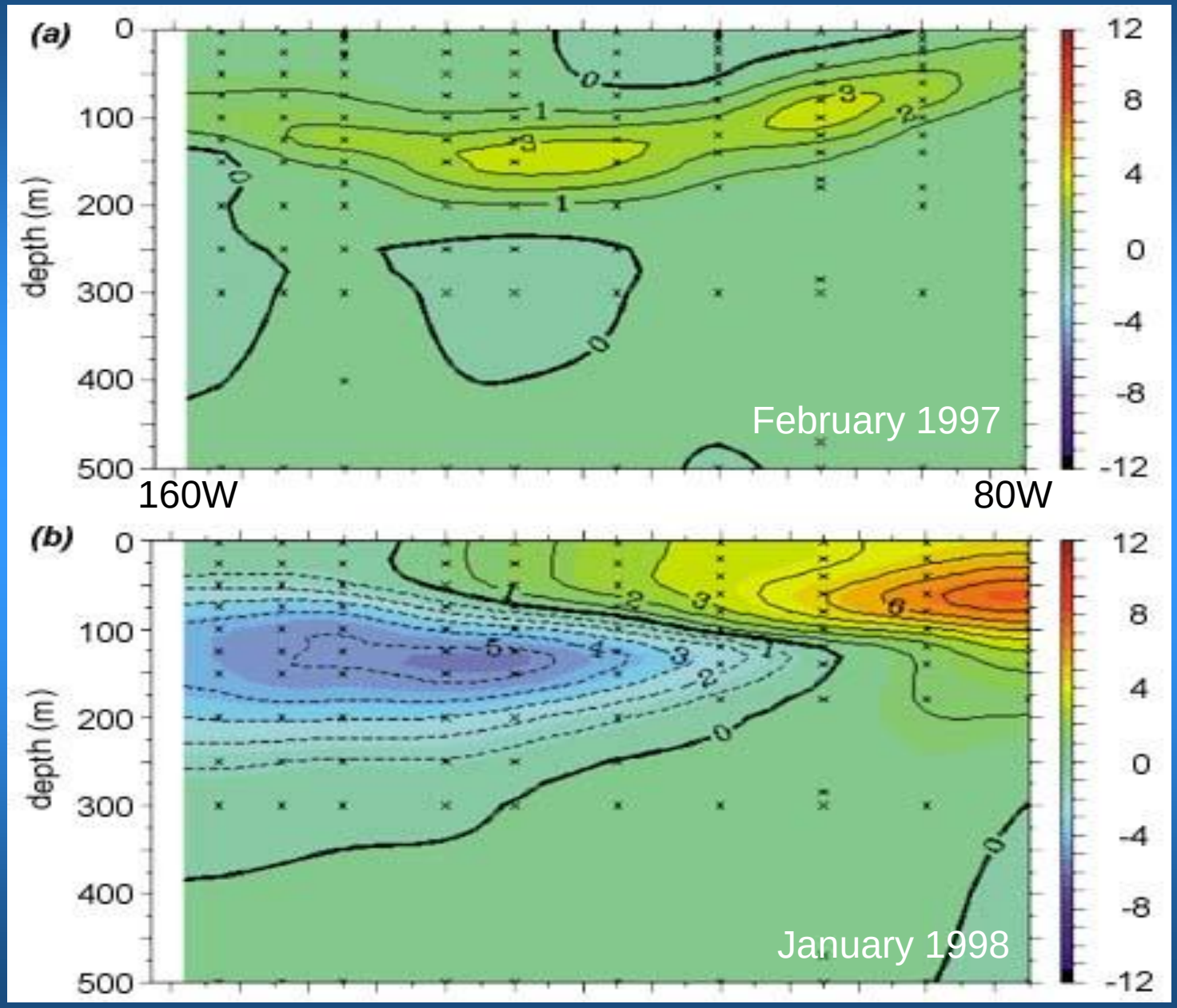
- El Niño warm phase about every 2–10 years
- Highly irregular
- Phases usually last 12–18 months
- 10,000-year sediment record of events
- ENSO may be part of Pacific Decadal Oscillation (PDO)
  - Long-term natural climate cycle
  - Lasts 20–30 years

Notable ENSO Events

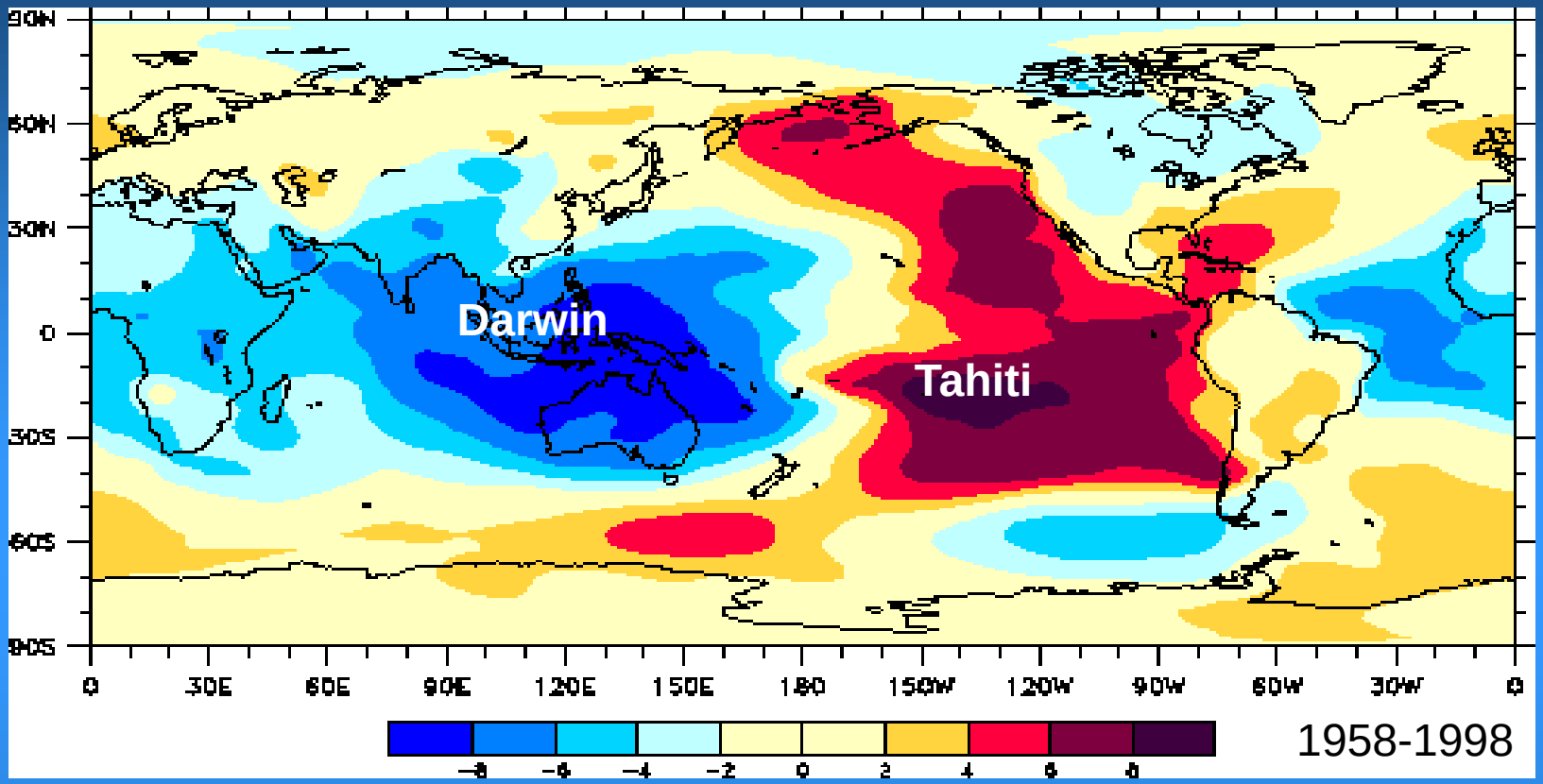
- 1982 – 1983
- 1997 – 1998
- Flooding, drought, erosion, fires, tropical storms, harmful effects on marine life
- Unpredictable



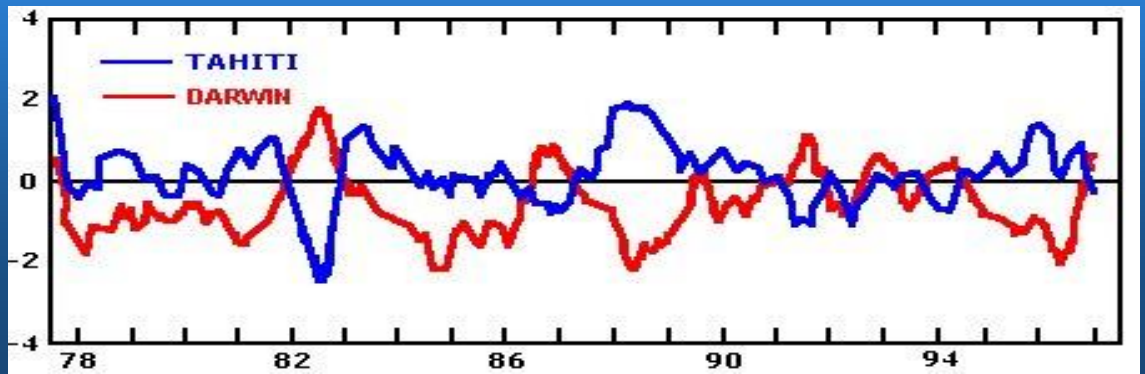
Vertical ocean temperature anomalies along the equator during 1997-1998 El Niño event.



Southern Oscillation

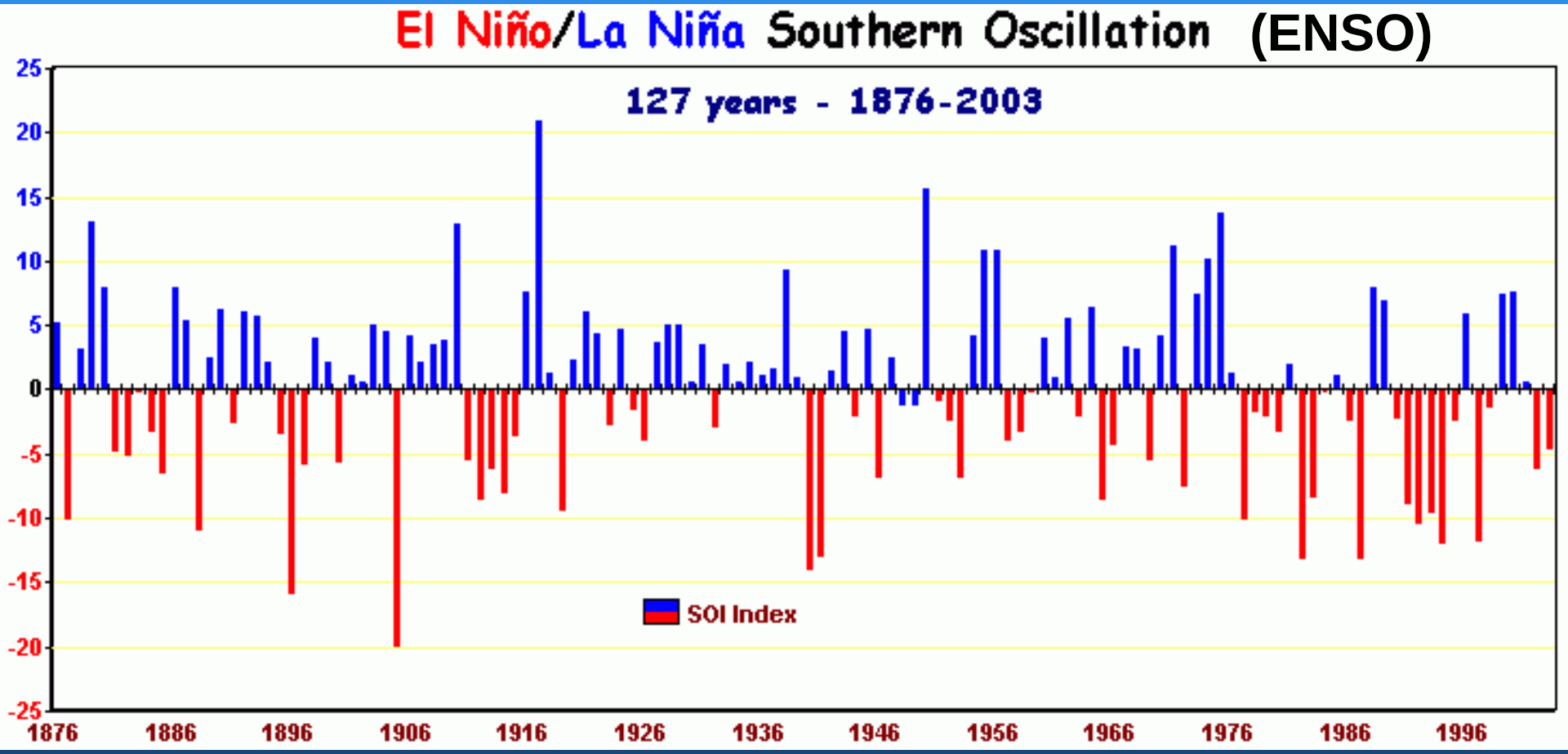


Sea level pressure anomaly at Tahiti and Darwin

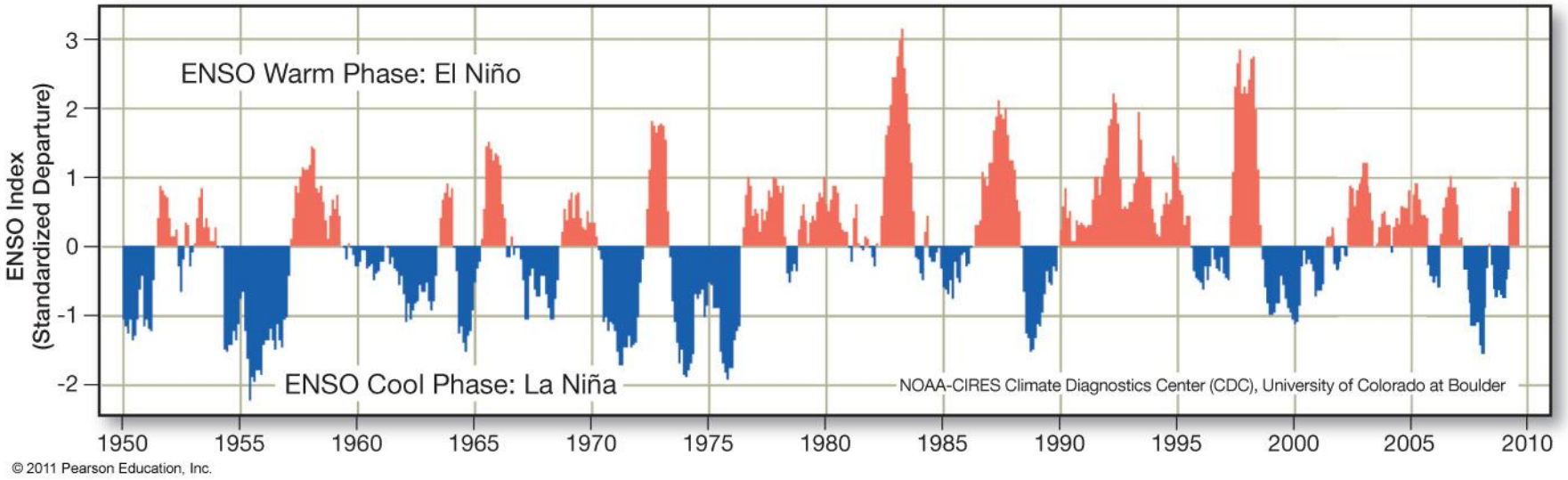


Southern Oscillation Index (SOI): defined as the pressure difference between Tahiti in the southeast Pacific and Darwin in the western Pacific.

Negative SOI corresponds to El nino
Positive SOI corresponds to La nina.

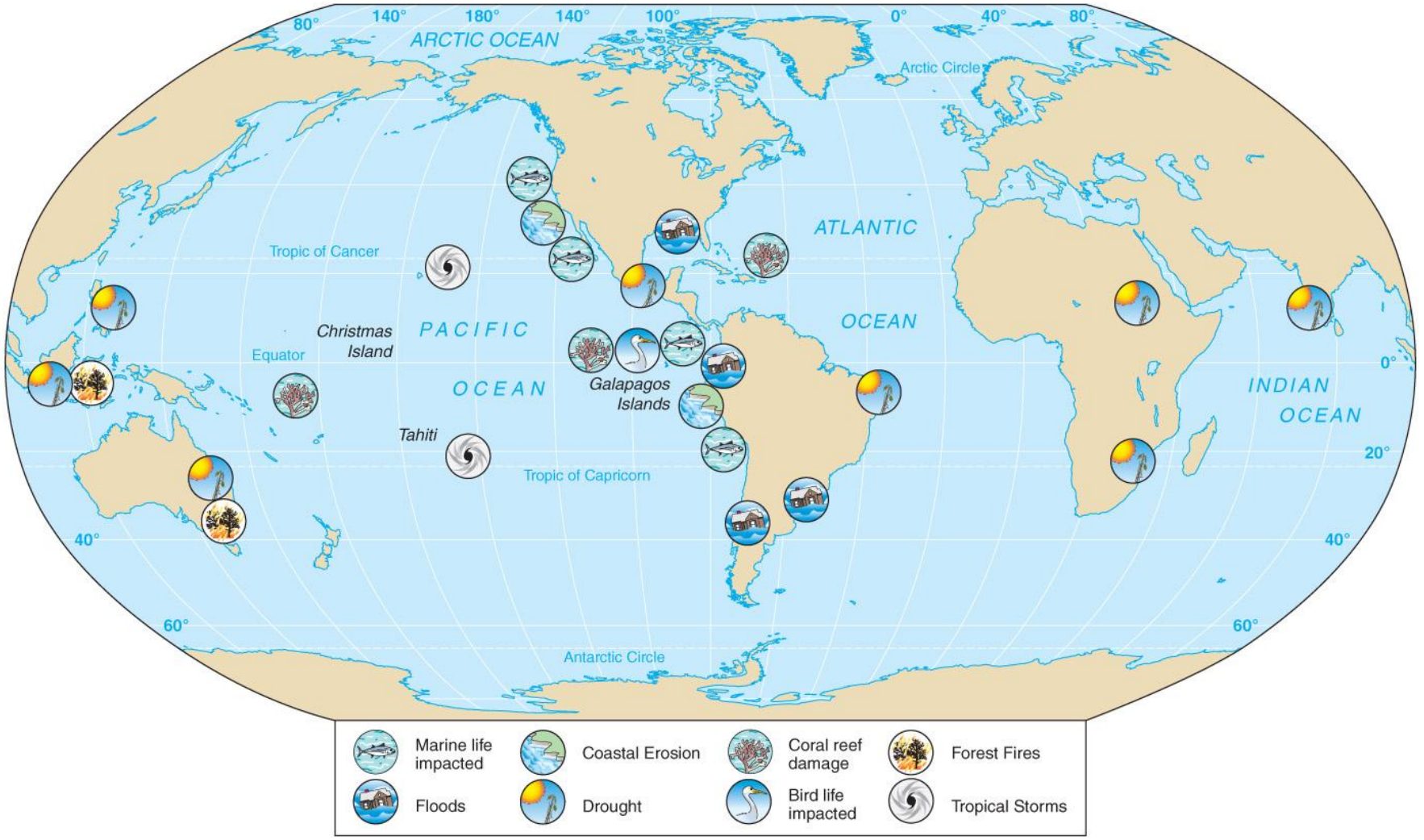


ENSO Occurrences

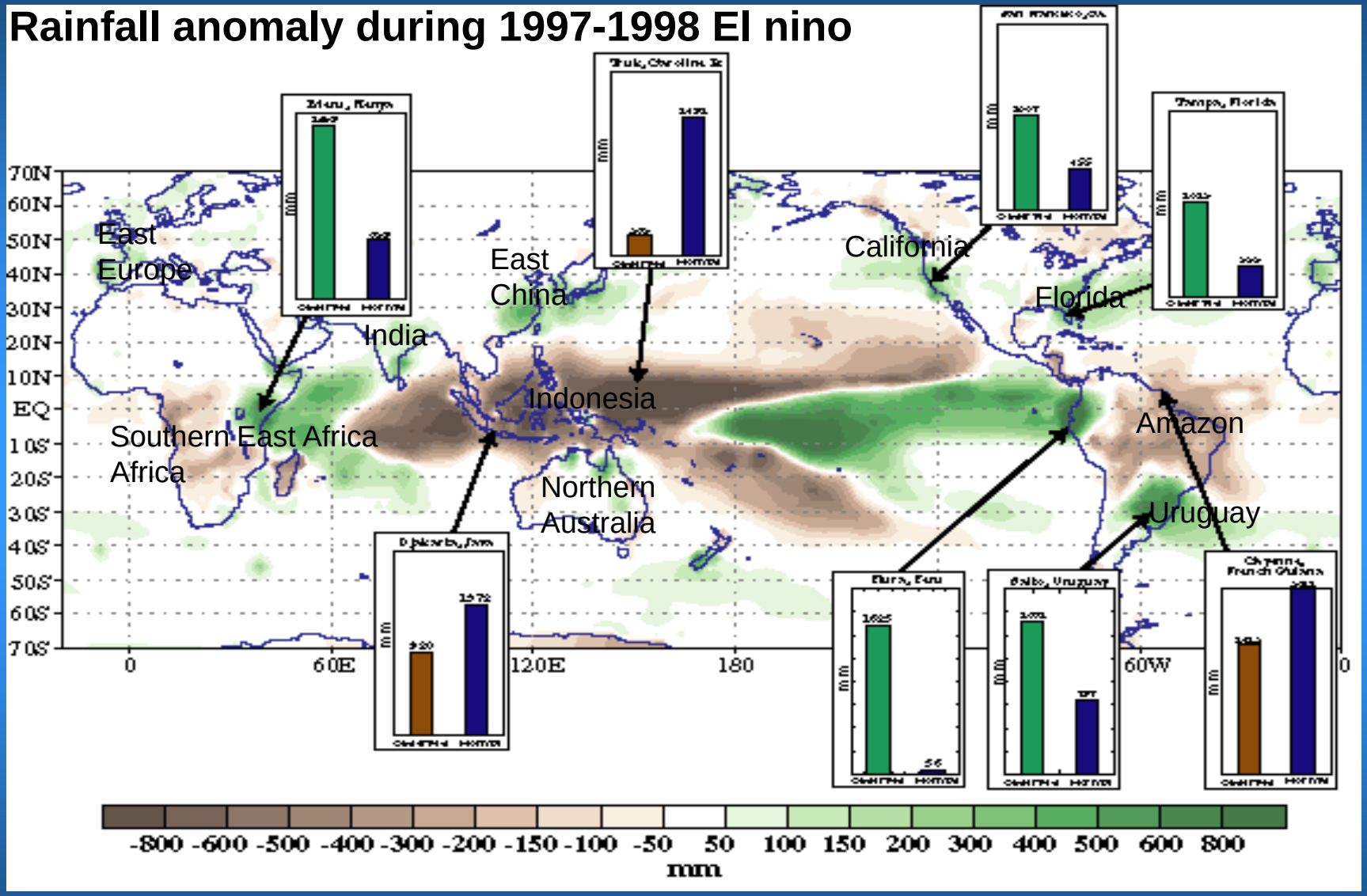


- Multivariate ENSO Index 1950-Present
- Calculated using a weighted average of pressure, winds, and SST

ENSO has Global Impacts

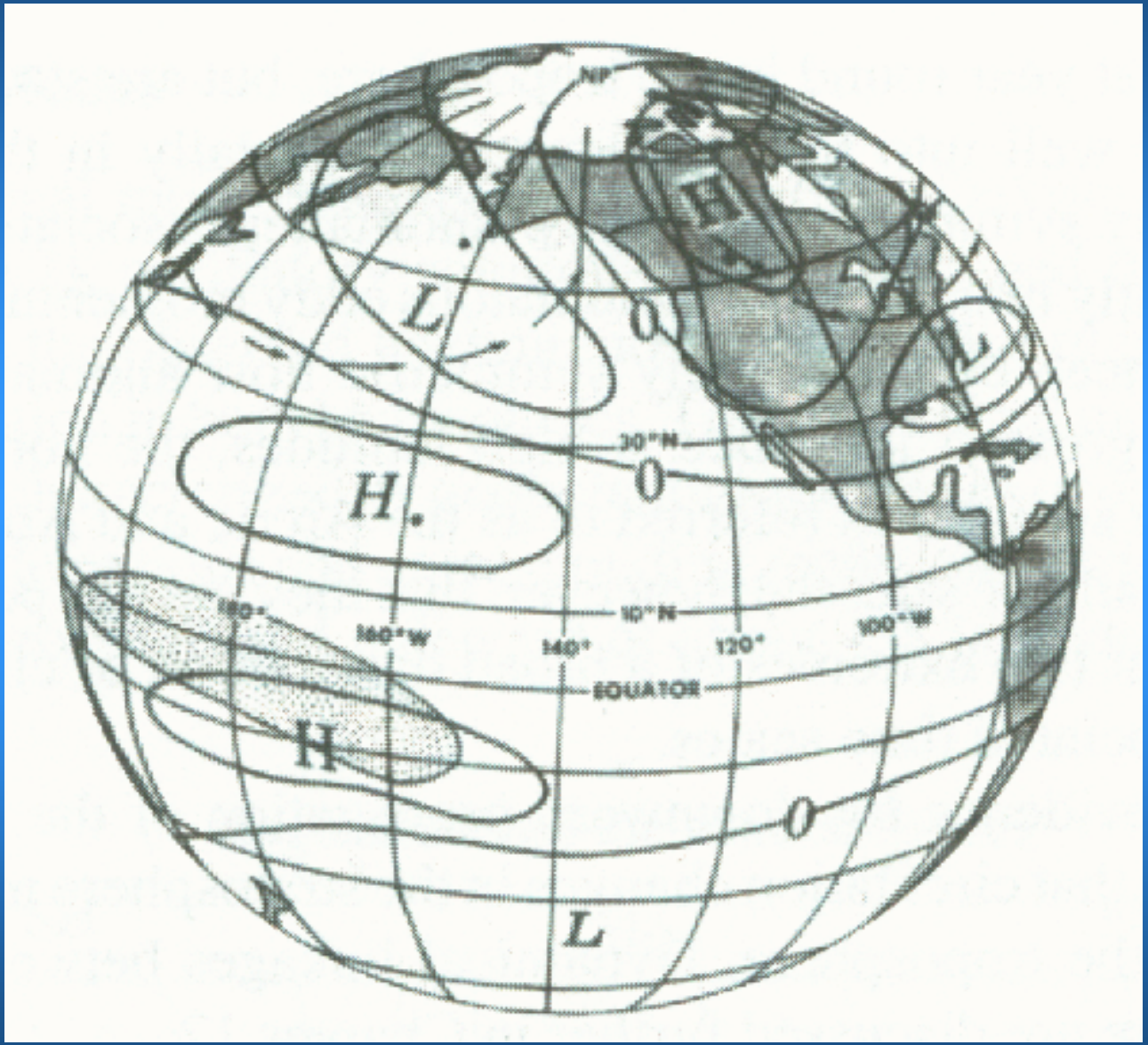


Impact of ENSO on Global Climate



Why an anomaly, such as ENSO in the equatorial region, can affect climate thousand miles away in mid and high latitude?

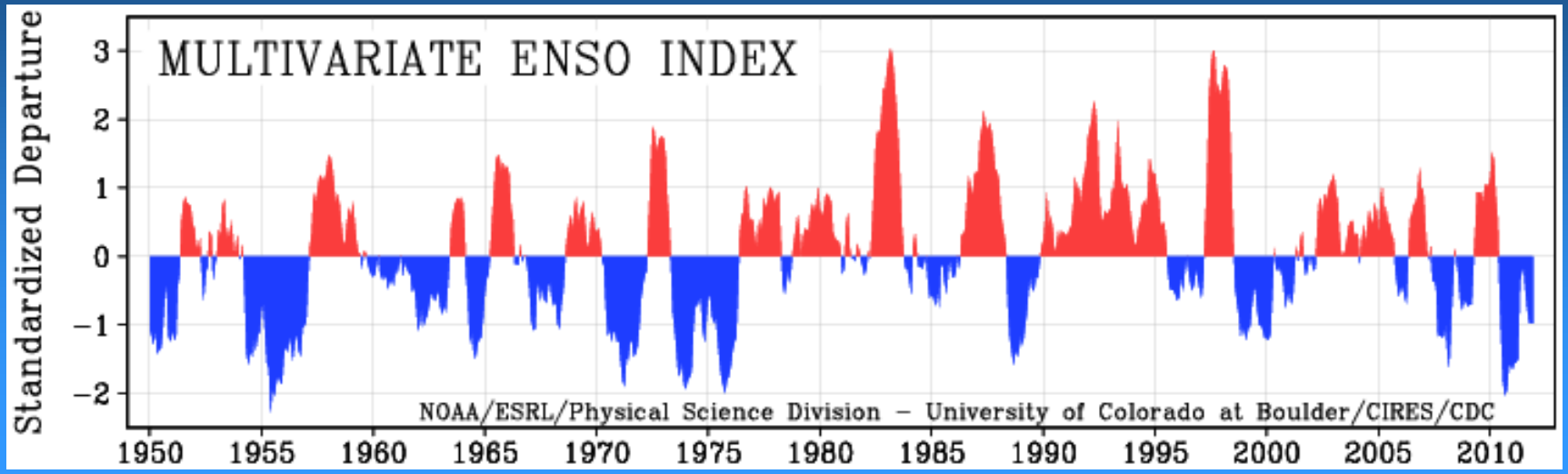
Teleconnections



Predicting El Niño Events

- Tropical Ocean–Global Atmosphere (TOGA) program
  - 1985
  - Monitors equatorial South Pacific
  - System of buoys
- Tropical Atmosphere and Ocean (TOA) project
  - Continues monitoring
- ENSO still not fully understood

ENSO and global warming: Is there a connection?



Several arguments

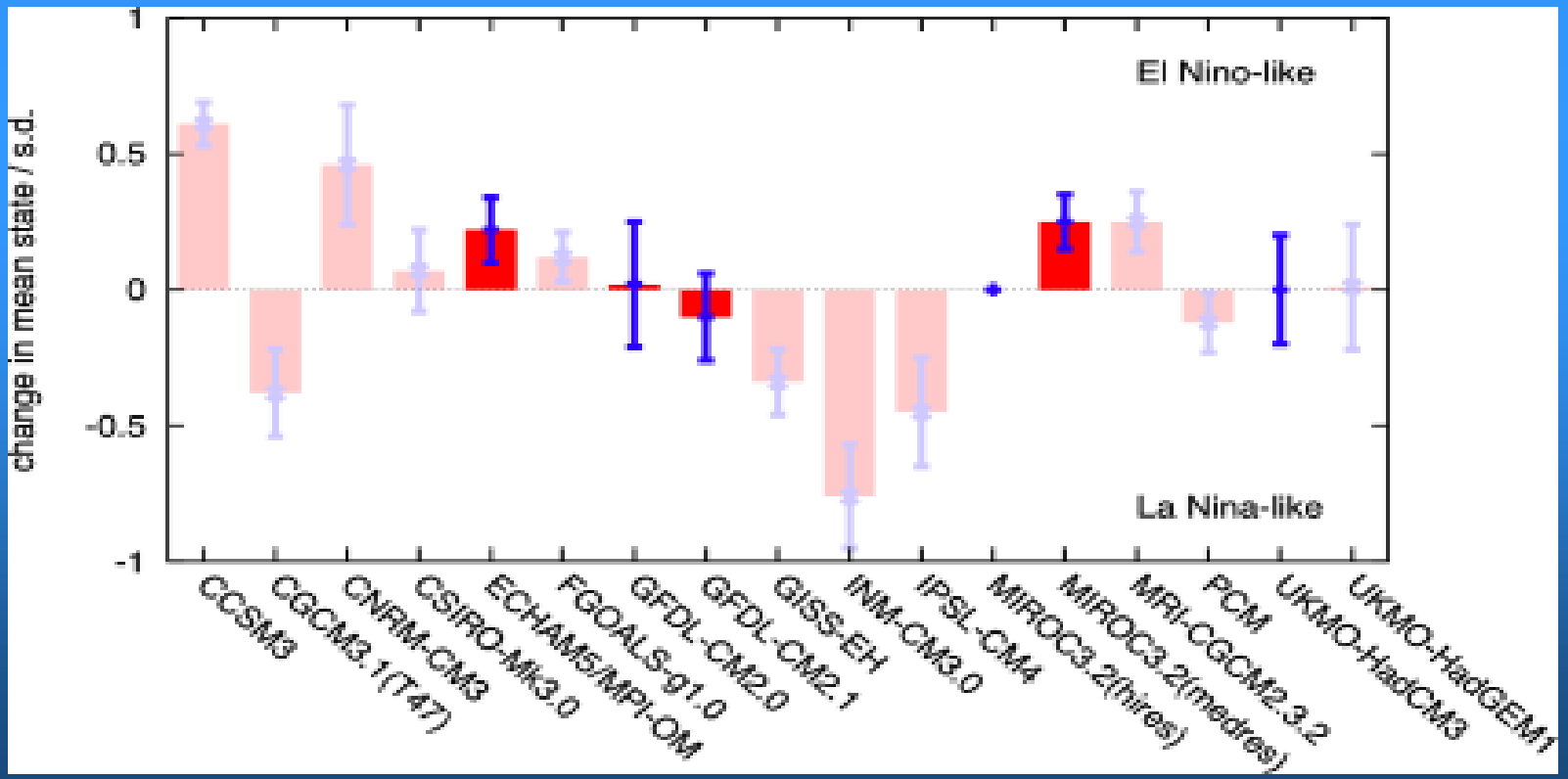
1. In the last 20 years, there have been more El Niños then La Niñas, whereas historically the two have occurred in about equal numbers.

2. El Niño serves as a mechanism for tropics to get rid of heat.

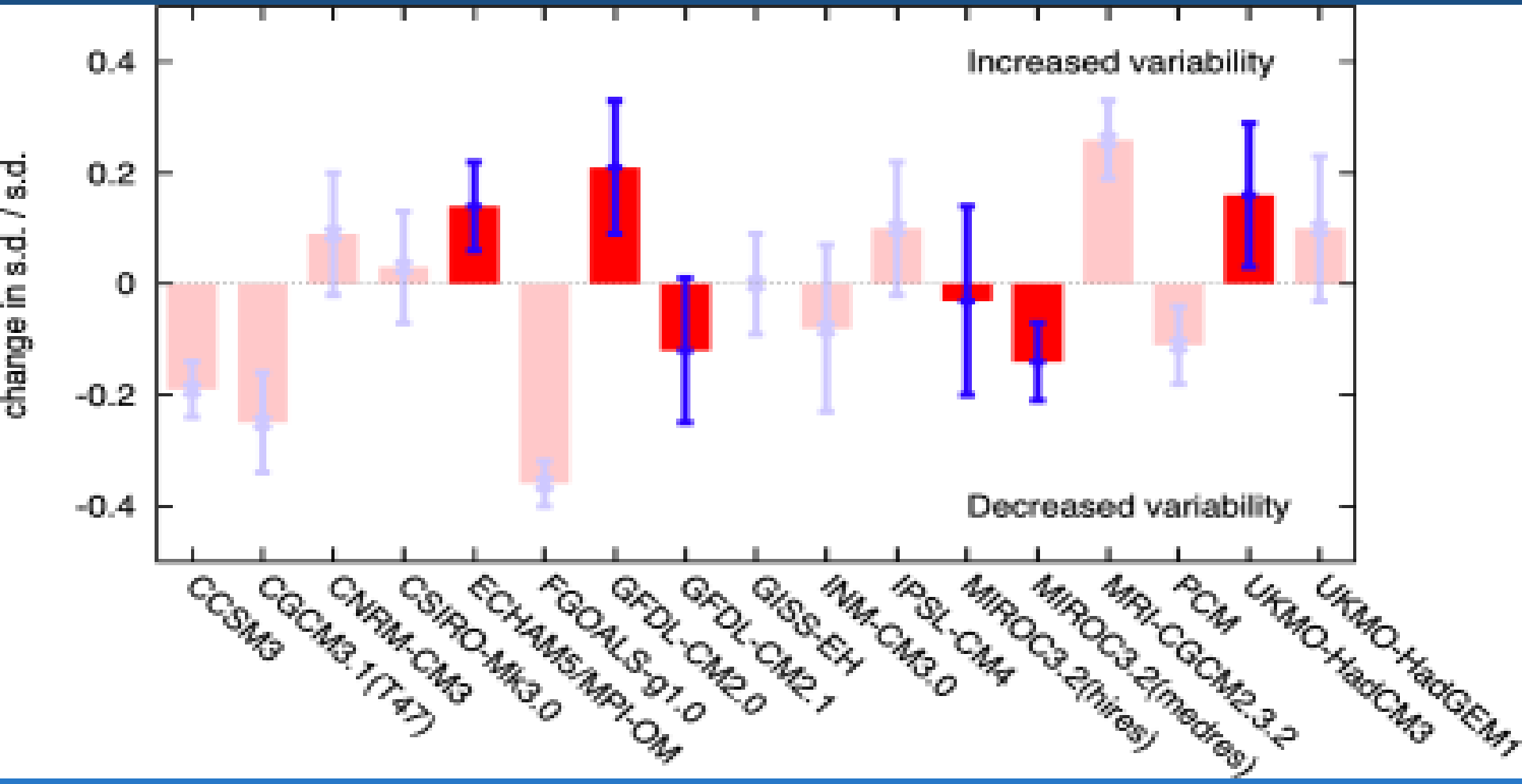
3. ENSO changes global precipitation pattern and intensity

WMO organized an intercomparison study by comparing the simulated ENSO in the next century in response to global warming by many different global climate models at the atmospheric research centers all over the world. They have looked at (1) the mean state of ENSO and (2) variability of ENSO.

Mean state of ENSO



Variability of ENSO



The inter-model difference is about as large as the natural variability from the second half of the 19th century to the middle of the 20th century!