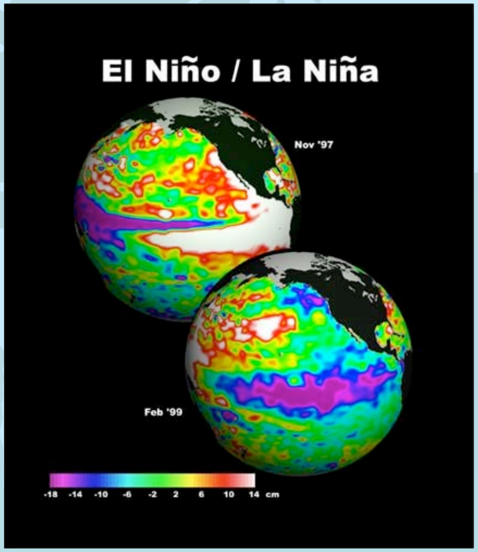
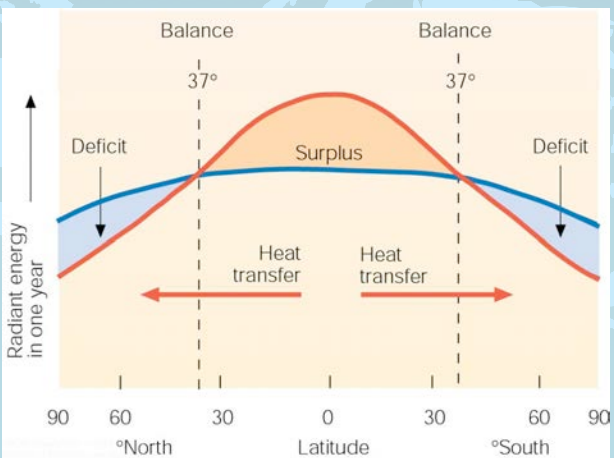
Lecture 13 El Niño/La Niña
Ocean-Atmosphere Interaction



Previous Lecture
Global Winds

- General Circulation of winds at the surface and aloft
- Polar Jet Stream
- Subtropical Jet Stream
- Monsoons

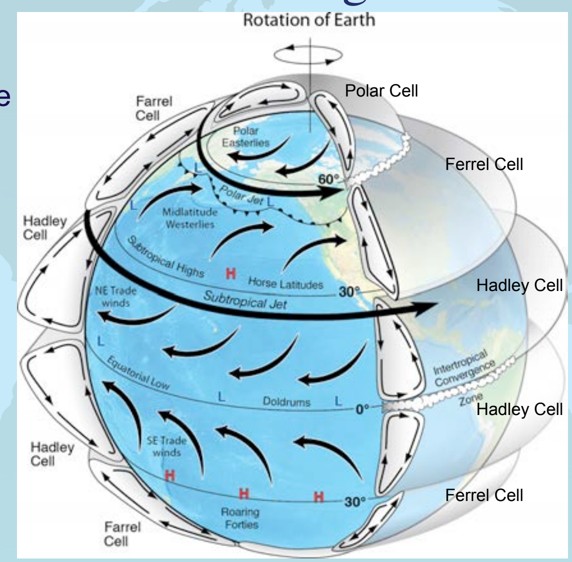
Radiation Budget
at the top of the Earth's Atmosphere



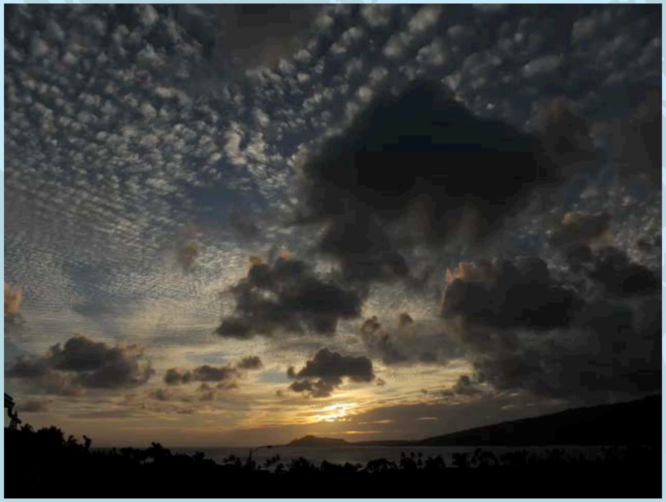
Red Line is incoming radiation from the sun
Blue Line is outgoing radiation emitted by the earth

Idealized 3-Cell Model of Wind Patterns on a Rotating Earth

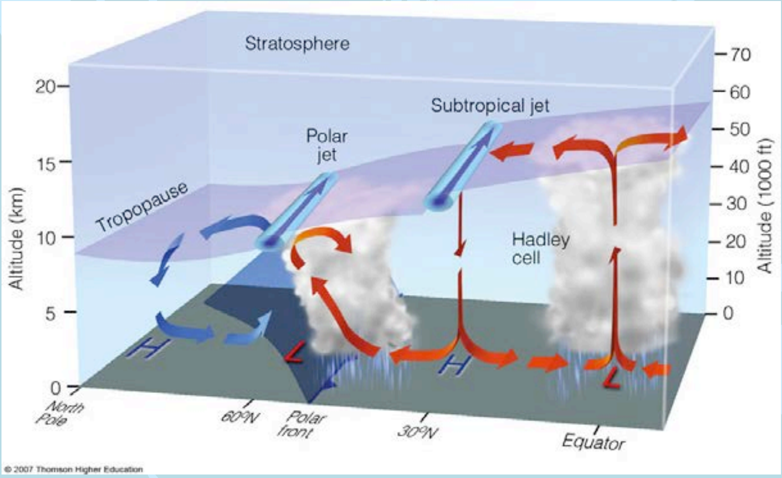
A schematic of the Earth's weather machine bringing warm moist air northward and cold dry air southward (latent and sensible heat).



Hadley Circulation in Action

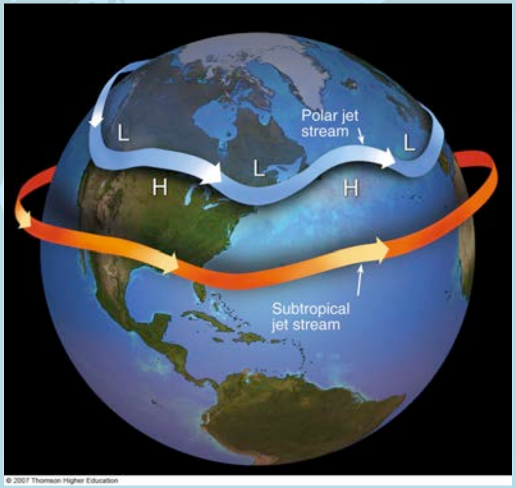


Equator to Pole Cross Section

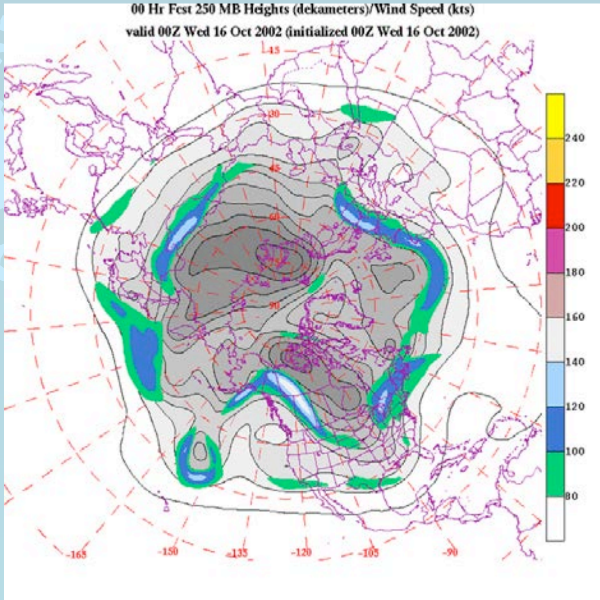


Jet Streams

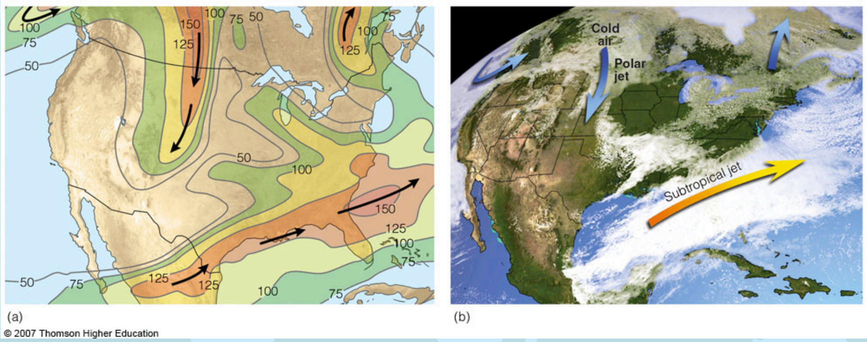
- Fast air currents, 1000’s of km’s long, a few hundred km wide, a few km thick
- Differential heating causes polar jet
- Conservation of angular momentum explains subtropical jet



Jet Stream has Waves



Waves in Jet Stream cause Storms



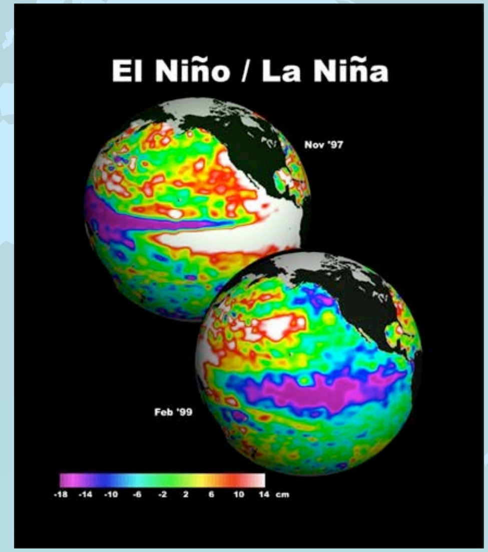
Wind speeds at 300mb (kt)   Cloud cover

(March 9 2005)

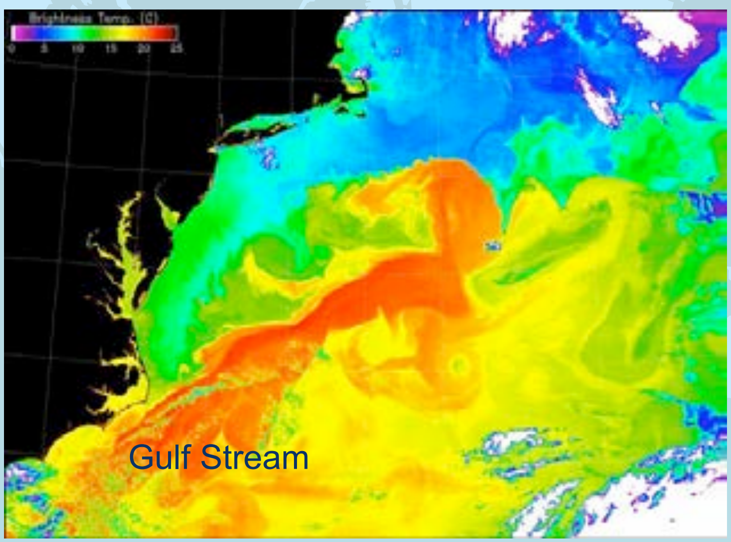
El Niño – La Niña
Ocean-Atmosphere Interaction

Outline

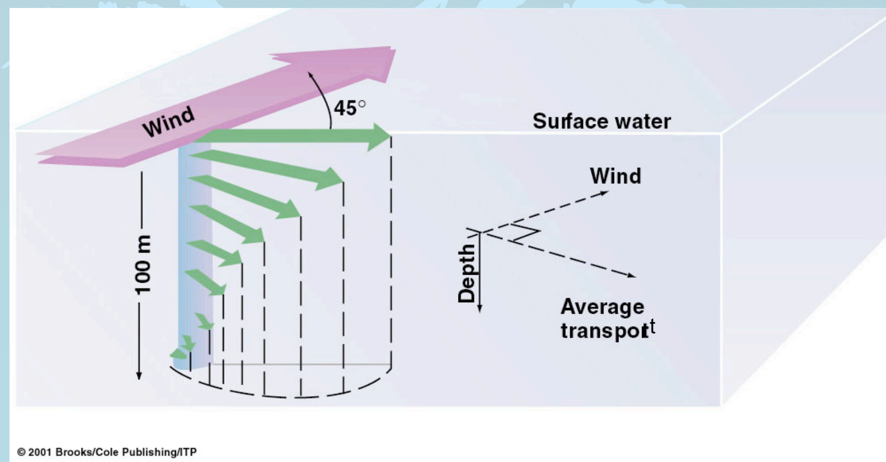
- Ocean Circulation
- El Niño
- La Niña
- Southern Oscillation
- ENSO



Intro to Ocean Circulation

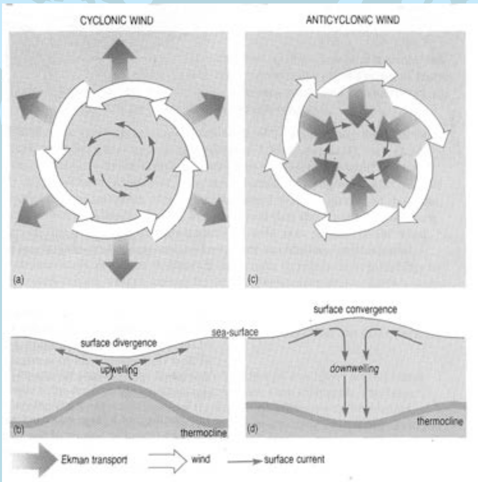


The Ocean Currents are Driven by Winds



Layer-mean water flow is at right angles to wind (to right in NH) as a result of the Coriolis force on the current.

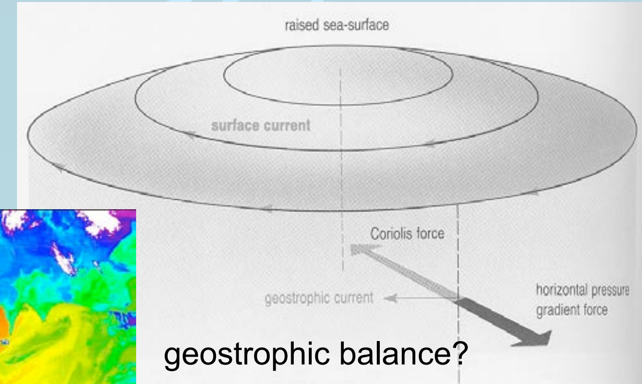
Formation of Ocean Gyres

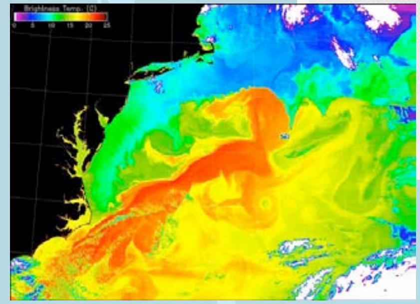


Anticyclonic winds cause water to pile up. Cyclonic wind result in a trough.

The thermocline is marked by strong vertical temperature change with cold water below. Piling up of water lowers the thermocline.

Force Balance in an Ocean Gyre

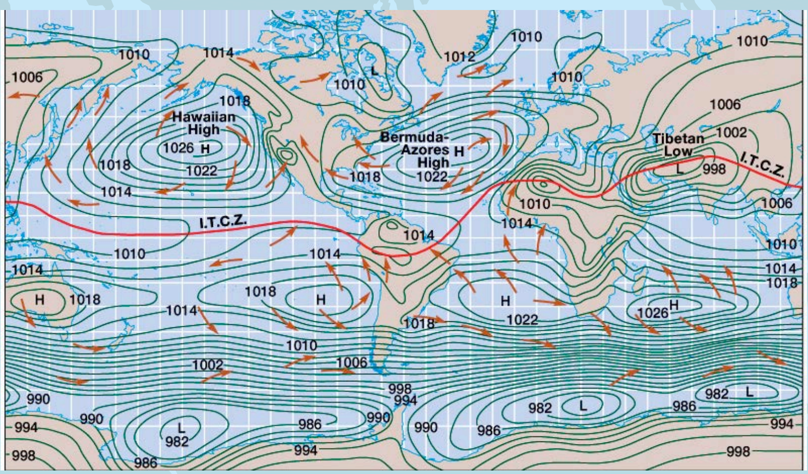




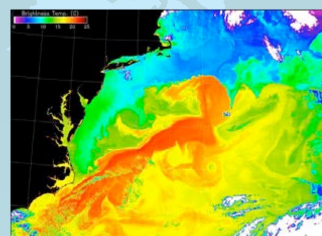
geostrophic balance?

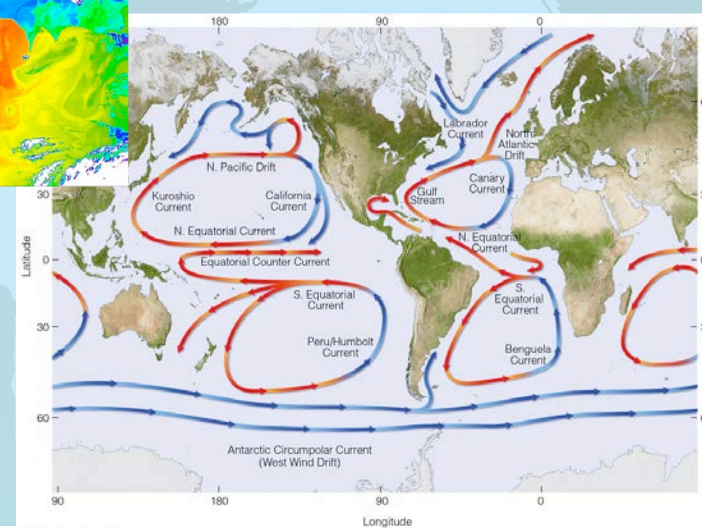
The wind-driven North Atlantic ocean gyre has clockwise (anticyclonic) flow in NH and is in ~geostrophic balance.

General Circulation - July

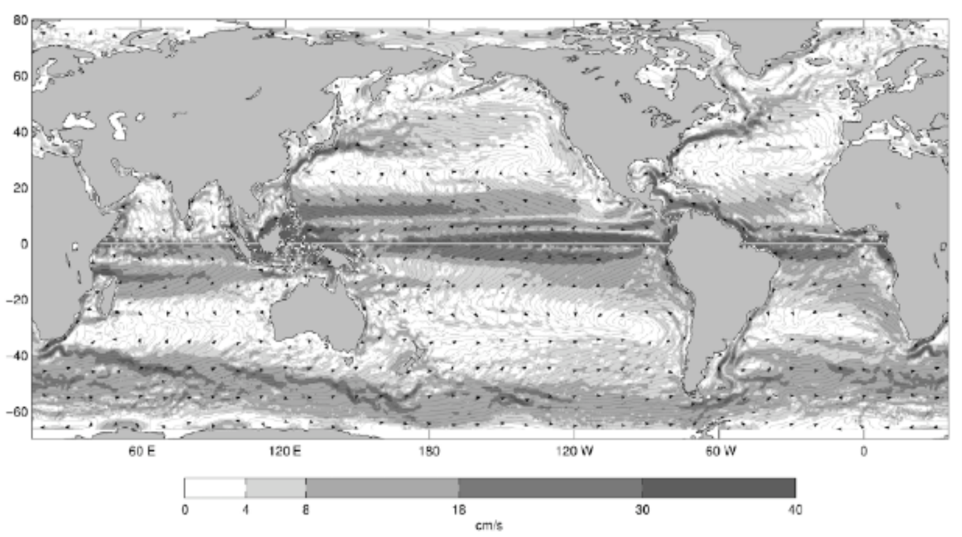


Average surface ocean currents



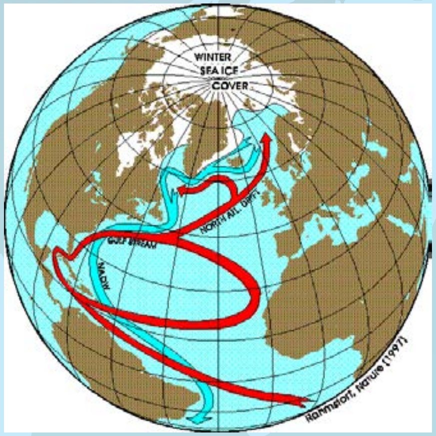


Long term mean current speed (shaded)



- This is a long term mean – and streamlines derived from satellite altimetry and near-surface drifters. Nikolai Maximenko, IPRC.

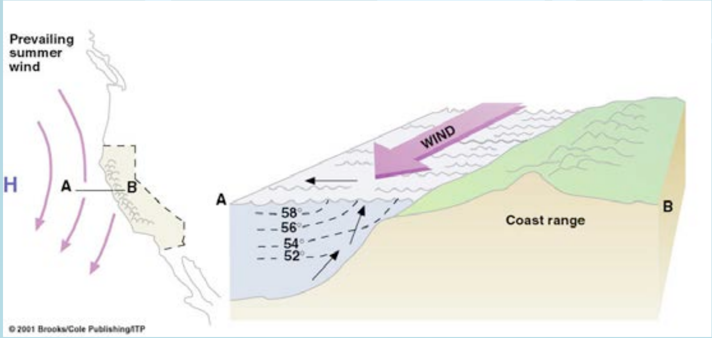
Shallow and deep currents



Deep ocean currents also exist – e.g. after dense water sinks at high latitudes (where the water is less salty and cold i.e. dense) it returns southwards at great depth as part of the 'Global conveyor Belt'

Coriolis force and upwelling

- Prevailing along-shore winds drive currents away from shore, producing upwelling of colder water from below.
- Cold upwelling is prevalent along the West Coast of the US (e.g., California) and Europe (Portugal).
- The resulting cool near-shore ocean water helps produce the dry Mediterranean climate these areas are known for. Why? Cold water supports low humidity.



Coastal upwelling brings cold water to the surface

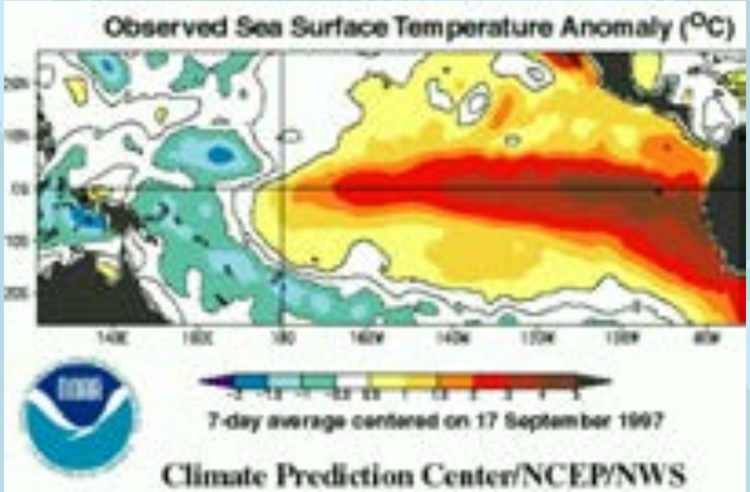
Winds and Ocean Currents

Summary

High pressure dominates the subtropical North Atlantic and North Pacific in summer.

This leads to the formation of an ocean gyre and clockwise currents in the ocean basins, and warm ocean currents on the east side of continents and cold currents on the west side of continents.

Why do we care about El Niño-Southern Oscillation (ENSO)?



Impacts of El Niño

- Droughts
  - Increased Wild Fires
  - Water supply
- Extreme Precipitation
  - Floods
  - Erosion
  - Disease
  - Transportation
- Impacts food chain and economy
  - Agricultural productivity

Impacts of El Niño

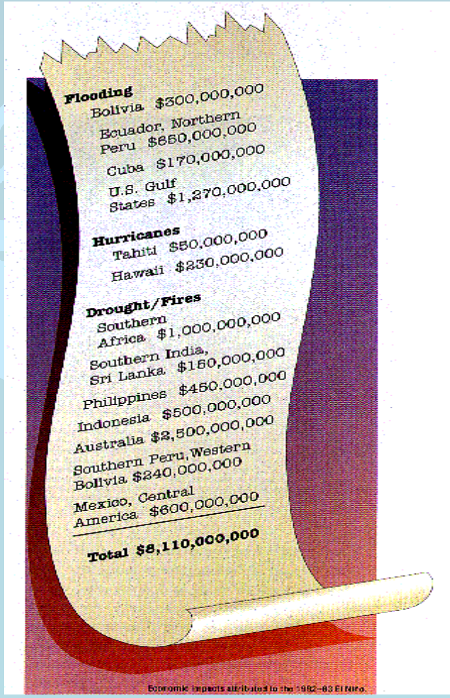
An Example of

Estimated Losses

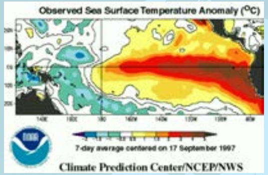
from 1982/83

El Nino Event

$8.11 Billion



El Niño-Southern Oscillation (ENSO)



- Every few years El Niño, a sea-surface temperature (SST) warming over the central equatorial Pacific Ocean, persists and is widespread.
  - Alters weather patterns globally.
  - Large ecosystem impacts and economic losses.
- Long timescale of ENSO (months) yields improved seasonal prediction.
- Better insight into coupled behavior of ocean and atmosphere may lead to better overall understanding of climate and climate change.

What is El Niño?

The name El Niño (referring to the Christ child) was originally given by Peruvian fisherman to a warm current that appeared every few years around Christmas.

The term El Niño refers to a rapid, dramatic warming of the sea-surface temperatures (SSTs) in the eastern and central equatorial Pacific, beginning along the north-central coast of South America and extending westward, that results in large-scale changes in the winds and rainfall patterns.

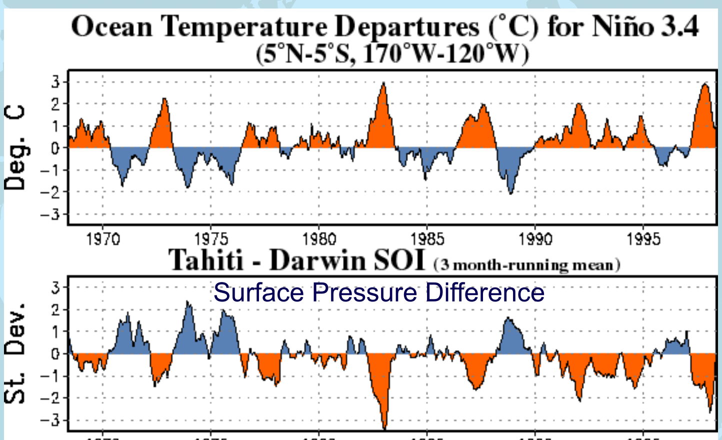
Southern Oscillation

The Southern Oscillation was named by Sir Gilbert Walker in 1923, who noted that "when pressure is high in the Pacific Ocean it tends to be low in the Indian Ocean from Africa to Australia". Walker was Director of Observatories in India and was mostly concerned with variations in the Indian monsoon. His was the first recognition that changes across the tropical Pacific and beyond were not isolated phenomena but were connected as part of a larger oscillation in equatorial SST that we now refer to as El Niño and La Niña.

ENSO Indices Correlate

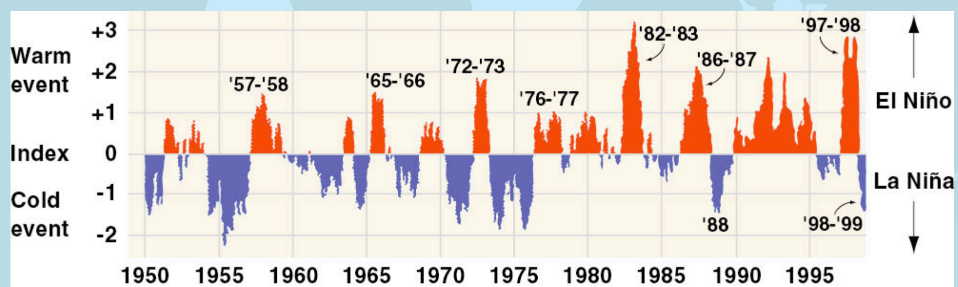
Ocean

Atmosphere



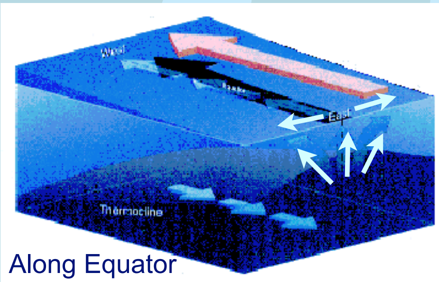
ENSO

The complete phenomenon is known as the El Niño – Southern Oscillation, or ENSO. The warm El Niño phase typically lasts for 8 -10 months or so. The entire ENSO cycle lasts usually about 3 -7 years, and includes a cold phase, known as La Niña, that may be similarly strong. However, the ENSO cycle is not a regular oscillation like the change of seasons, but can be highly variable in strength and timing.

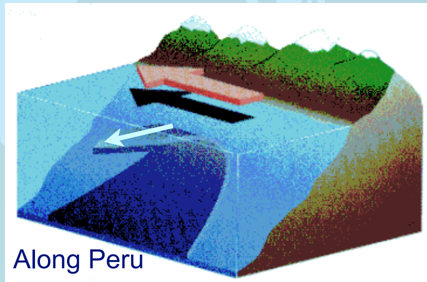


Physical Explanation for ENSO

- Trade winds promote cold water upwelling in eastern tropical Pacific as a result of Coriolis force on currents.
  - Cool, deep water is nutrient rich and supports rich ecosystem (plankton, fish, birds,…)
- Weaker trades lead to weaker upwelling. Warm nutrient-poor tropical water replaces the cold, nutrient-rich water.
  - called El Niño (the boy in reference to its occurrence near Christmas)

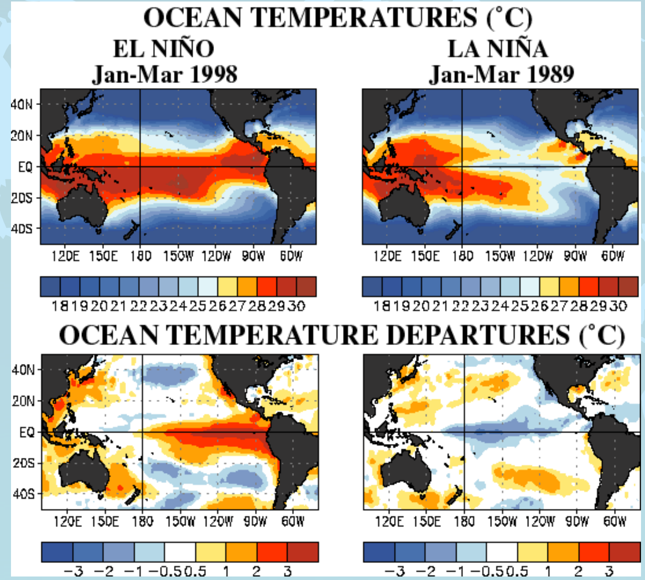


Along Equator



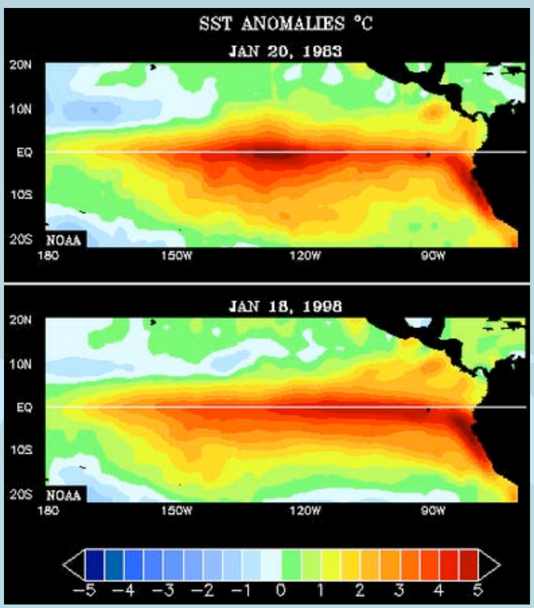
Along Peru

SST Maps During NH Winter



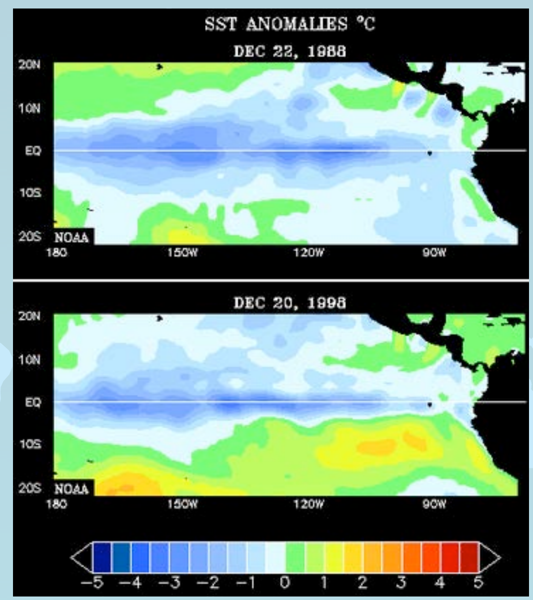
El Niño SST Anomalies

During el niño weaker easterly winds over the equator result in less upwelling and warmer SST.

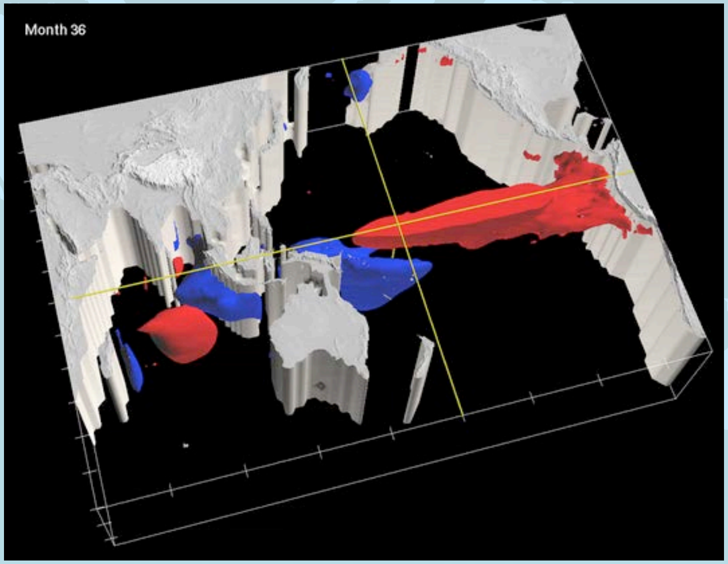


La Niña SST Anomalies

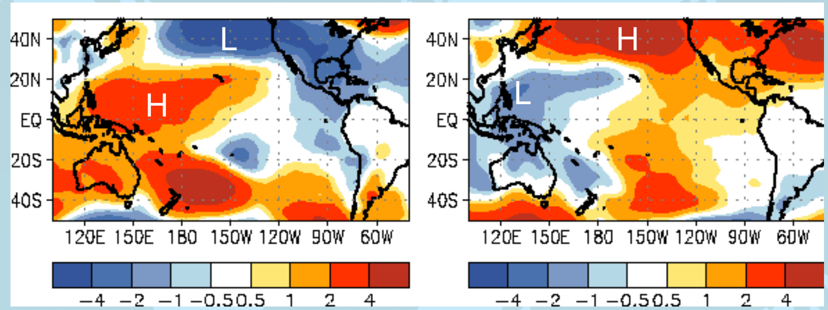
During la niña stronger easterly winds over the equator result in more upwelling and colder SST.



ENSO Animation



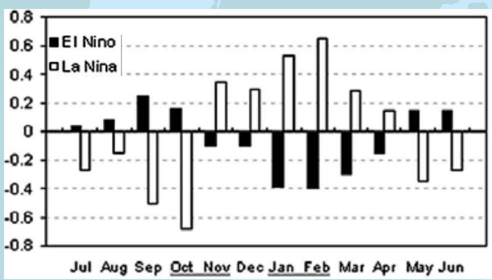
ENSO Pressure Anomalies



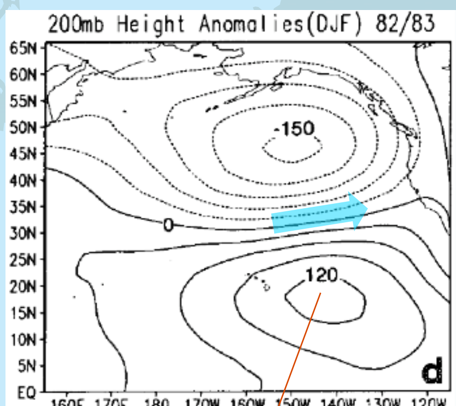
Average Sea-Level Atmospheric Pressure Anomalies (mb) for January through March associated with El Niño (left) and La Niña (right).

El Niño's Influence on Hawaii Climate

Dry in the El Niño Winter



Normalized Hawaii rainfall index

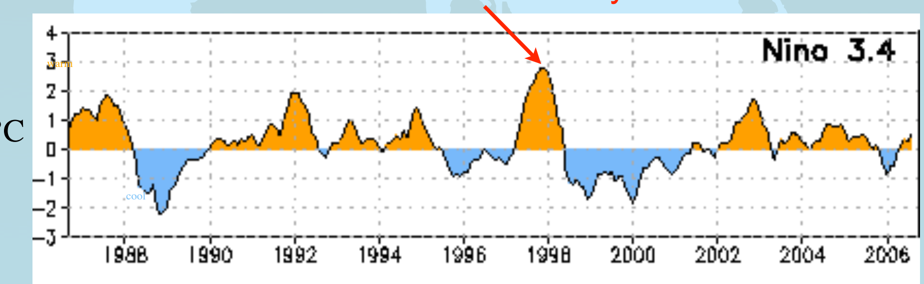


Enhanced subsidence due to strong convection in the central and eastern equatorial Pacific

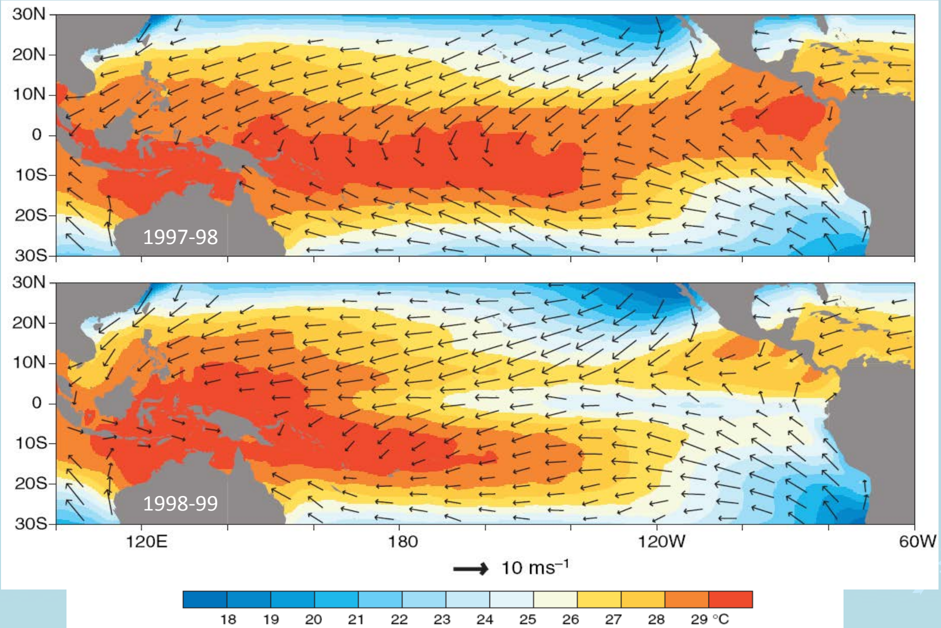
Time series of El Niño Index

El Niño of the Century

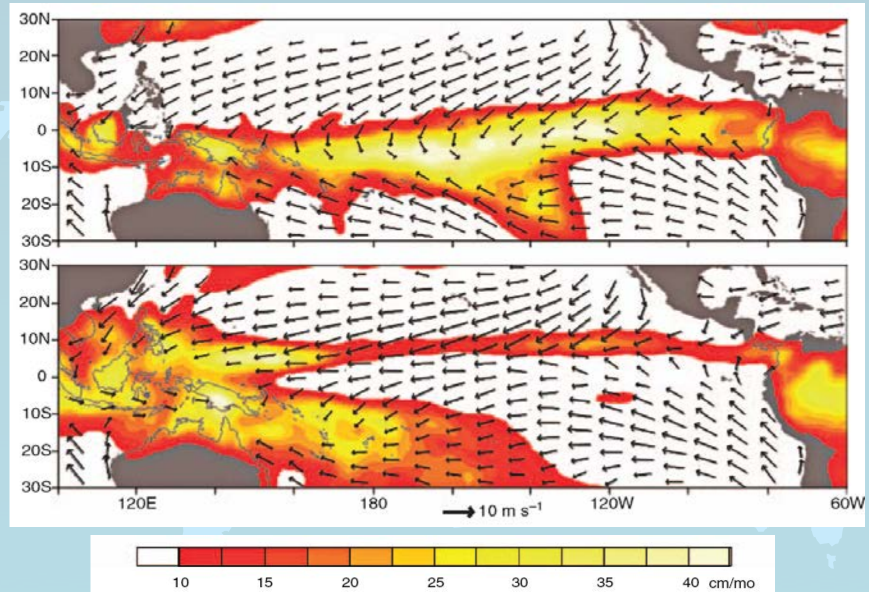
°C



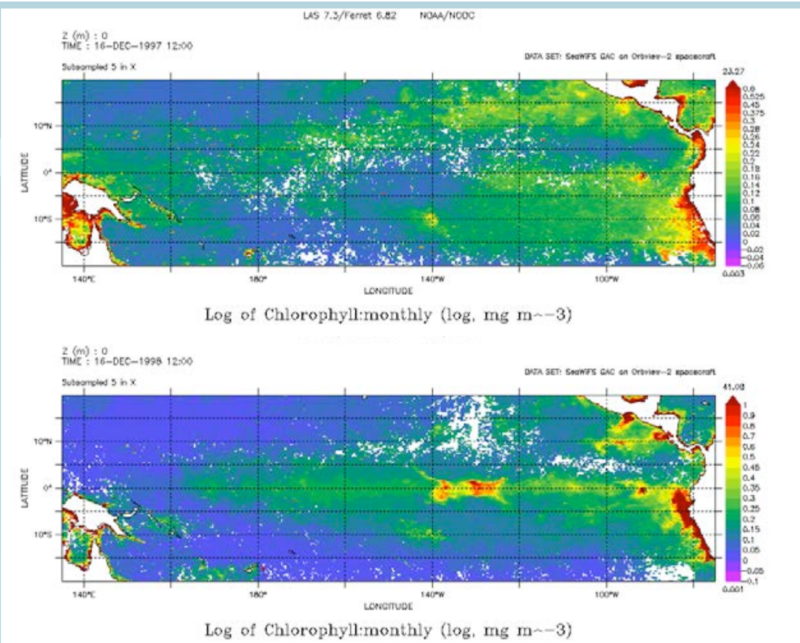
El Niño: peaks in the northern hemisphere winter months (Dec., Jan. Feb.)



Sea surface temperature and surface winds during November-April of 1997-98, and 1998-99.

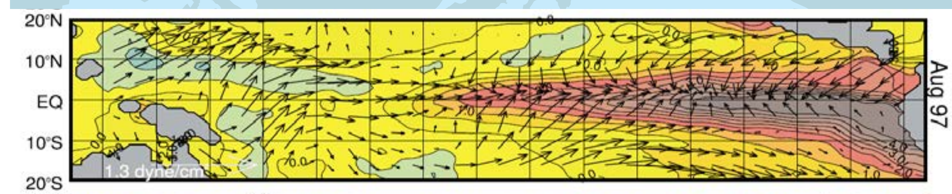


Precipitation (CMAP) and surface winds (ERS-2) during Nov.-April of 1997-98, and 1998-99.

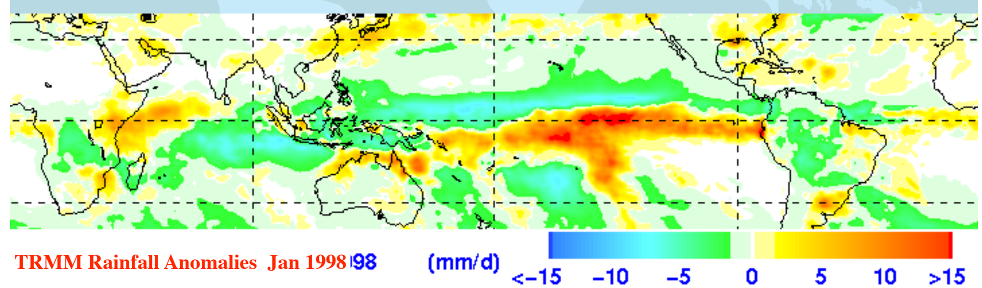


Chlorophyll – shows where nutrient upwelling is taking place in Dec. 1997 and Dec. 1998

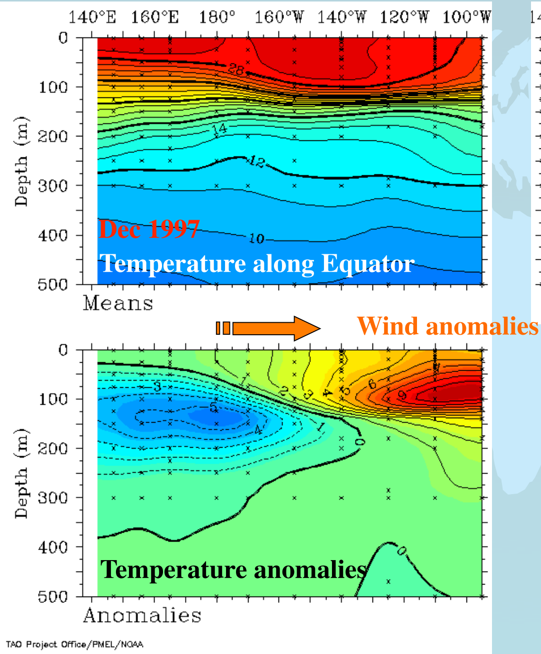
Ocean-Atmosphere Anomalies



SST anomaly (colors) and SSM/I wind stress anomalies (vectors) for August 1997. Picaut et al. (2002, JGR)

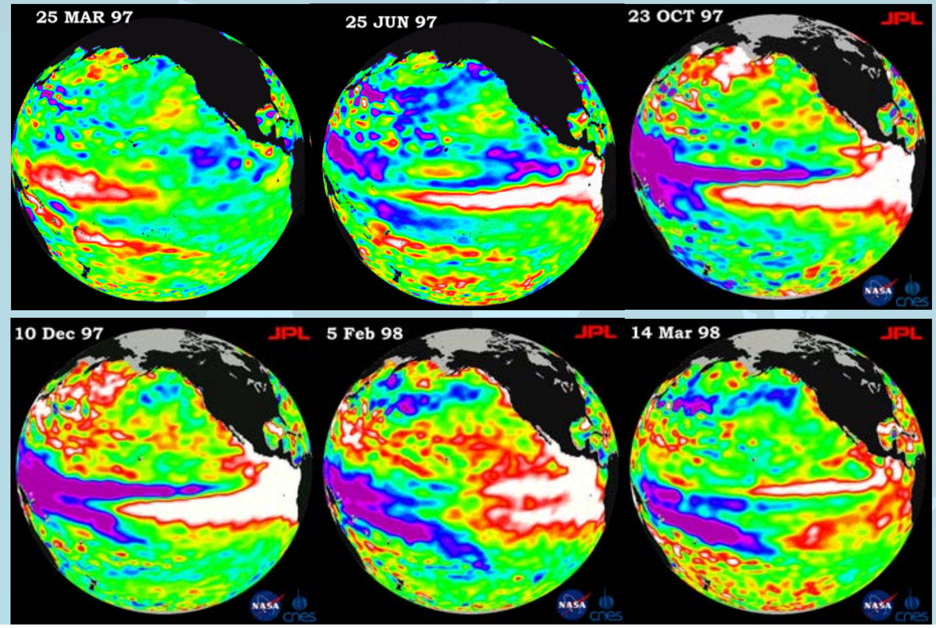


Interaction of thermocline depth, SST and winds



Satellite altimeters observe heat redistribution in the ocean

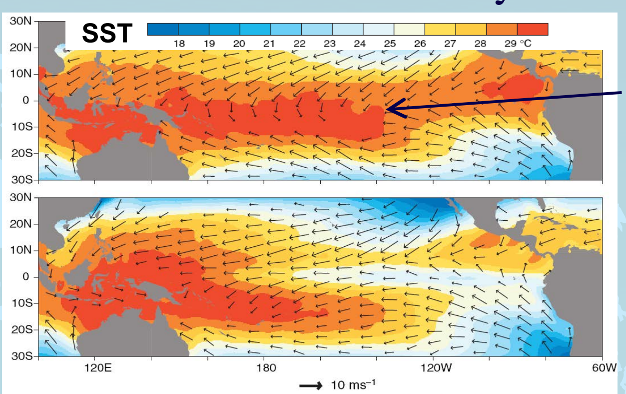
(thick warm water layer in red & white)



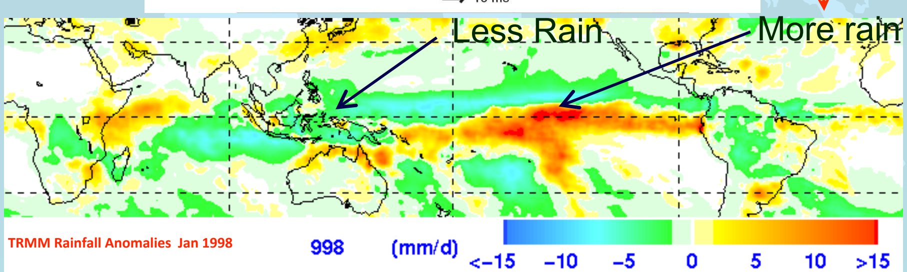
El Niño of the Century

1997-1998
Nov.-April
El Niño
weak winds

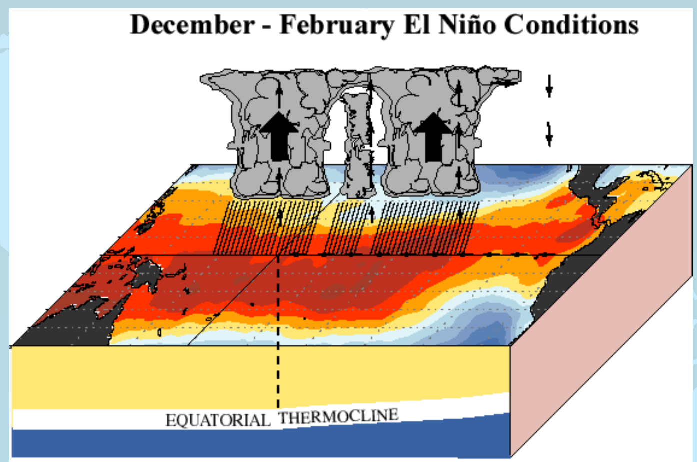
1998-1999
Nov.-April
normal
winds



Warmer Ocean

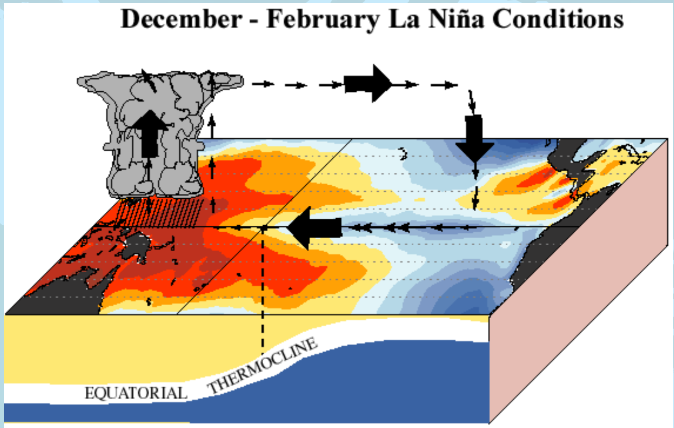


El Niño (Warm Phase)



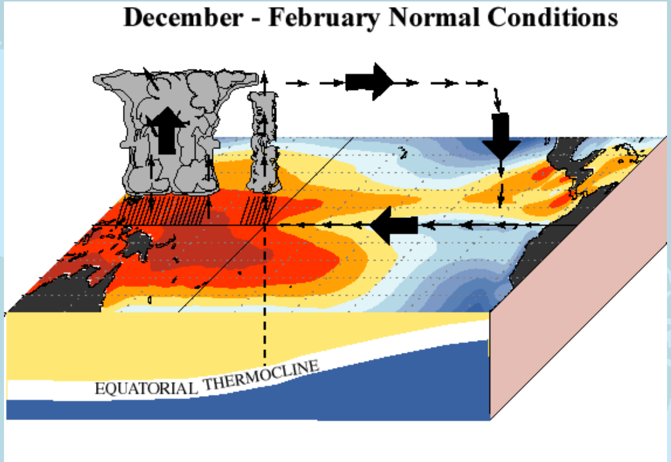
- Weaker tradewinds leads less upwelling
- Warmest SSTs, convection & rainfall shift to central Pacific
- Warmer SST's in eastern Pacific

La Niña (cold phase)



- Winds and surface water flow toward west, upwelling
- Warmest SSTs, convection & rainfall shift to Western Pacific
- Colder SST’s in eastern Pacific

ENSO Neutral (Average)



- Surface water flow from east toward west, upwelling
- Deep thermocline and warm water in western Pacific (associated deep convection & rainfall)
- Shallow thermocline and cool SST’s in east Pacific