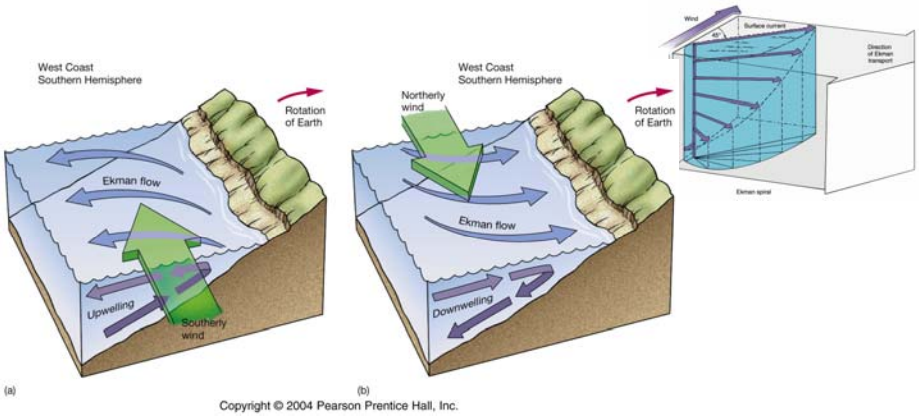
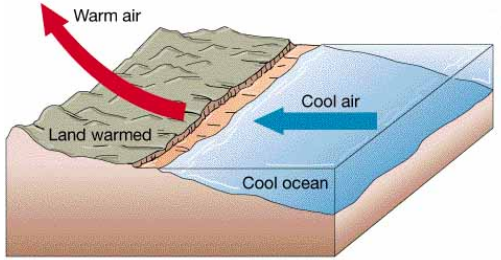


Note on Fig. 8.11. Shows the case for southern hemisphere!

Coastal upwelling and downwelling.

- Upwelling is caused by along shore winds, that initiate Ekman transport away from the coast (N Hemisphere)
- Downwelling is caused by along shore winds from the south, pushing water against the coast (N Hemisphere)

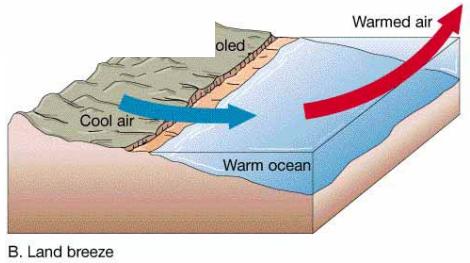
Example of regional winds of small scale



A. Sea breeze

Sea and land breezes

These do not cause Upwelling and Downwelling! You need winds for a long period and over a large area!



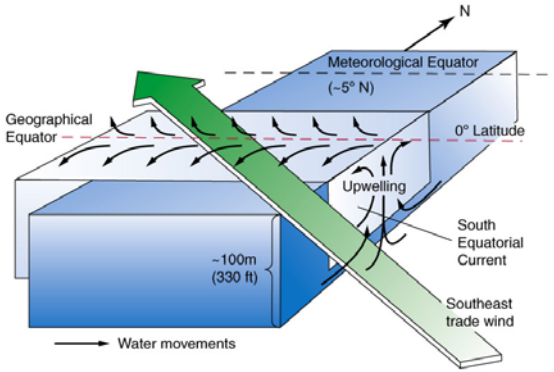
B. Land breeze

(disregard 8.12a!)

Equatorial upwelling

Equatorial upwelling.

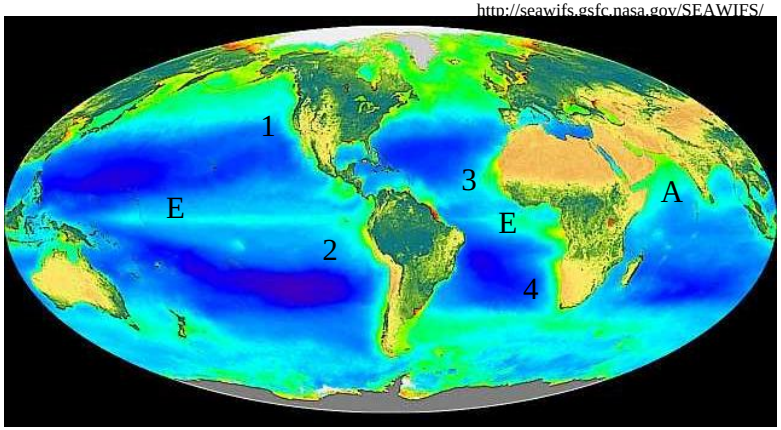
* Because the meteorological equator (ITCZ) is moved north, the SE trade winds an the South Equatorial Current straddle the equator.
* North of the equator its water is veered to the right, south of it to the left. This causes nutrient rich deep water to enter the surface water which gives rise to rich plankton communities.
* Remember the **siliceous ooze** that underlies



Equatorial upwelling

Fig. 8-9

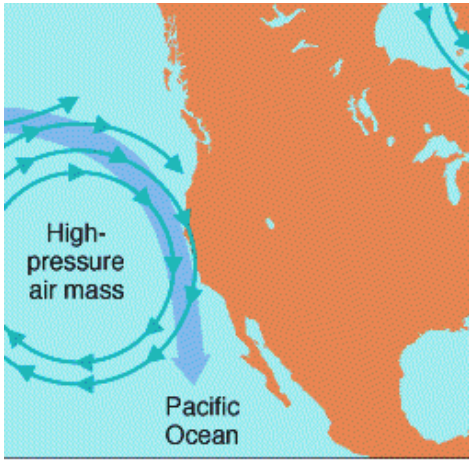
http://seawifs.gsfc.nasa.gov/SEAWIFS/



The **major coastal upwelling areas** can be found along the western sides (Eastern Boundary Current) of the continents.
There are four major ones:
1. Off California/Oregon (California Current)
2. Off Peru (Peru Current)
3. Off NW Africa (Canary Current)
4. Off SW Africa (Benguela Current)

A special case is the **Arabian Sea** where upwelling is tied to the **monsoons**.
E upwelling also occurs at the **equator**

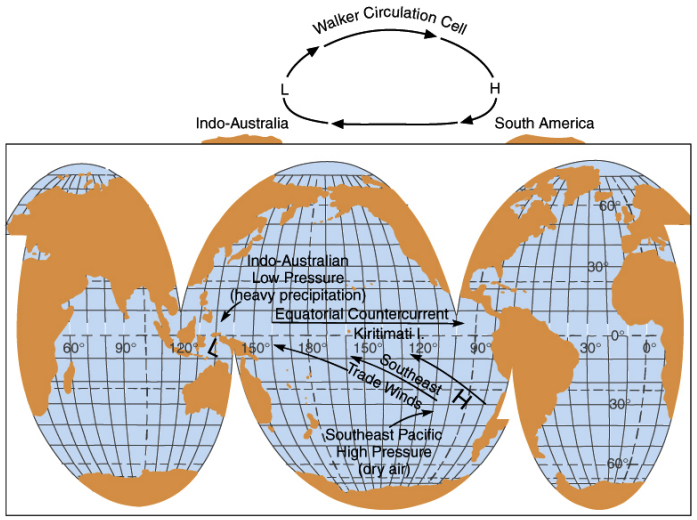
Why is there upwelling along north-west coast of US even though it is not within the trade wind system?



Anticyclonic (clockwise) air flow in the high pressure system that lies off the west coast in summer causes alongshore winds causing upwelling off Washington, Oregon and northern California.

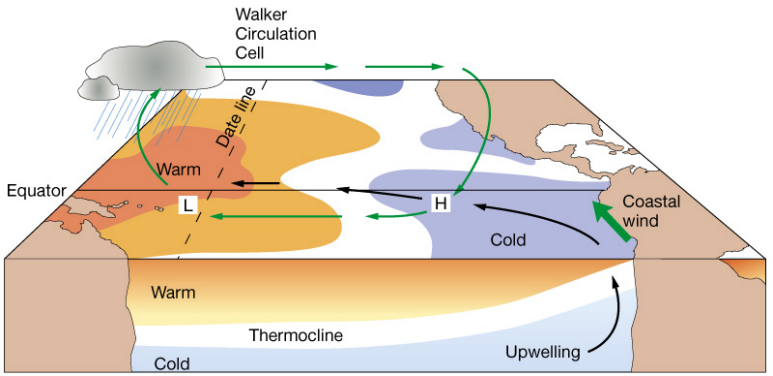
El Niño-Southern Oscillation (ENSO)

- **El Niño** = warm surface water in equatorial eastern Pacific that occurs periodically around Christmastime
- **Southern Oscillation** = change in atmospheric pressure over Pacific Ocean accompanying El Niño
- **ENSO** describes a combined oceanic-atmospheric disturbance

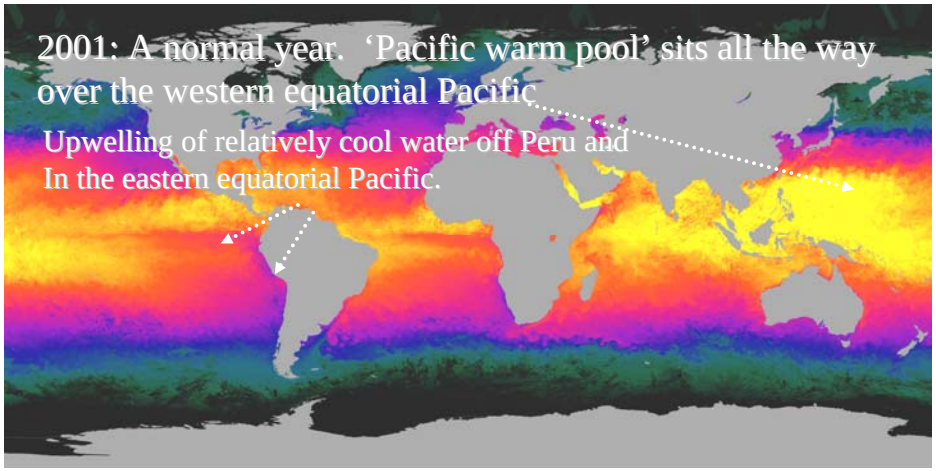


The Southern Oscillation (SO), discovered by G.T. Walker in 1920: Summer high pressure over southeastern Pacific occurs in conjunction with the low pressure system over the Indio-Australian region. This pressure gradient oscillates from higher to lower than average. A lower than average pressure gradient favors El Niño conditions.

Normal conditions in the Pacific Ocean

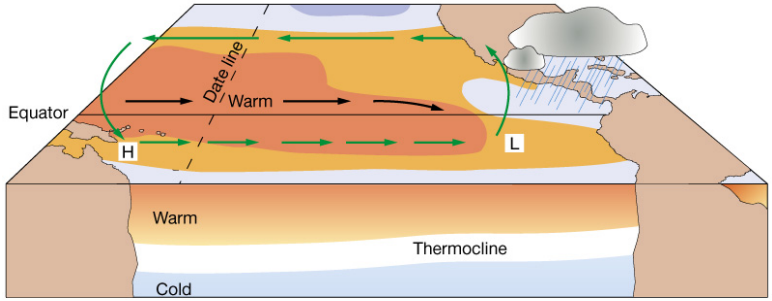


(a) Normal conditions



Sea surface temperatures from June 2–9, 2001 measured by the Moderate Resolution Imaging Spectroradiometer (MODIS).
Cold waters are black and dark green. Blue, purple, red, yellow, and white represent progressively warmer water. http://earthobservatory.nasa.gov/Newsroom/SST/

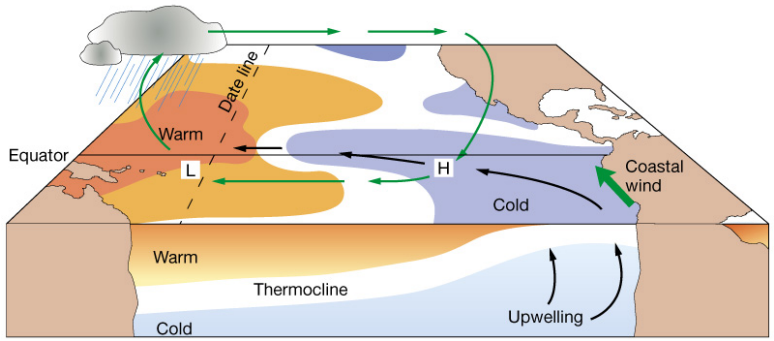
El Niño conditions (ENSO warm phase)



(b) El Niño conditions

8-18b

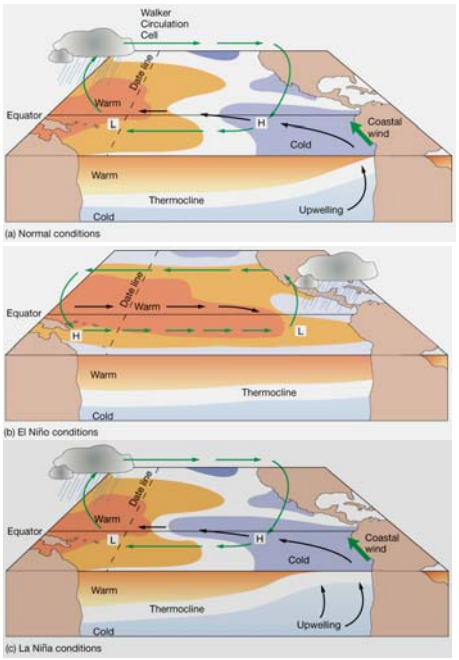
La Niña conditions (ENSO cool phase; opposite of El Niño)



(c) La Niña conditions

8-18c

ENSO



normal

El Niño

La Niña

8-18, a-c

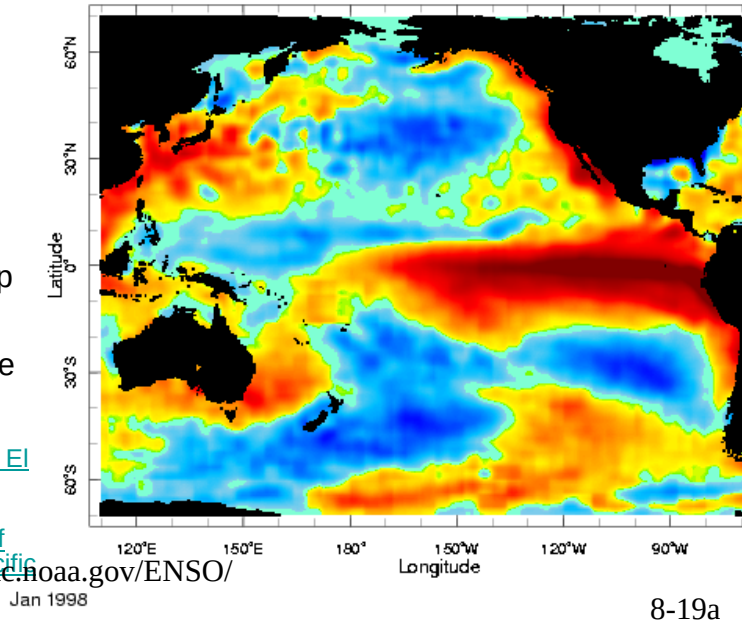
The 1997-98 El Niño

Sea surface temperature anomaly map shows warming during severe 1997-98 El Niño

Internet site for El Niño visualizations

Current state of the tropical Pacific

http://www.cdc.noaa.gov/ENSO/



El Niño recurrence interval

- Typical recurrence interval for El Niños = 2-12 years
- The nineties have been the decade with the most El Niños on record
- Linked to the Pacific Decadal Oscillation (PDO) (20-30yr cycle, warm phase 1977-1999)

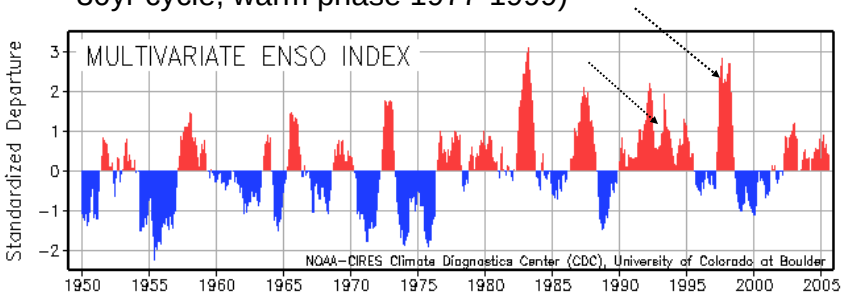


Figure 8-20 updated

El Niño global

- Strong El Niños have global implications (teleconnections)
- May alter atmospheric jet stream
- Areas that are drier or wetter than normal can be close to each other and variable
- **Usually** suppress hurricane formation in the Atlantic

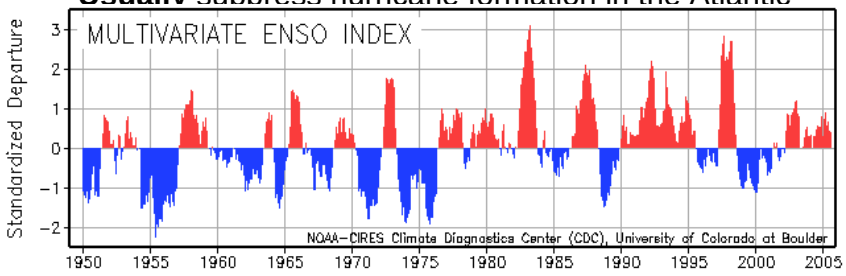
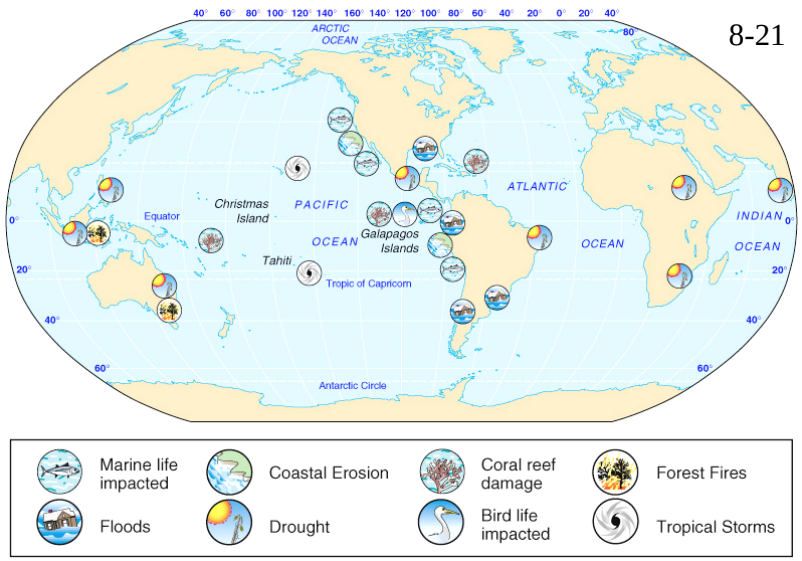


Figure 8-20 updated

Impacts of El Niño

- The **anchovy fishery** off Peru and Ecuador yields in a normal year up to 10^7 tons. The fishery exits because of the coastal upwelling along Peru/Ecuador. During El Niño the catch **declines to one-fifth** of the peak catches
- **Higher than normal rain falls** in Ecuador, northern Peru, southern coastal states of US, **flooding**, destruction of irrigation channels, houses, roads, soil erosion, **landslides**
- **Diseases** in middle America: Occurrence of **Malaria** in Colombia is closely related to El Niño events (due to higher precipitation)
- **Drought** in Indonesia, Australia, Brazil, Africa, **famines**, bush fires
- **Bad harvests** in southeast Asia cause world wide shortage of coconut oil, prices rise
- **Coral bleaching** in Australia, the Keys, and Galapagos linked to El Niño

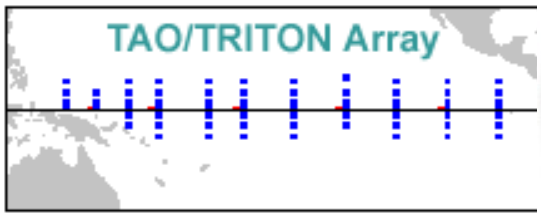
Effects of severe El Niños



Global impacts of La Niña (cold part of the ENSO cycle)

- Higher probability of **tropical cyclones and storm activity** over the Caribbean; higher probability of tornadoes
- Excessive **rain falls and flooding** in Caribbean
- **Colder than normal winters** over Great Plains, Alaska, Western Canada
- **Drier and sunnier and warmer** conditions in the US Southwest
- **Extreme flooding eastern African coast** (coinciding with normal southwest Monsoon)

Predicting ENSO Events



- The **Sea Surface Temperature (SST) anomaly** over the eastern equatorial Pacific is predictable about one year in advance.
- The **TAO (Tropical Atmosphere Ocean) Array**, consists of approximately 70 moored ocean buoys in the tropical Pacific Ocean
- Provides oceanographic and meteorological data for climate analysis and forecasting
- The array is supported by a multi-national partnership of institutions, and is a major component of global ocean and climate observing system
- Tropical SST monitoring enables short-range climate predictions over many regions of the globe
- Facilitates agricultural decisions.
- Real time data at http://www.pmel.noaa.gov/tao/jsdisplay/