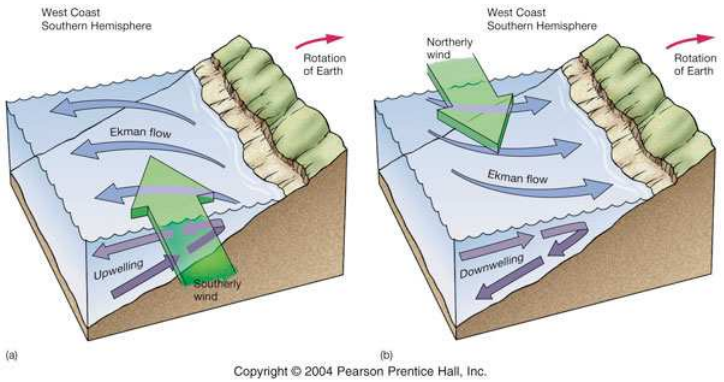
Ekman transport, ENSO & IOD

EKMAN TRANSPORT & UPWELLING

- Upwelling occurs in the open ocean and along coastlines when wind causes surface water to subside along a coastline.
- Subsurface water rises to the surface as a result and is typically colder, nutrient-rich, and biologically productive supporting rich fishing grounds (e.g. west coasts of Africa and South America).
- How does this happen?

EKMAN TRANSPORT & UPWELLING



ENSO

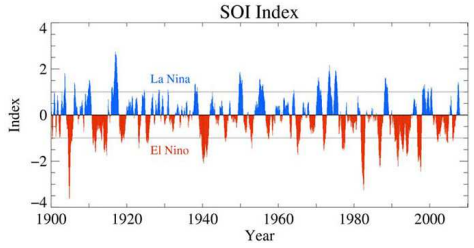
- El Niño and La Niña are opposite phases of the *El Niño-Southern Oscillation* (**ENSO**) cycle;
- ENSO describes the fluctuations in temperature between the ocean and atmosphere in the east-central Equatorial Pacific; **La Niña is the cold phase** and **El Niño the warm phase**.
- These deviations from normal surface temperatures can have large-scale impacts not only on ocean processes, but also on global weather and climate.

http://oceanservice.noaa.gov

ENSO

- El Niño and La Niña episodes typically last 9 to 12 months, but some events may last years. They often begin to form between June and August, reach peak strength between December and April, and then decay between May and July of the following year.

http://oceanservice.noaa.gov

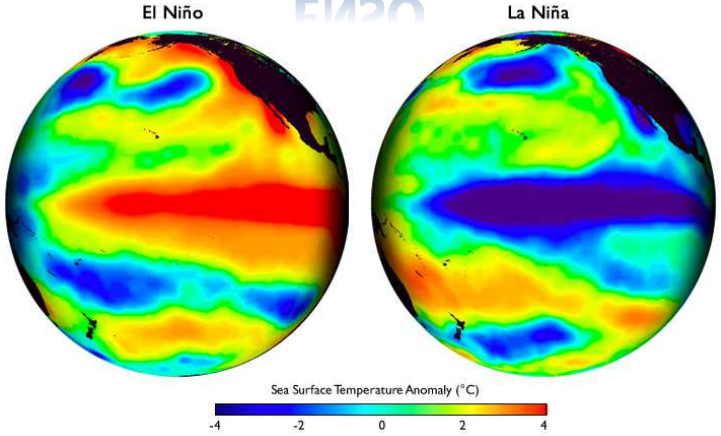


ENSO

- While irregular, El Niño and La Niña events occur about every 3 to 5 years. Typically, El Niño occurs more frequently than La Niña.
- **El Niño**: Large-scale ocean-atmosphere climate interaction linked to periodic warming in sea surface temperatures across central and east-central Equatorial Pacific.
- **La Niña**: Periods of below-average sea surface temperatures across the east-central Equatorial Pacific.

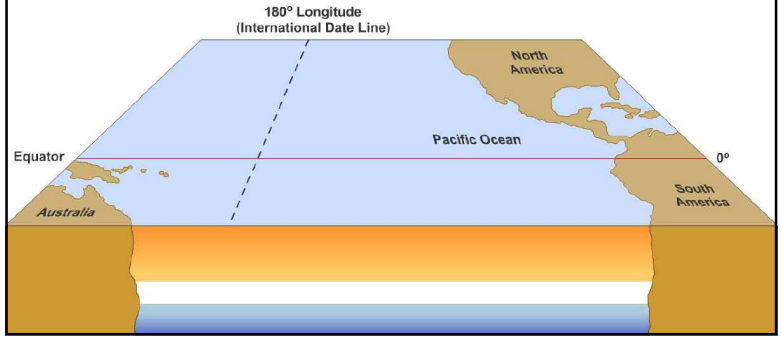
http://oceanservice.noaa.gov

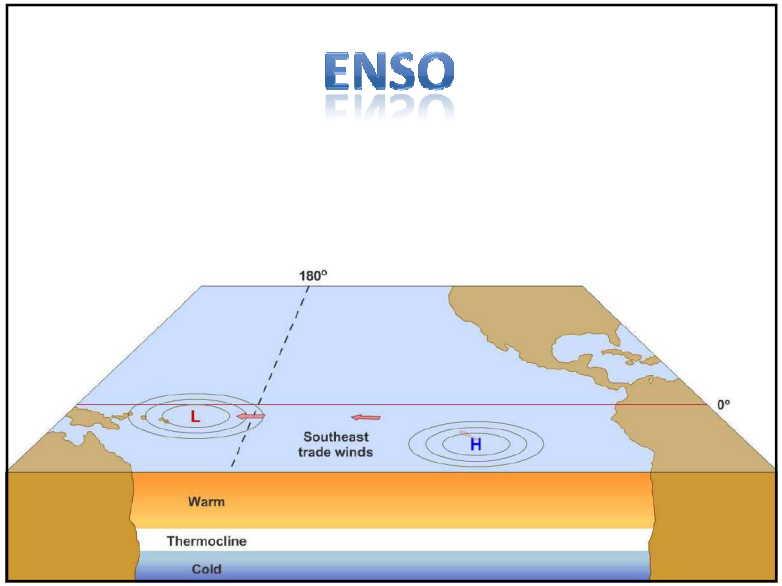
ENSO

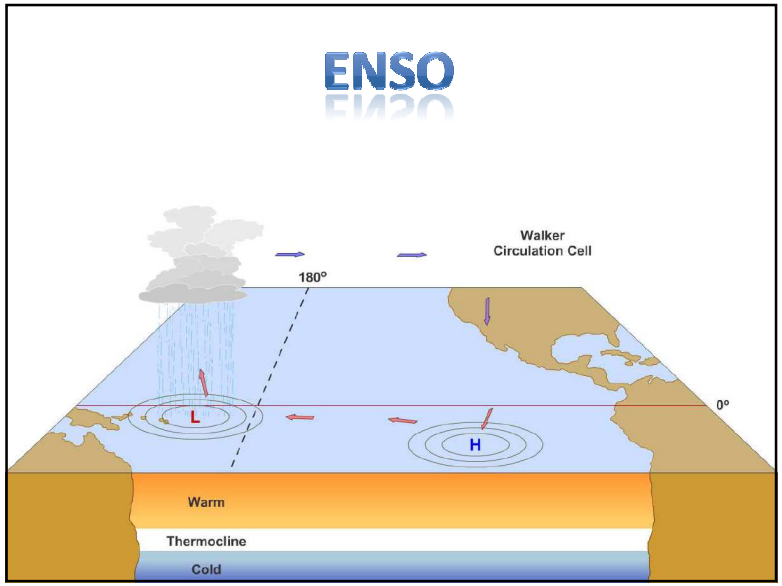


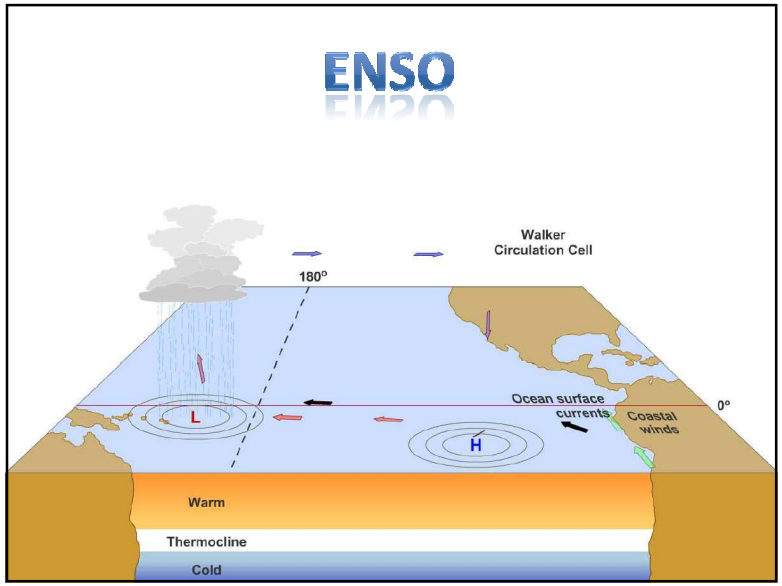
ANIMATION: http://esminfo.prenhall.com/science/geoanimations/animations/26_NinoNina.html

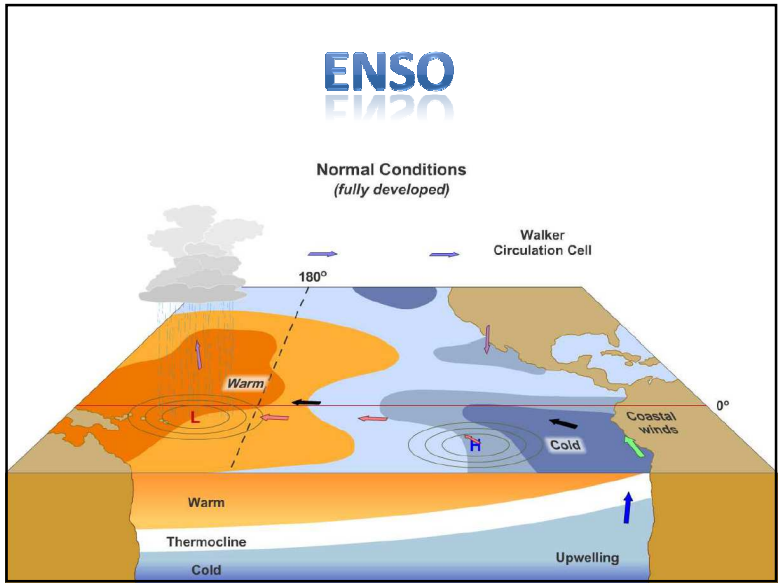
ENSO



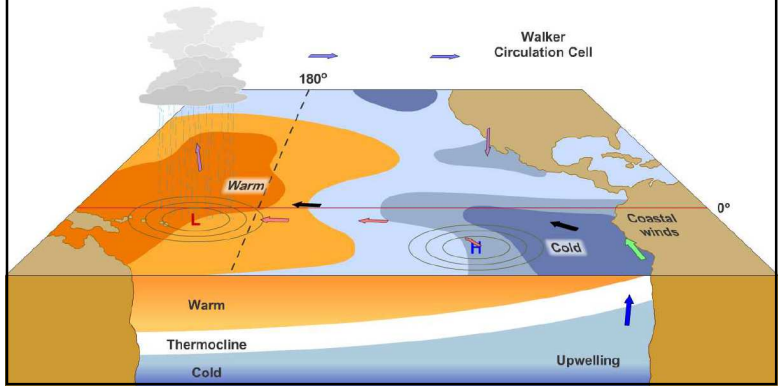

ENSO
180°
0°
L
H
Southeast
trade winds
Warm
Thermocline
Cold


ENSO
Walker
Circulation Cell
180°
0°
L
H
Warm
Thermocline
Cold

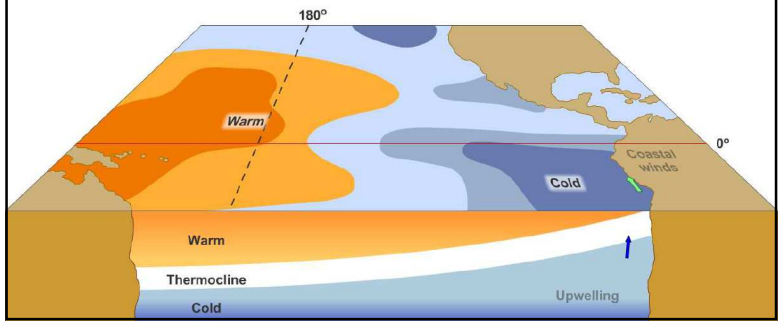

ENSO
Walker
Circulation Cell
180°
0°
L
H
Ocean surface
currents
Coastal
winds
Warm
Thermocline
Cold


ENSO
Normal Conditions
(fully developed)
Walker
Circulation Cell
180°
0°
Warm
L
H
Cold
Coastal
winds
Warm
Thermocline
Cold
Upwelling

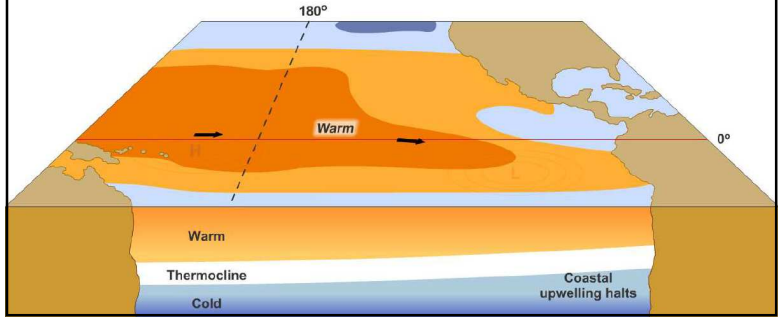
ENSO



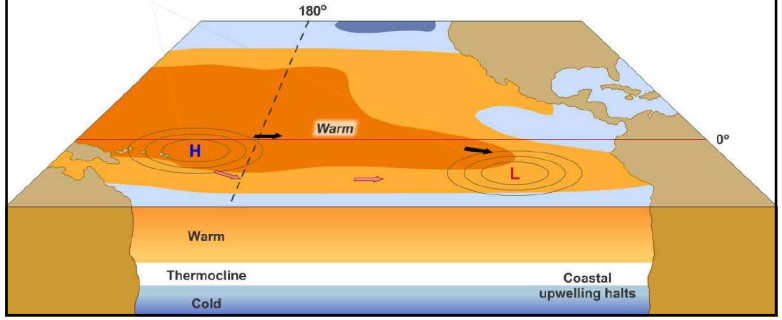
ENSO

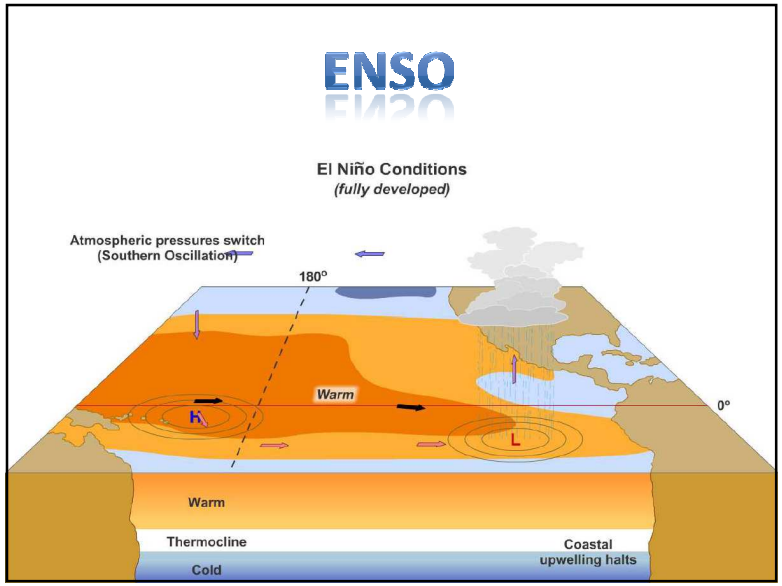


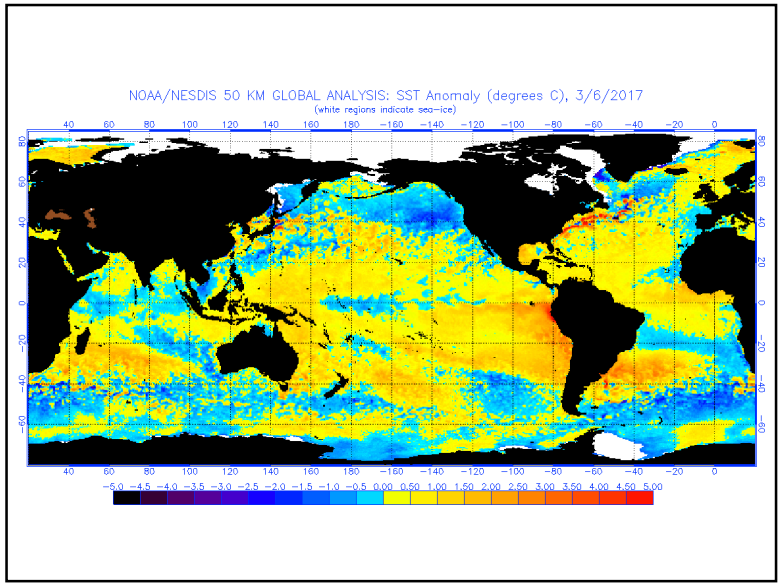
ENSO

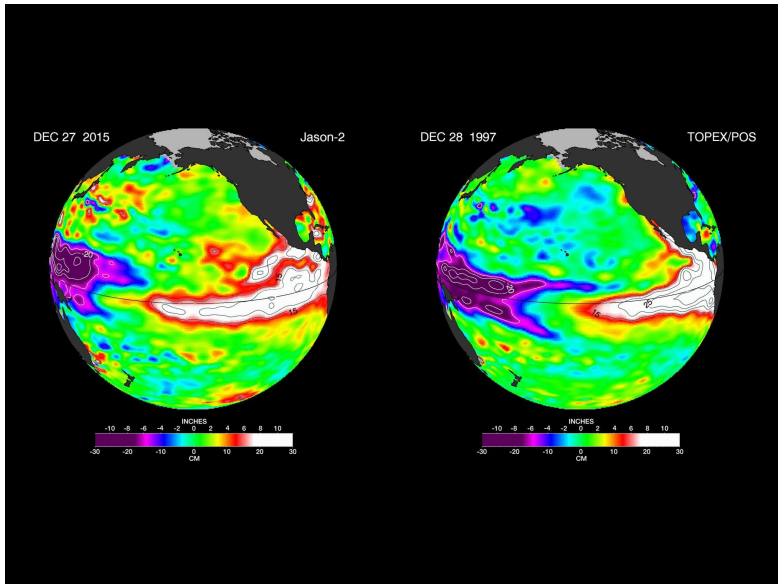


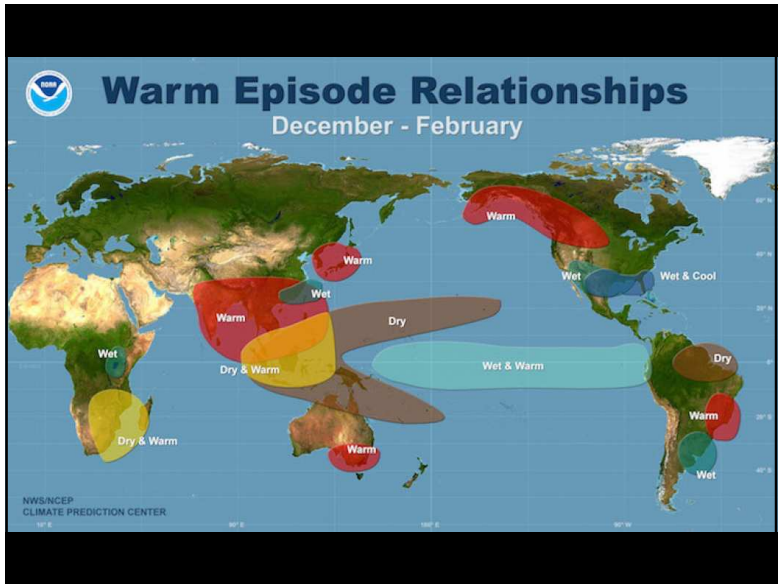
ENSO

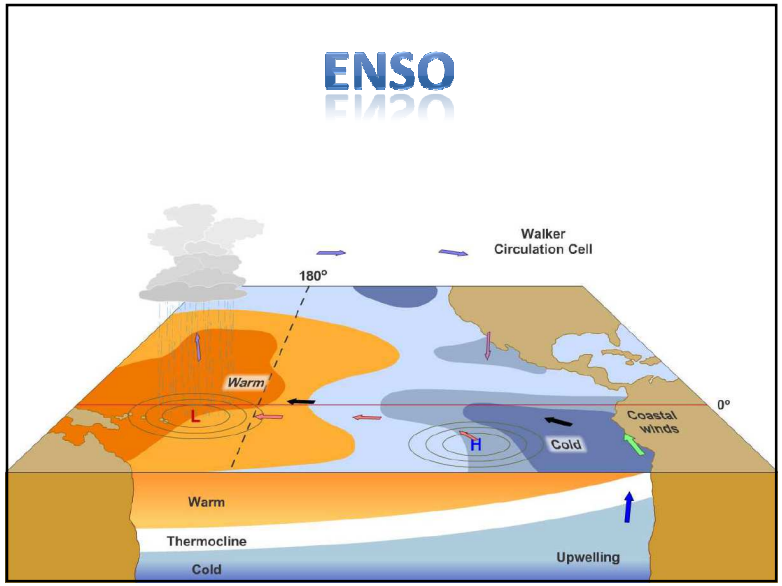


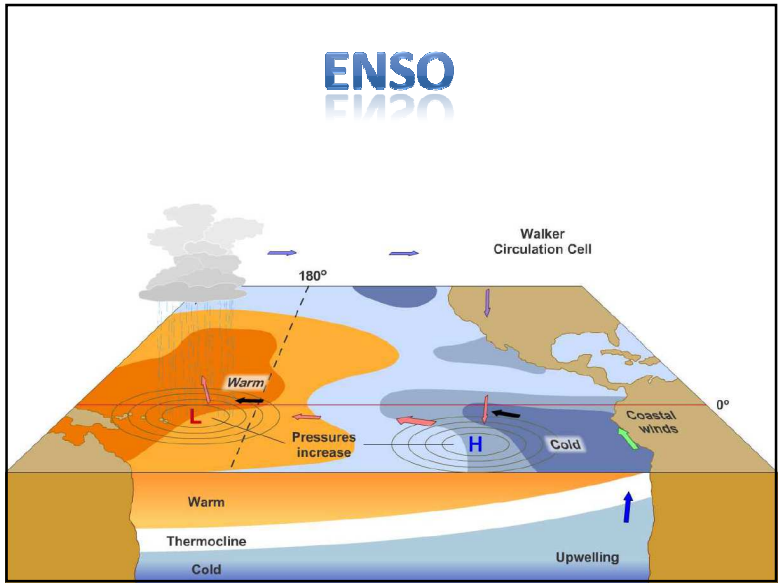

ENSO
El Niño Conditions
(fully developed)
Atmospheric pressures switch
(Southern Oscillation)
180°
0°
Warm
H
L
Warm
Thermocline
Cold
Coastal
upwelling halts

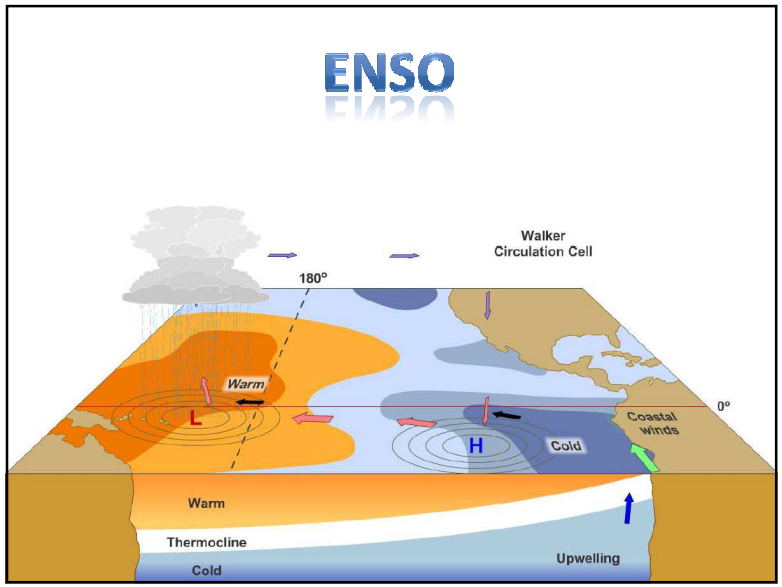

NOAA/NESDIS 50 KM GLOBAL ANALYSIS: SST Anomaly (degrees C), 3/6/2017
(white regions indicate sea-ice)

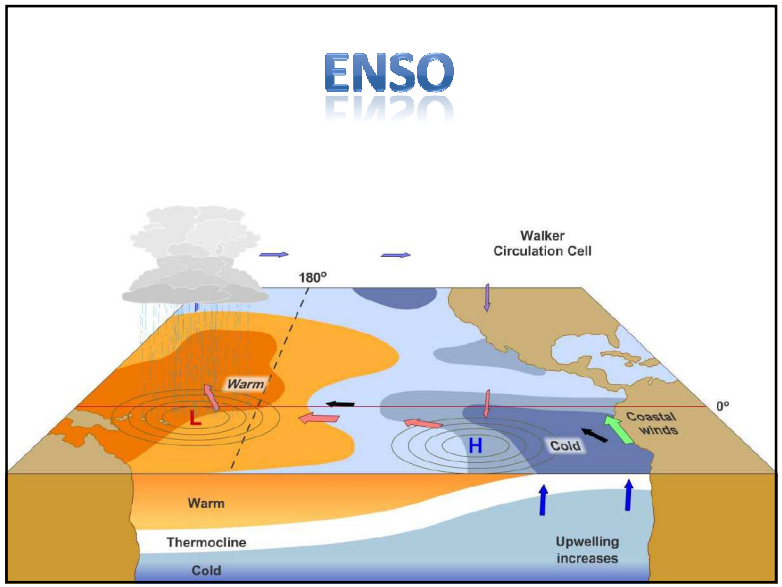

DEC 27 2015
Jason-2
DEC 28 1997
TOPEX/POS
INCHES
CM

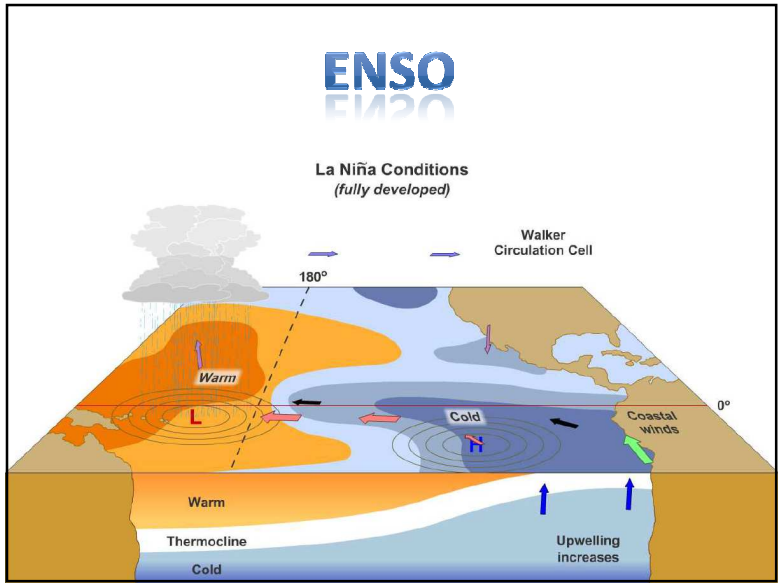

Warm Episode Relationships
December - February
Warm
Warm
Wet
Wet & Cool
Warm
Dry
Wet
Dry & Warm
Wet & Warm
Dry
Warm
Dry & Warm
Warm
Wet
NWS/NCEP
CLIMATE PREDICTION CENTER

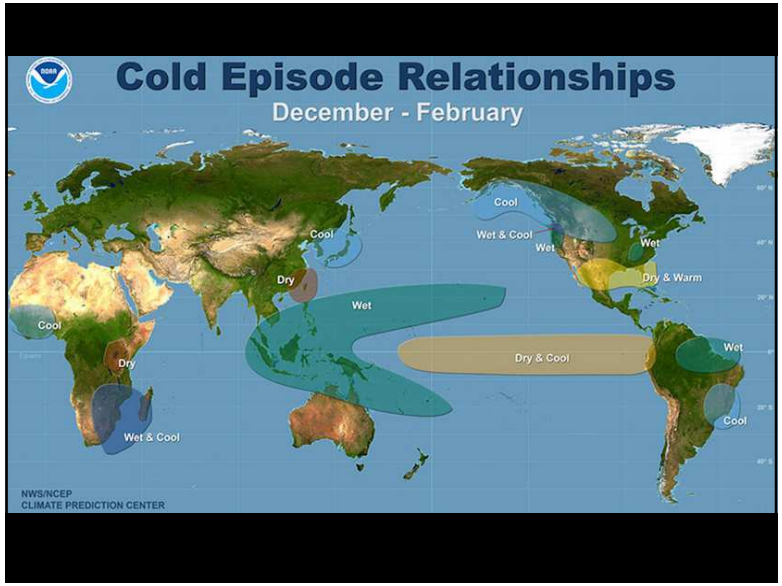

ENSO
Walker
Circulation Cell
180°
0°
Warm
L
H
Cold
Coastal
winds
Warm
Thermocline
Cold
Upwelling


ENSO
Walker
Circulation Cell
180°
0°
Warm
L
Pressures
increase
H
Cold
Coastal
winds
Warm
Thermocline
Cold
Upwelling


ENSO
Walker
Circulation Cell
180°
0°
Warm
L
H
Cold
Coastal
winds
Warm
Thermocline
Cold
Upwelling


ENSO
Walker
Circulation Cell
180°
0°
Warm
L
H
Cold
Coastal
winds
Warm
Thermocline
Cold
Upwelling
increases



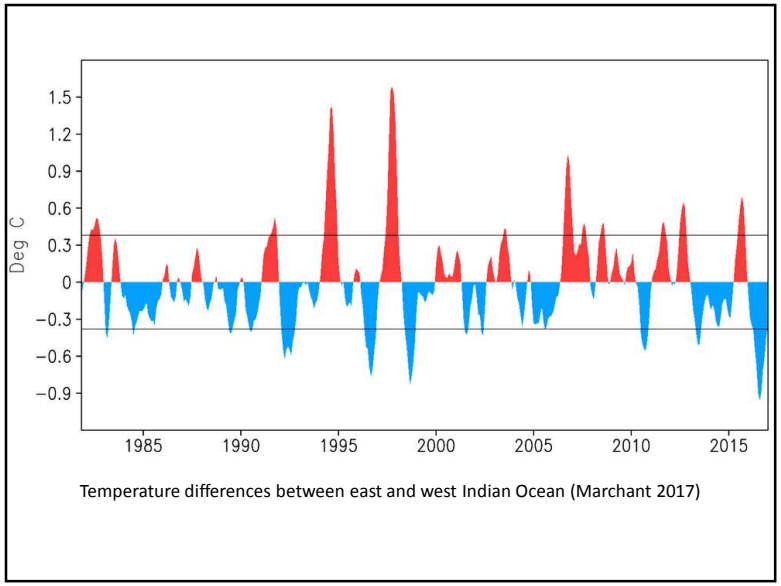


INDIAN OCEAN DIPOLE

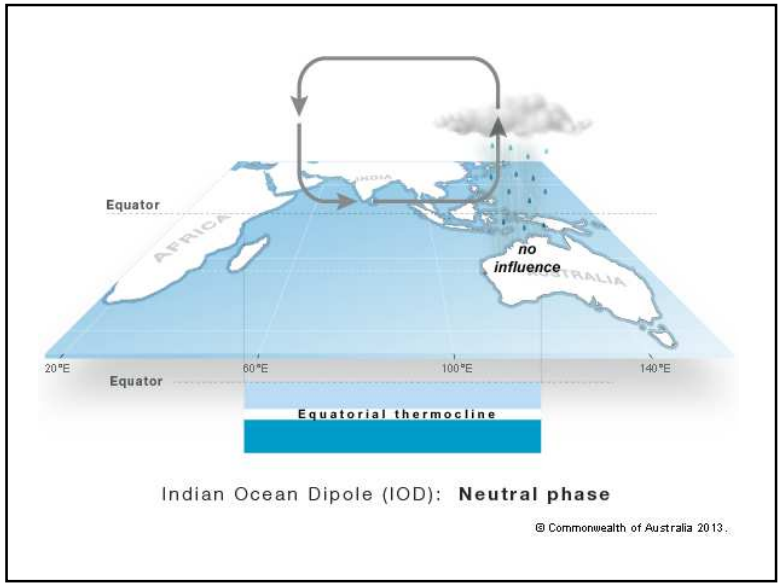
- East African droughts can be <u>partly explained</u> by the IOD; sustained changes in difference between sea surface temperatures of the tropical western and eastern Indian Ocean.
- Three phases: neutral, positive and negative.
- Usually starts early winter (May/June), peaks in spring (August/October) and decays at end of spring.

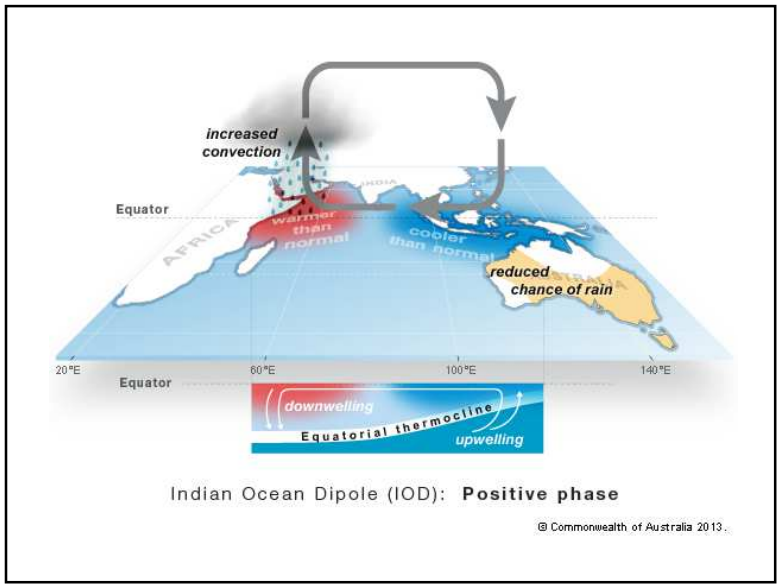
http://www.bom.gov.au/climate/iod/

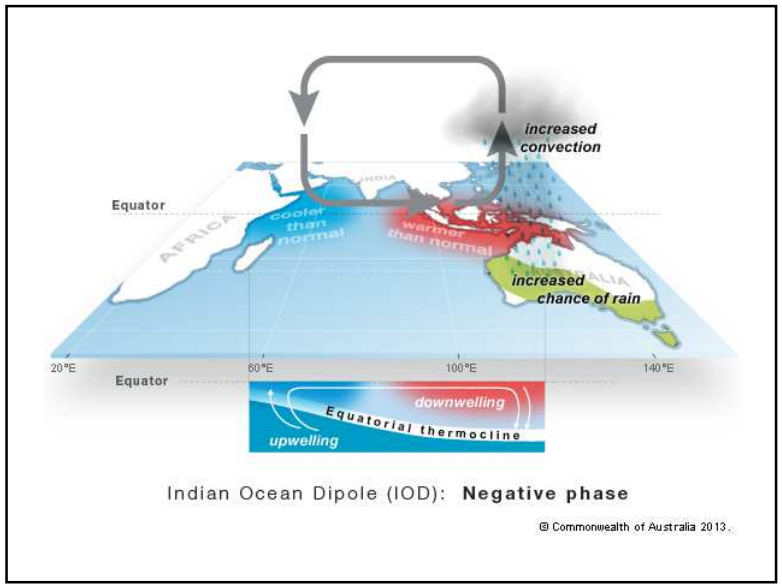
- Since 1960 to 2013 there have been nine negative and nine positive IOD events (each phase occurs every 3-5 years).
- Farmers in the Horn of Africa rely on moisture from the Indian Ocean to generate the “short rains” that run from October to December and the “long rains” from March to June.
- During the negative phase, winds blowing out to sea makes the air drier than usual; exacerbated drought events.



Temperature differences between east and west Indian Ocean (Marchant 2017)



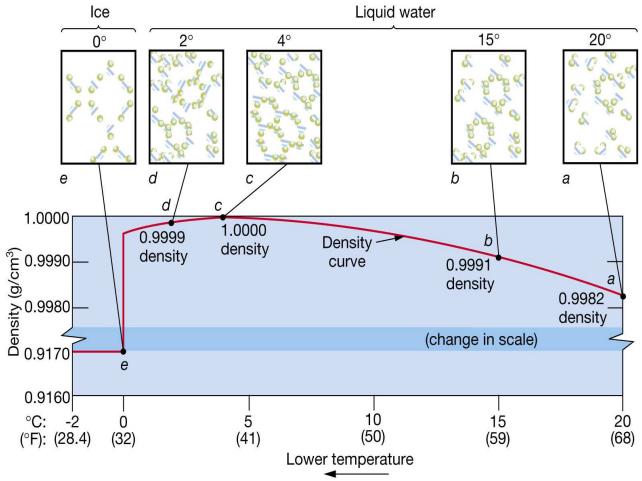


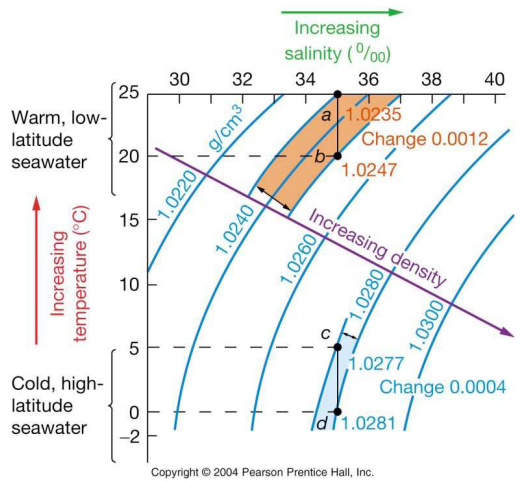


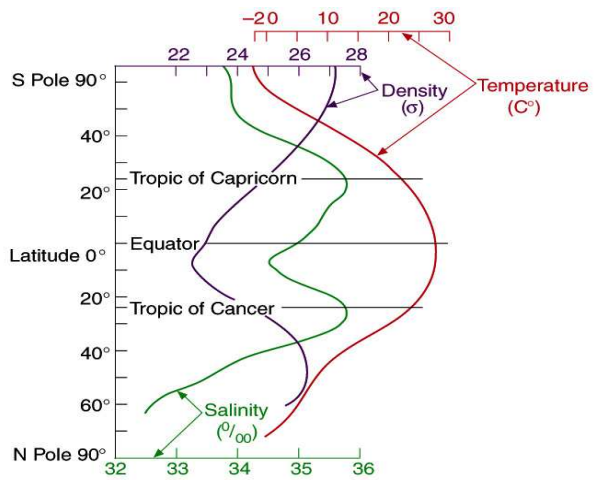
Thermohaline Circulation & Great Ocean Conveyor

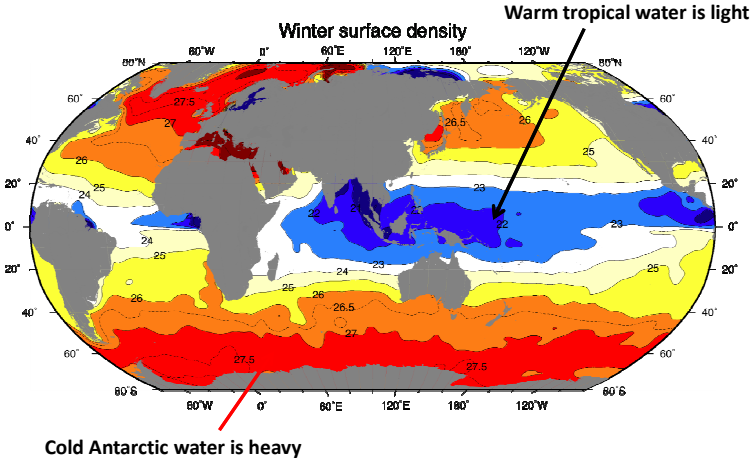
Water density (kg m^{-3})

- Dependent on <u>temperature</u>, <u>salinity</u> and <u>pressure</u>
- Differences in fluid density ➔ horizontal layering (stratification); less dense fluid floats on top of denser fluid. E.g. oil floating on water.
  - **Pure water = 1000 kg m^{-3}**
  - **Sea water = 1025 kg m^{-3}**



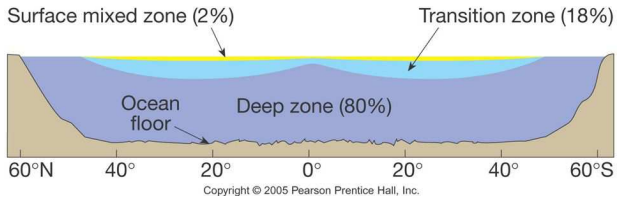






Three-layered ocean

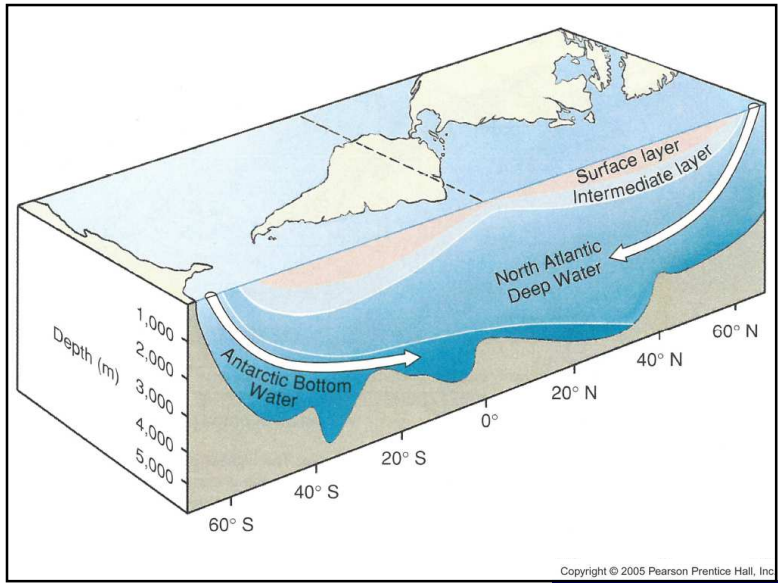
1) **Surface (mixed) layer**: ~100-200 m deep. Generally mixed by wind, waves and currents but calm summer conditions may warm this layer creating temporary thermoclines.



2) **Intermediate (pycnocline) layer**: Below surface layer at ~1000-1500 m. Main thermocline lies within this layer; this is generally permanent and a key feature of open ocean (continental shelf too shallow).

3) **Deep & bottom layers**: >1500 m. These are similar in being uniformly cold (<4°C).

NB: Thermoclines and pycnoclines seldom develop at high latitudes. WHY?


Surface layer
Intermediate layer
North Atlantic Deep Water
Antarctic Bottom Water
Depth (m)
1,000
2,000
3,000
4,000
5,000
60° S
40° S
20° S
0°
20° N
40° N
60° N
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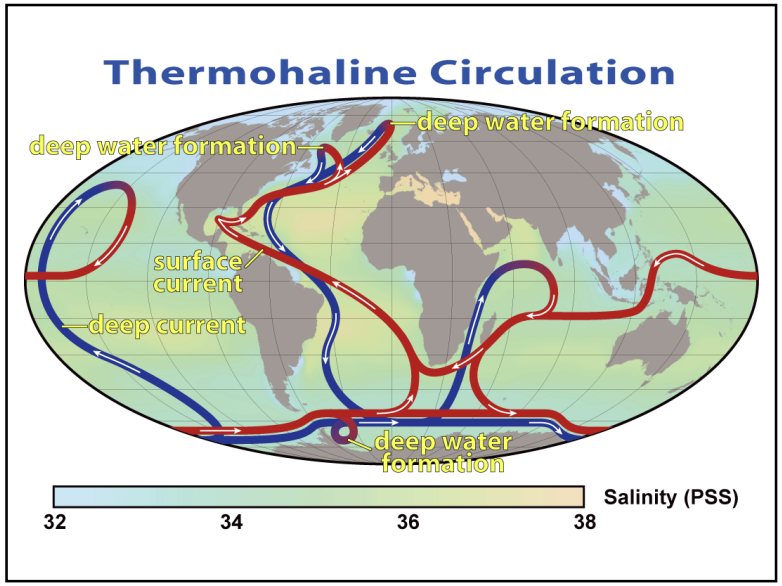
Thermohaline Circulation
deep water formation
deep water formation
surface current
deep current
deep water formation
Salinity (PSS)
32
34
36
38