Learning objective: Understand the observed ocean-atmosphere anomalies associated with ENSO & thermohaline circulation - concept & heat transport

Specifics:
1. The normal tropical Pacific & annual cycle;
2. ENSO phenomenon;
3. Thermohaline circulation (THC) & heat transport
Ocean basin of the tropical Pacific & index regions

From Ecuador in the east (80w) to Maritime continent (a collection of Islands of Indonesia-Australia) in the west; spans about 151 degrees.

Index regions
Southern Oscillation Index (SOI) Sea Level Pressure (SLP) difference between Tahiti & Darwin
1. The observed normal tropical Pacific: surface
Annal mean SST & surface wind  Surface wind, ITCZ, etc
3-D: Normal Pacific ocean-atmosphere conditions

White arrows: currents
Black arrows: winds

D20: depth of 20°C isotherm

Walker circulation

Observed Temperature along EQ Pacific.
Normal Pacific EQ currents

EUC: 200km wide, and 100m deep
Pacific Annual Cycle of SST & winds
Summary: normal ocean-atmosphere circulation

1) Normal condition: Walker circulation;
2) SST, zonal surface currents, sea level and thermocline depth;
3) Seasonal cycle of surface wind, SST;
4) The cold tongue is the strongest, and the east-west SST gradients are the largest during which season?
5) What about the seasonal variation of the ITCZ?
2. The El Niño – Southern Oscillation (ENSO)

Index regions

Southern Oscillation Index (SOI) Sea Level Pressure (SLP) difference between Tahiti & Darwin

East-west SLP dipole called “Southern Oscillation”
La Niña (cold phase): Enhanced Normal Condition:
1. Enhanced Walker circulation & larger positive SOI;
2. Stronger SEC & EUC;
3. Eastern EQ Pacific: colder SST, shallower thermocline, enhanced upwelling, nutrient rich & good fishery.

El Niño (warm phase):
1. Convection shifts to central EQ pacific & negative SOI;
2. Weaker SEC & EUC;
3. Eastern EQ Pacific: warmer SST, deeper thermocline, reduced upwelling & reduced nutrient in euphotic zone, bad fishery.
Why is it called El Nino?

• Originally named by Peruvian fisherman

• For very warm water in the Pacific Ocean, occurring around Christmas.

• El Niño means *The Little One* in Spanish. (Christ Child).

• El Niño means a warm event that occurs about every 2-7 years across the tropical Pacific Ocean.
ENSO Evolution: SST Variability in Nino3.4 region

NINO3.4 SST Anomaly Time series

Phase-lock: fall-winter maximum, when cold tongue is strongest
ENSO evolution:
(July-Nov) regression
Onto EQ SSTA index

a) Surface wind+SLP anomalies

b) Surface wind+SST anomalies

c) Surface wind+OLR
Convection (outgoing longwave radiation) anomalies
a) Surface wind + SLP anomalies

b) Surface wind + SST anomalies

c) Surface wind + OLR anomalies
Do you expect a strengthened or weakened SEC?

Weakened.
Sea level height
thermocline

Ocean Temperature Anomalies
1997/98 El Niño: High SLA in E. Pacific

Satellite TOPEX/Poseidon Sea Level Anomaly (SLA):

- Red: high SLA;
- Blue: low SLA

SLA in averaged Over the boxed region
El Nino Sea Level Changes
Critical thinking

1) How does El Nino evolve from *summer-fall* to *winter*? (surface wind, SLP, convection & SST)

2) Based on the above observations, what are the most striking features that inspire you regarding El Nino evolution?

What do these features indicate regarding ENSO mechanisms?
3. Thermohaline circulation (THC)

*The THC is a global-scale ocean circulation driven by the equator-to-pole surface density differences of seawater.*

Different from the wind-driven ocean circulation, which is in the upper 1~2km, thermohaline circulation can extend to very deep ocean.
THC is a global ocean circulation driven by differences in the density of the sea water, which is controlled by temperature (thermal) and salinity (haline) variations.

Simplified schematic diagram of THC
The THC is often referred to as, or used interchangeably with, the deep Atlantic meridional overturning circulation (AMOC).

Strictly speaking, however, the AMOC represents the total “meridional overturning cell”, which includes both buoyancy and wind effects, whereas THC is buoyancy driven deep ocean circulation.

AMOC – an important component of global THC.
Shallow meridional overturning circulation in the Indian Ocean - *Wind driven*

Indian Ocean Shallow MOCs: Also referred to as the *Subtropical Cells*
Shallow meridional overturning circulation in the Pacific Ocean—Wind driven

The STCs carry cool **subtropical thermocline water into the tropics**. The two cells account for almost **30 Sv of overturning**.

Pacific Ocean Shallow MOCs: Also referred to as the **Subtropical Cells**
THC Climatic effect:
Observed meridional ocean heat transports (MOHT) in the World’s oceans

(Zonal and annually averaged MOHT)

Question: Major differences?

The Atlantic Ocean: All northward in both hemispheres
The MHT in the Pacific is roughly symmetric along the equator.

In the Indian Ocean, the MHT is southward everywhere due to the net heat gain in the northern Indian Ocean.

In the Atlantic, MHT is northward everywhere due to the THC. At 24°N, the northward MHT is about 1.2 PW (PW = 10^{15} W)

(Trenberth and Caron, 2001, J. Climate)
Atlantic Ocean

Surplus Heat Energy Transferred
By Atmosphere And Oceans
To Higher Latitudes

Watts m$^2$

North  Latitude  South

Net Shortwave
Net Longwave
THC: complex structure

Schematic

Observations
What will happen if the THC (often referred to as Atlantic MOC - AMOC) slows down or collapses?

Changes of AMOC – changes in climate (such as the Younger Dryas cold event: 12,800 ~ 11,500 yrs BP, is thought to be associated with the collapse of AMOC)
If the AMOC is shut down, a cooling is induced in most part of the Northern Hemisphere, and the cooling in the Nordic Sea and Greenland can be as much as 10°C. On the other hand, the Southern Hemisphere would experience a weak warming due to the reduced northward heat transport by the MOC. Stouffer et al., J Climate, 2006 (surface temperature anomalies)

The SST anomaly will force atmospheric response – affecting global climate.
AMOC: Mechanisms

The AMOC is a major part of the global general ocean circulation & it supplies deep water for all ocean basins – its variability is a key element in global climate system.

Extensive studies – understand AMOC’s transport (strength) variability, and its underlying mechanisms.

The understanding is incomplete – complexity of its dynamics
Within the Atlantic basin, driven by:
(a) surface buoyancy flux in the North Atlantic: EQ-pole density contrast;
(b) deep water formation, mixing that provides energy for the upwelling branch;
(c) upper ocean transport from the Southern Atlantic – via EQ region into the North Atlantic.

Complexity - AMOC is also influenced by:
Winds over the Atlantic Ocean & Southern Ocean; water transport from the southern ocean, basin geometry, bottom topography, advection, and small scale processes…
Complexity of THC - AMOC:
Not simply 2-dimensional zonally mean. Rather, It involves 3-dimensional oceanic dynamical adjustment processes.

Complexity: The poleward thickening of the upper layer along the eastern boundary due to Kelvin-wave adjustments, the westward propagation of the coastal structure by Rossby waves, and their damping by mixing; the resulting zonal pressure gradient causes the surface MOC branch to converge into the northern basin near the eastern boundary.

Will be covered in ATOC5061