ATOC 5051 INTRODUCTION TO PHYSICAL OCEANOGRAPHY

Class 27: Thermohaline Circulation

Objectives of today's class:

1. Thermohaline circulation (THC): concept, structure & climatic effect;
2. Mechanism description;
3. Final review guideline.

1. Thermohaline circulation (THC)

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

Thermohaline

Temperature → Density

Salinity → Density

Heat flux

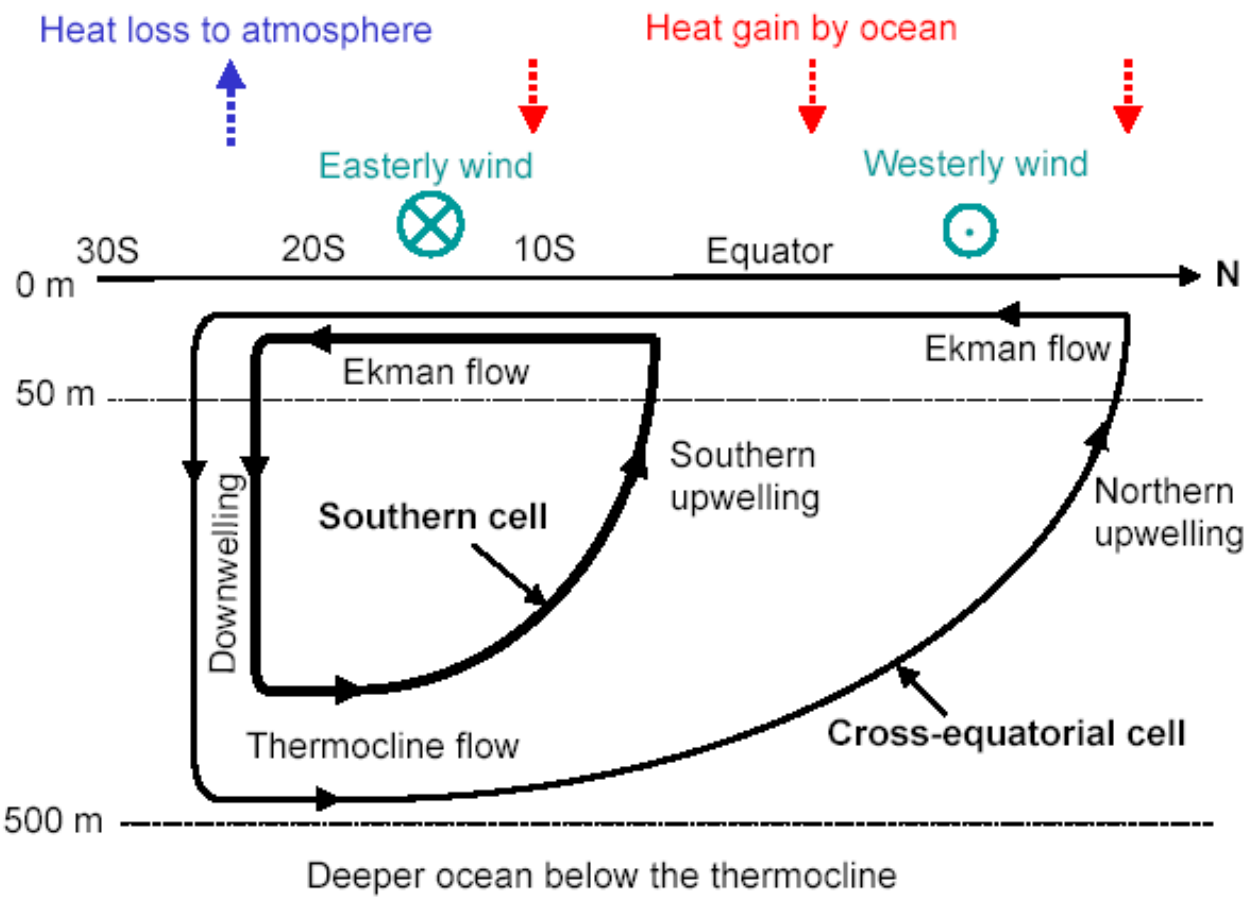
freshwater flux

Different from the wind-driven ocean circulation, which is in the upper 1~2km, thermohaline ciruclation can extend to very deep ocean.

The THC is often referred to as, or used Interchangeably with, the deep Atlantic meridional overturning circulation (AMOC).

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

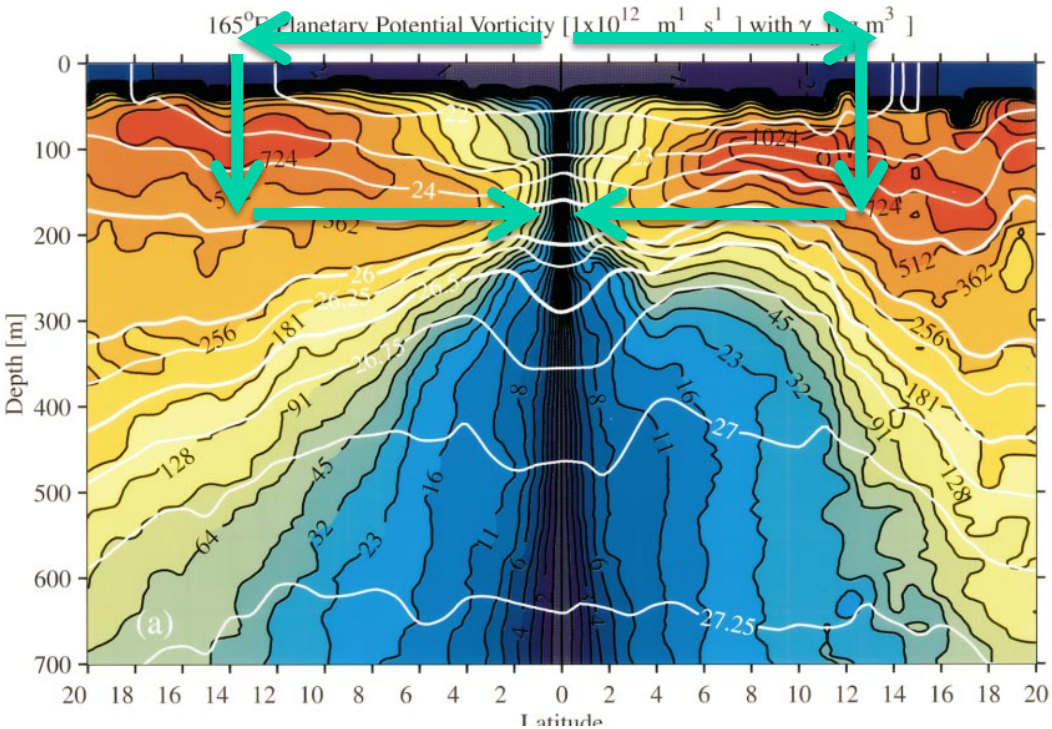
Shallow meridional overturning circulation in the Indian Ocean-*Wind driven*



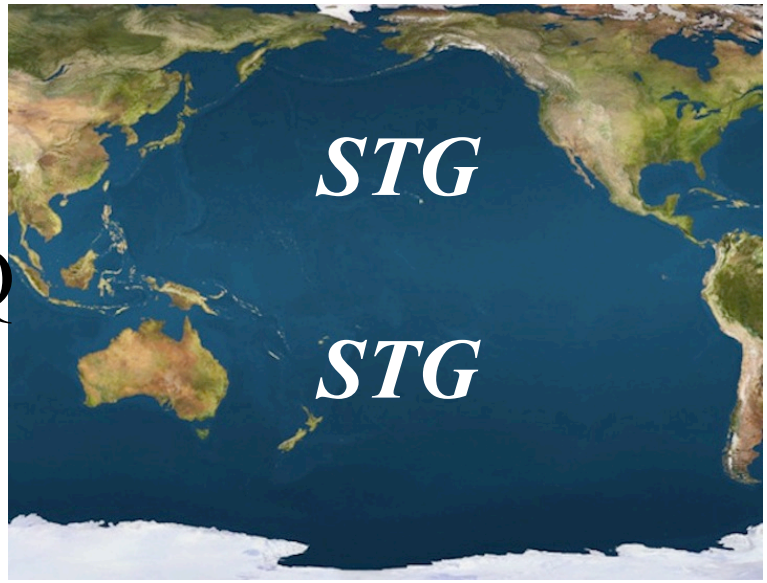
Asian continent

Indian Ocean Shallow MOCs: Also referred to as the ***Subtropical Cells***

Shallow meridional overturning circulation in the Pacific Ocean-***Wind driven***

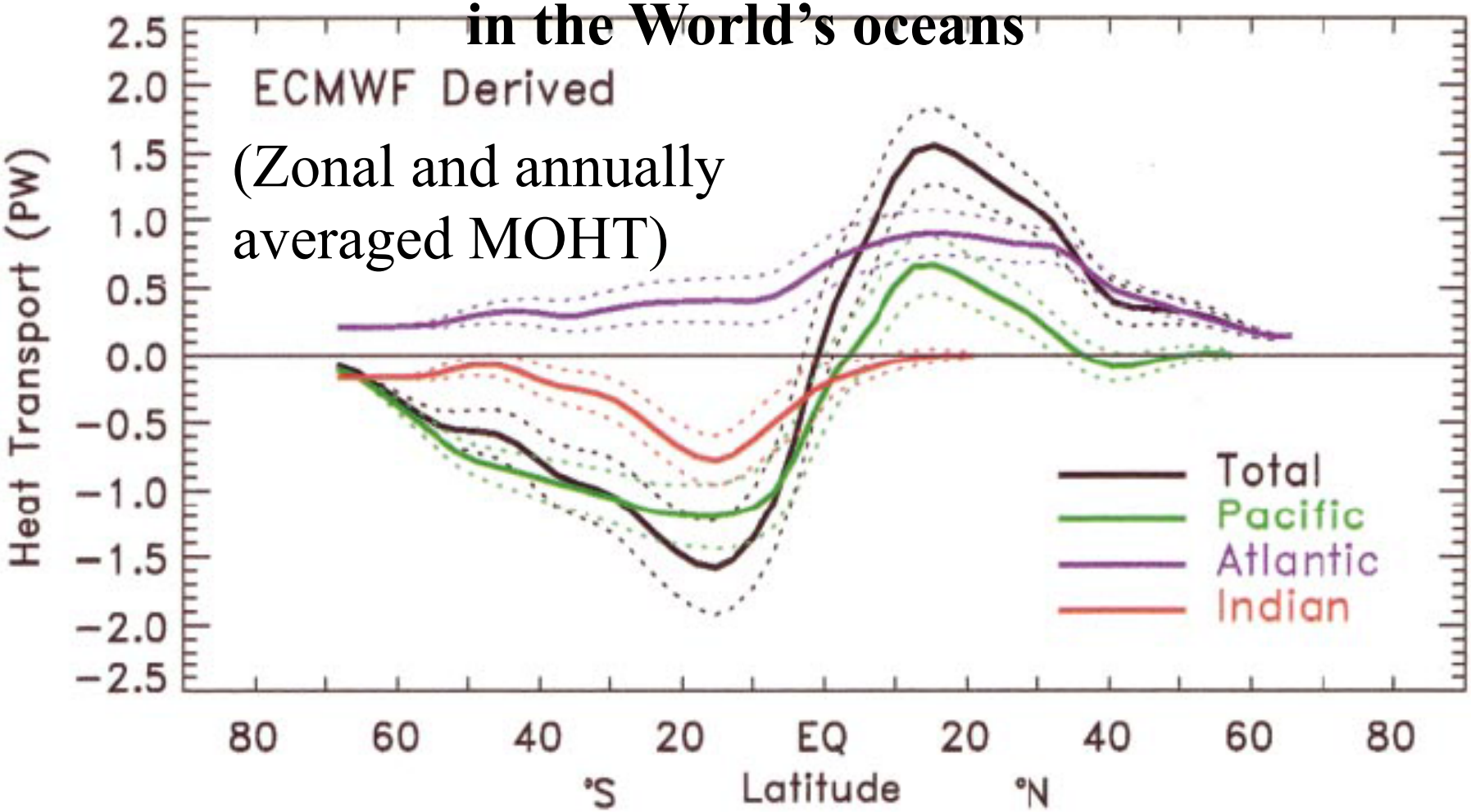


EQ



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



Question: Major differences?

The Atlantic Ocean: All northward in both hemispheres

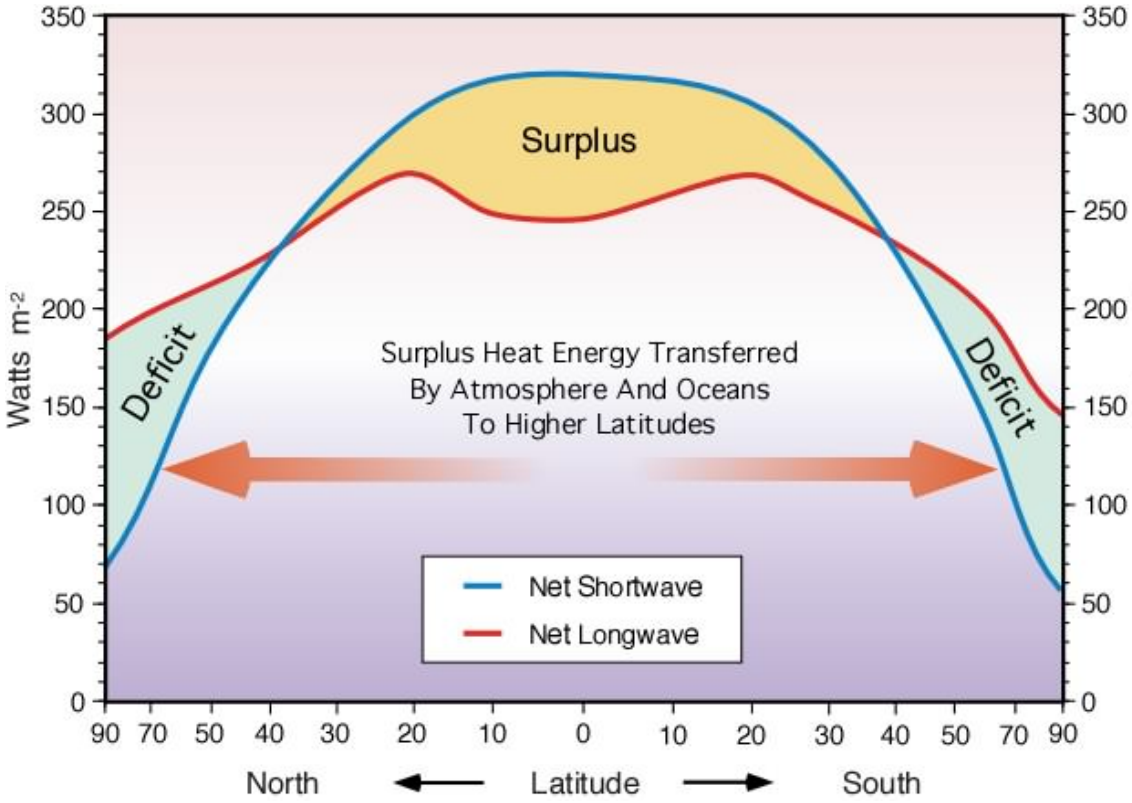
The MHT in the Pacific is roughly symmetric along the equator.

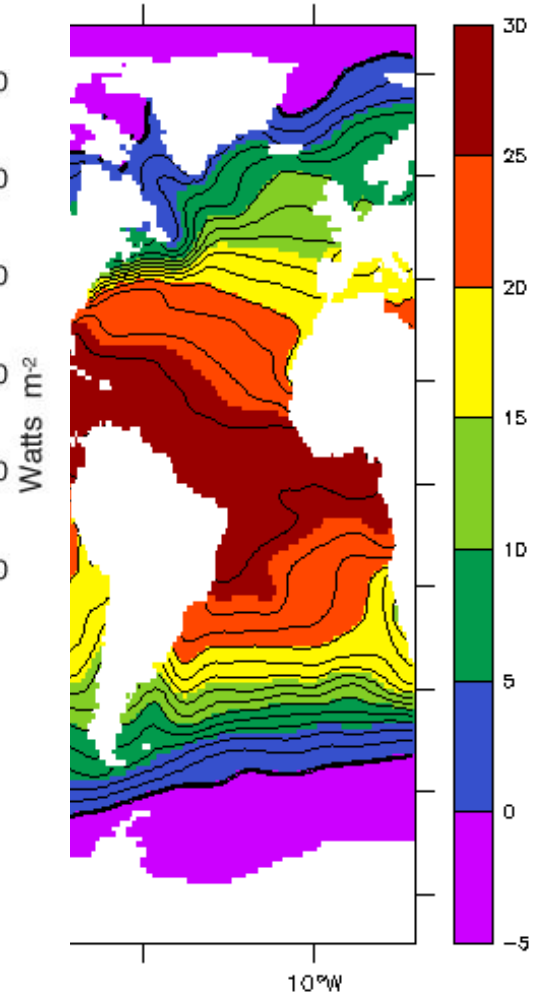
In the Indian Ocean, the MHT is southward everywhere due the net heat gain in the northern Indian Ocean.

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

(Trenberth and Caron, 2001, J. Climate)

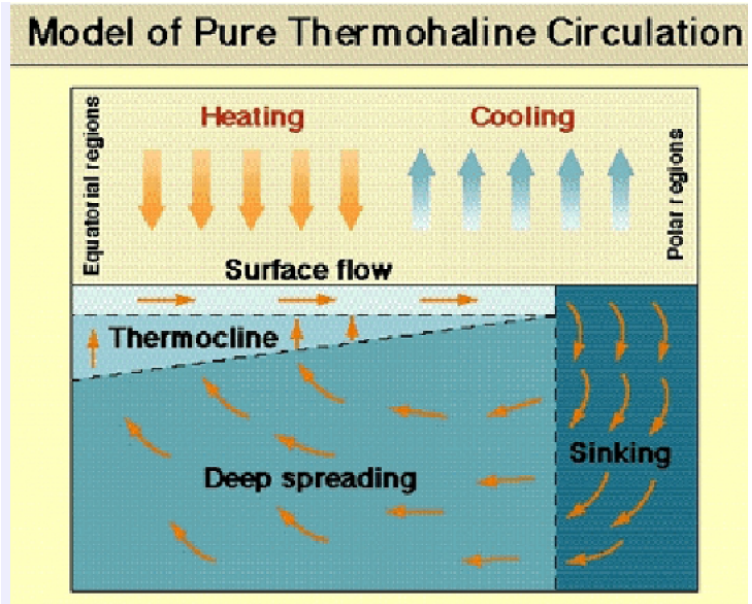
Atlantic Ocean

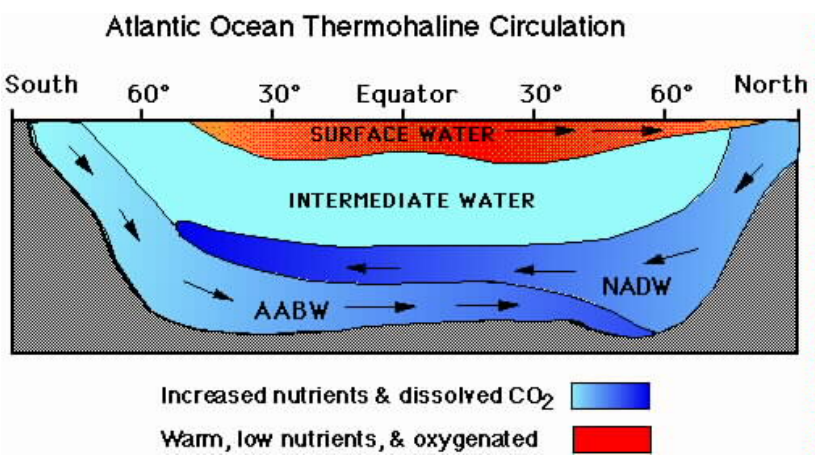




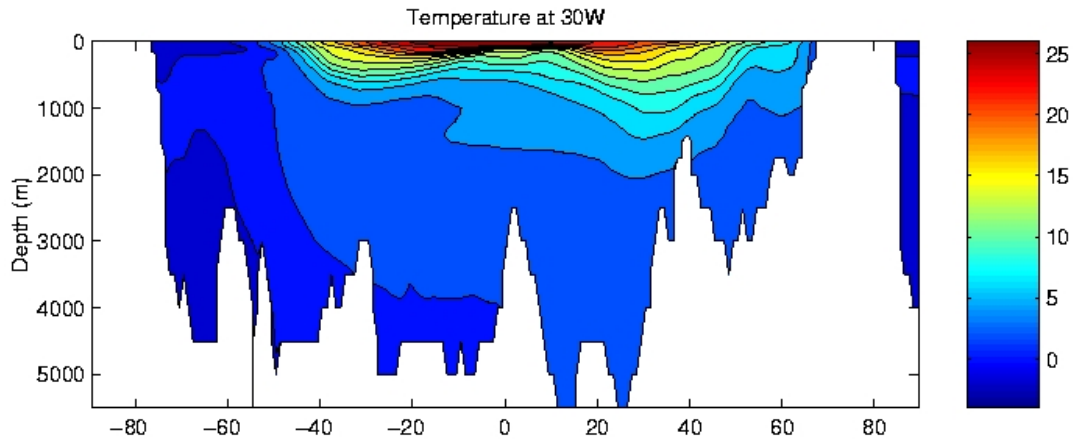
THC: complex structure

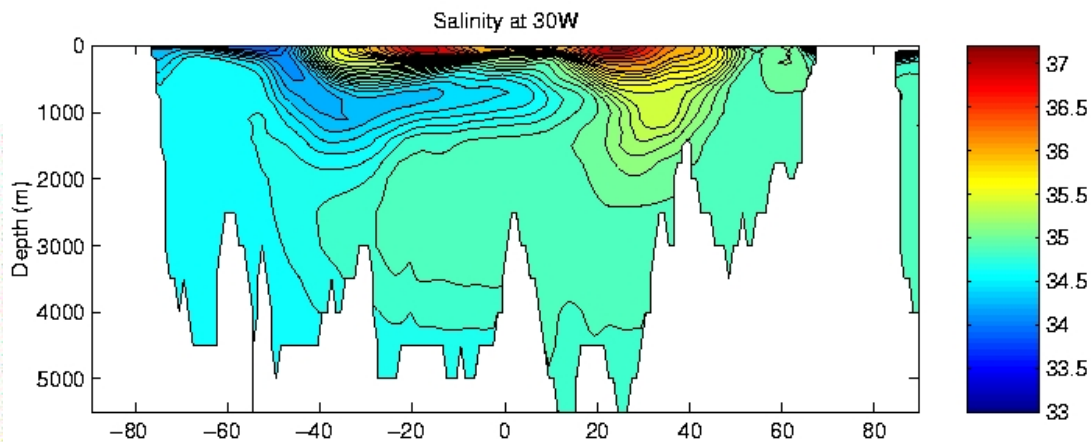
Schematic



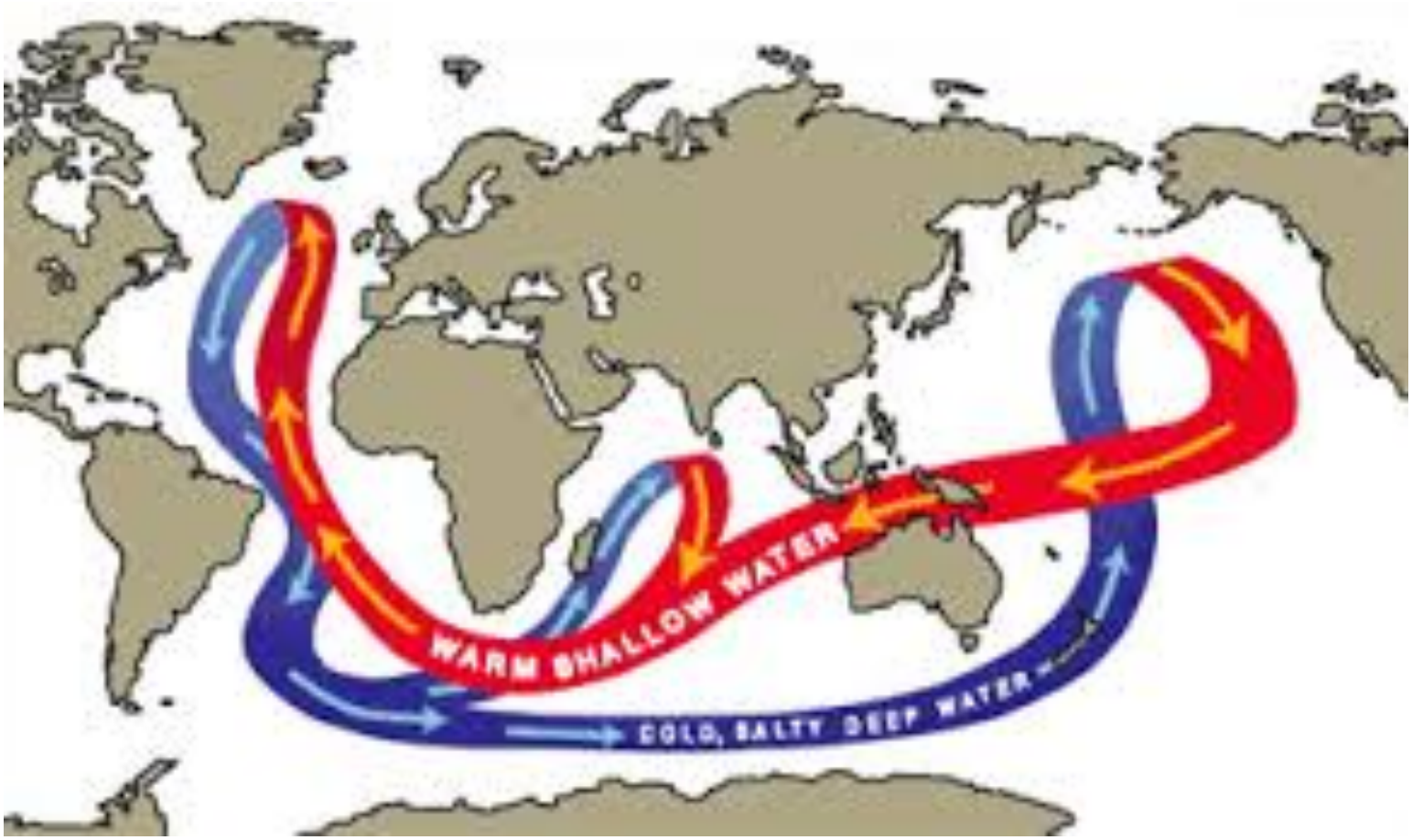


Observations



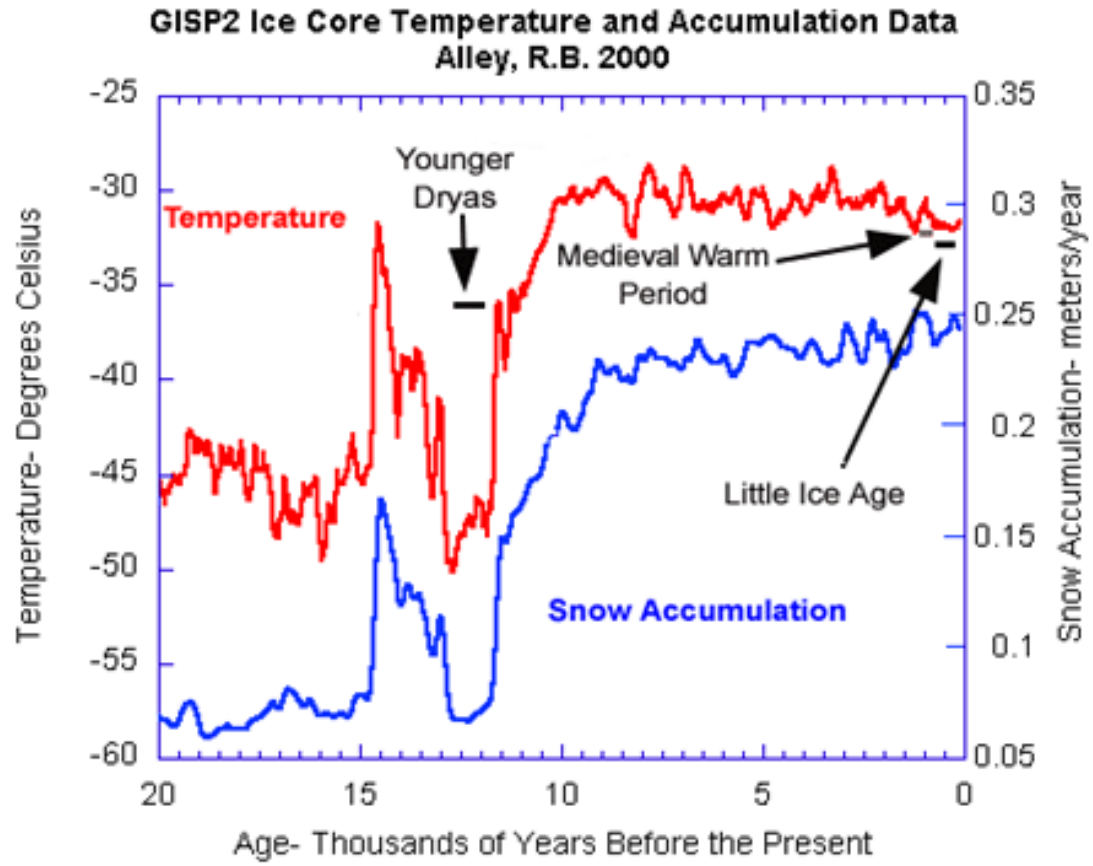


THC is a global ocean circulation driven by differences in the density of the sea water, which is controlled by temperature (thermal) and salinity (haline) variations.



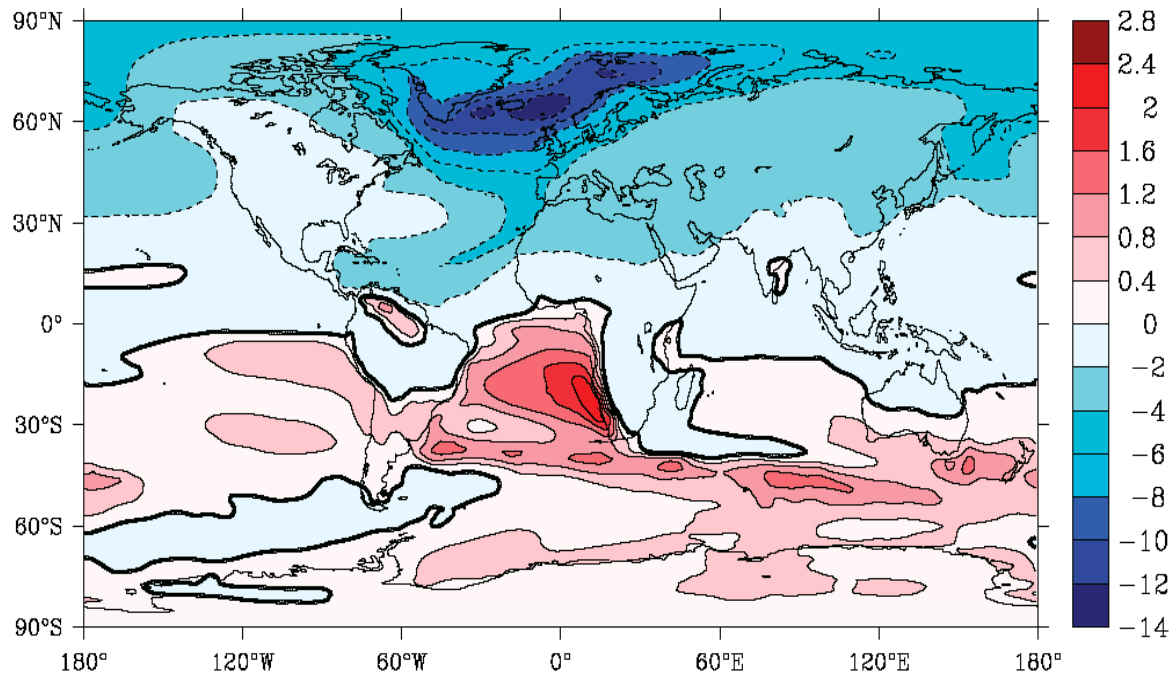
What will happen if the THC (often referred to as Atlantic MOC - AMOC) slows down or collapses?

Changes of AMOC – changes in climate (such as the Younger Dryas 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

This SST anomaly will force atmospheric response – affecting global climate.

2. 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

Complexity of THC - AMOC:

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 – 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.

Schloesser Fabian, et al. 2012:
Dynamics of the Atlantic meridional overturning circulation. Part 1: Buoyancy-forced response. Progress in oceanography.
Schloesser Fabian, et al. 2013: Dynamics of the Atlantic meridional overturning circulation. Part 2: Forcing by winds and buoyancy

3. Final review

Final exam: Materials before the midterm: 35%;
Materials after the midterm: 65%

Chapter 1: Basins and Properties of Seawater

Properties: major S, T (P);
Each basin's character (not detailed numbers):
say, the Pacific (largest); Atlantic, Indian, and Arctic (dilution basin)
[Sound and light: understand]

Chapter 2: Ocean observations

Only the observed ocean circulation parts (no test on the observational methods): Major western boundary currents, ACC, Equatorial current systems (SEC, ECC, EUC, NEC);
Concentration basin, dilution basin.

Chapter 3: Dynamics

Understand equations; know balance of forces
For example:
geostrophic balanc, hydrostatic balance; Rossby number, Ekan Number; know how to perform scale analysis.

Chapter 4: Ocean waves

Dispersion relations; Understand the wave characters, symmetric property, existing frequency, & excitation by winds.

Chapter 5: Mixing processes

Stratification, double diffusion, salt fingering, layering;
Instabilities: barotropic, baroclinic, and Kelvin-Helmholtz;
Criteria, energy source, etc.

Chapter 6: ENSO

Atmosphere-ocean circulation anomalies for normal condition, El Nino and La Nina;
Understand the 3 existing mechanisms.

Chapter 7: Thermodynamics

Understand the mixed layer temperature equation and processes; know how to explain observations using this equation.

Know the processes that affect sea surface salinity.

Chapter 8: Wind-driven Ocean Circulation

Explanation of Subtropical Gyre:
interior solution, Sverdrup balance; scaling, Western boundary solution; physical differences between them.

Stommel's western boundary layer; Munk's western boundary layer; what's the major differences?

Coastal and EQ ocean circulations:

Wind-driven eastern boundary circulation: current (coastal jet) and eastern boundary undercurrent; offshore flow; sea level, thermocline; upwelling, nutrients, coastal trapping scale.

Chapter 9: THC – AMOC (today's lecture)

THC: concept & climatic impacts; structure and dynamical complexity.