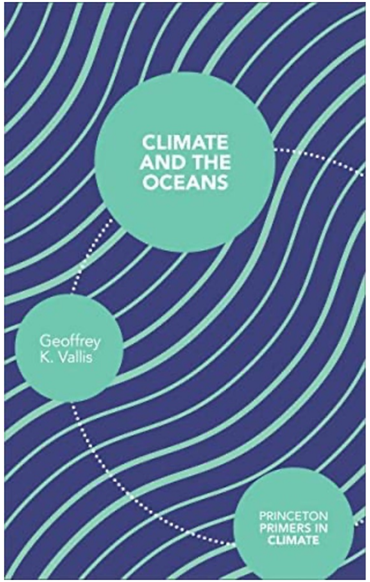
Oceanic Influence on the Climate and its Variability



Climate and the Oceans – Geoffrey Vallis
Chapter 5 and Chapter 6

Rachel Wegener
AOSC 680

Learning Goals for Today

- Be able to describe how the ocean stores heat
- Be able to describe how the ocean transports heat
- Understand how the effect of the ocean is different based on time scale
- Describe ENSO even better than you can right now

By what mechanisms does the ocean influence climate?

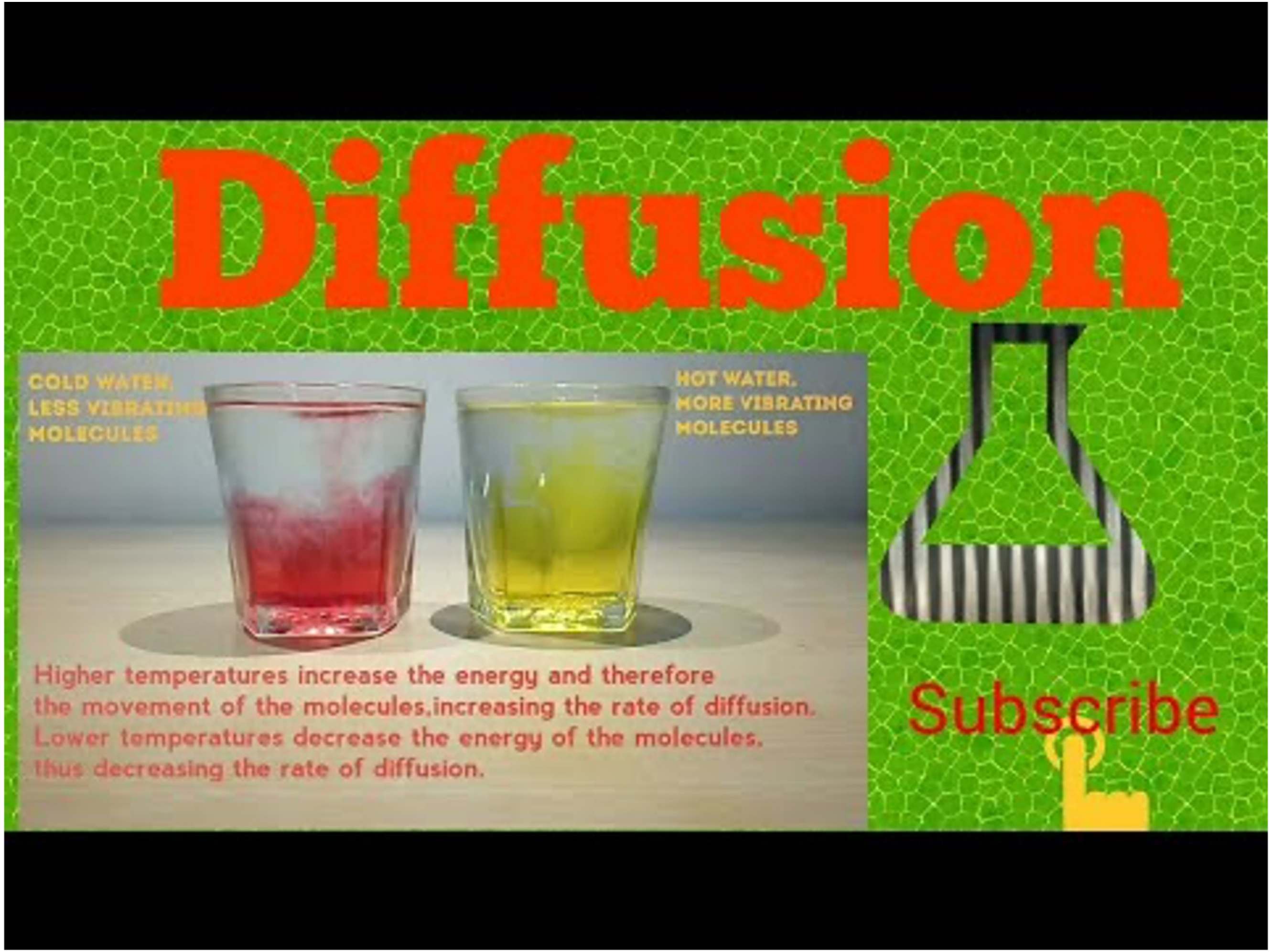
What effect does this have? → *Timescale dependent*

1. Daily - lag in temperature maximum/minimum
2. Seasonal - moderates seasons; lag in temperature maximum/minimum
3. Interannual - ENSO, NAO

How does the ocean **store** heat?

How does the ocean store heat?

"... the ocean has an effective heat capacity that is about 100 times greater than that of land."
(Vallis, p. 109)


Diffusion
COLD WATER.
LESS VIBRATING
MOLECULES
HOT WATER.
MORE VIBRATING
MOLECULES
Higher temperatures increase the energy and therefore
the movement of the molecules,increasing the rate of diffusion.
Lower temperatures decrease the energy of the molecules.
thus decreasing the rate of diffusion.
Subscribe

The ocean has absorbed more than ? % of the heat gained by the planet between 1971 and 2010

Cheng L, et al. (2017) Improved estimates of ocean heat content from 1960 to 2015.

Where is all this heat getting stored?

0.33 = 125/375
0.33 = 5/15
Atlantic stores ⅓ of heat in surface and lower ocean

~300 ZJ

~375 ZJ

~15 ZJ

0.77 = 300/(375+15)

~75% of heat stored in the surface 700m

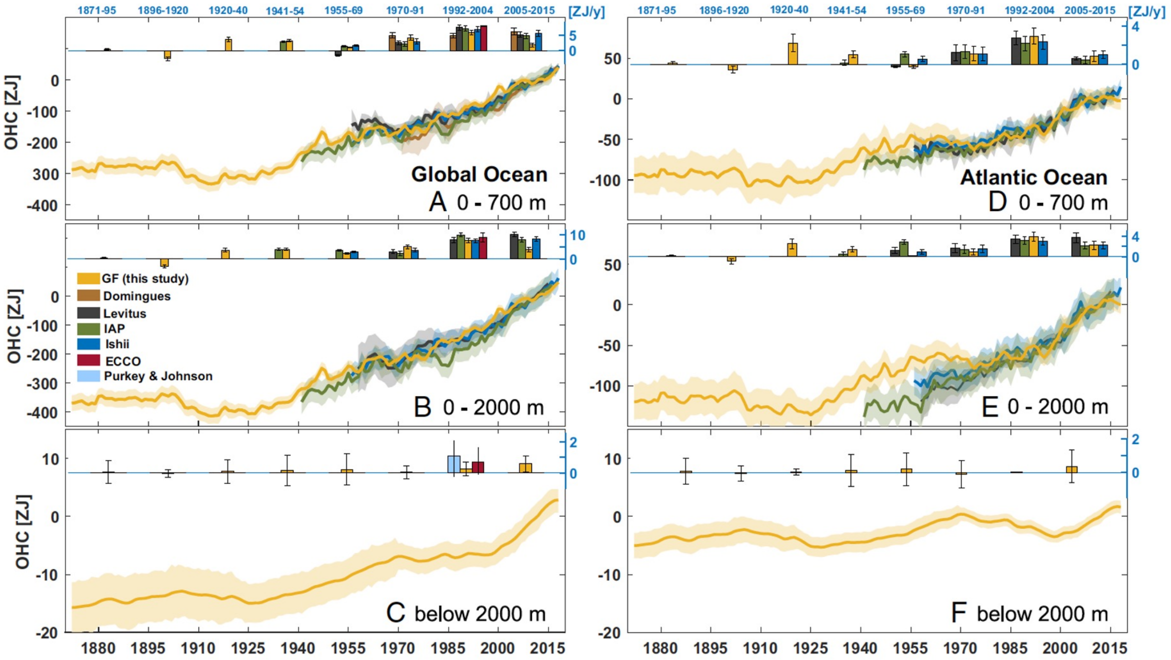


Fig. 1. Global and Atlantic OHC timeseries and trends for GF and observational estimates relative to 2006–2015. Timeseries of global (*A–C*) and Atlantic (*D–E*) OHC changes in zetajoules (1 ZJ = 10^{21} J): (*A* and *D*) top 700 m, (*B* and *E*) top 2,000 m, and (*C* and *F*) below 2,000 m. The OHC timeseries include the reconstruction based on GFs (orange) and direct measurements from the NCEI (2) (black), the IAP (1) (green), Ishii et al. (20) (blue), and Domingues et al. (updated from refs. 21 and 22) (brown). The latitudinal range for all products used here is 80° S to 80° N, except for the product from Domingues et al. (21), which uses 65° S to 65° N. The shading represents the uncertainty associated with each estimate (*Materials and Methods*). *Insets* above each panel represent the linear trends and associated error (zetajoules per year) over different periods for each best estimate available (see text). For the global ocean (*A–C*), we include trends from the ECCO-GODAE solution (red) and for the deep ocean (*C*) the updated estimates from refs. 1, 23, and 24 (cyan).

~100 ZJ

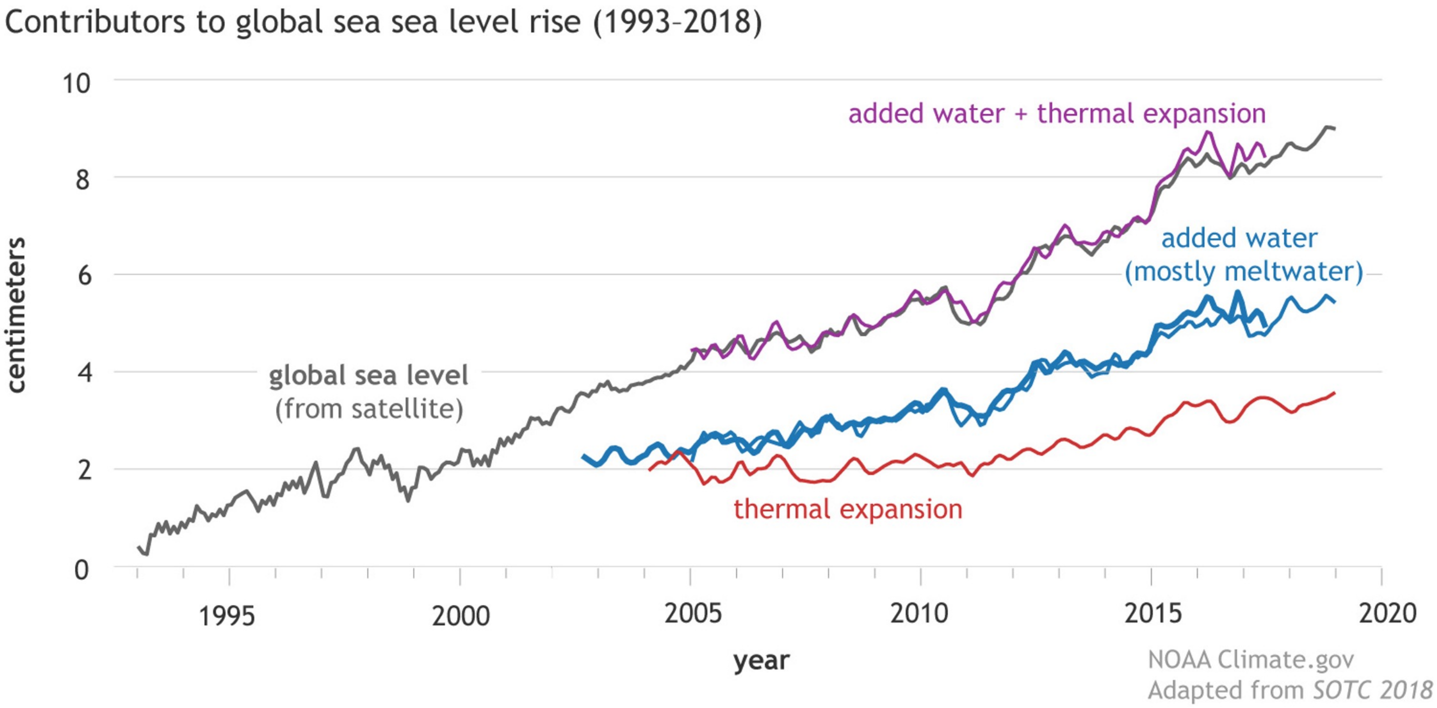
~125 ZJ

~5 ZJ

(Zanna, et al. 2018 PNAS)

Sea Level Rise

Thermal Expansion is a significant contributor to sea level rise



https://www.climate.gov/news-features/understanding-climate/climate-change-global-sea-level

How does the ocean **move** heat?

Observations?

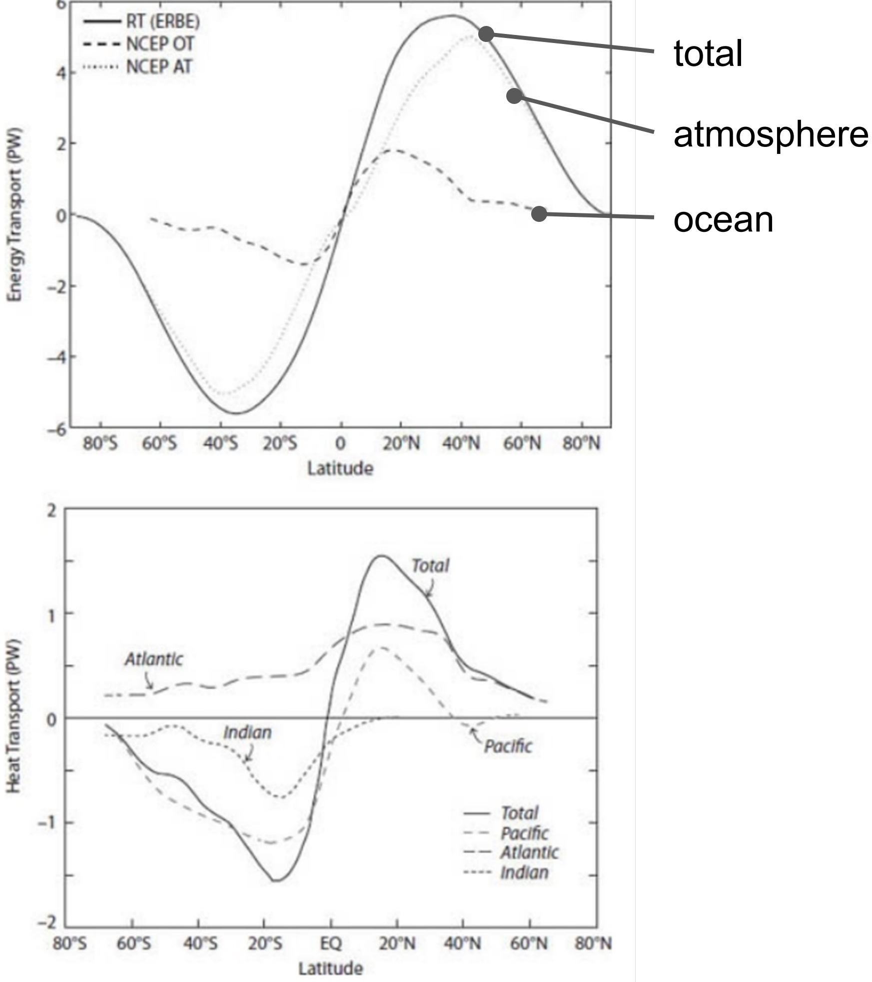


Figure 5.3. Upper panel: Heat transport in the total atmosphere-ocean system (solid line), in the ocean (dashed line), and in the atmosphere (dotted line). Lower panel: Oceanic heat transport, subdivided into the various basins. Source: Trenberth and Caron, 2004.

https://cimi.org/blog/what-is-a-gyre-and-how-does-it-work/

Ocean Circulation

Ocean Circulation

Driven by?

Meridional Overturning Circulation (MOC)

Driven by: wind-driven upwelling

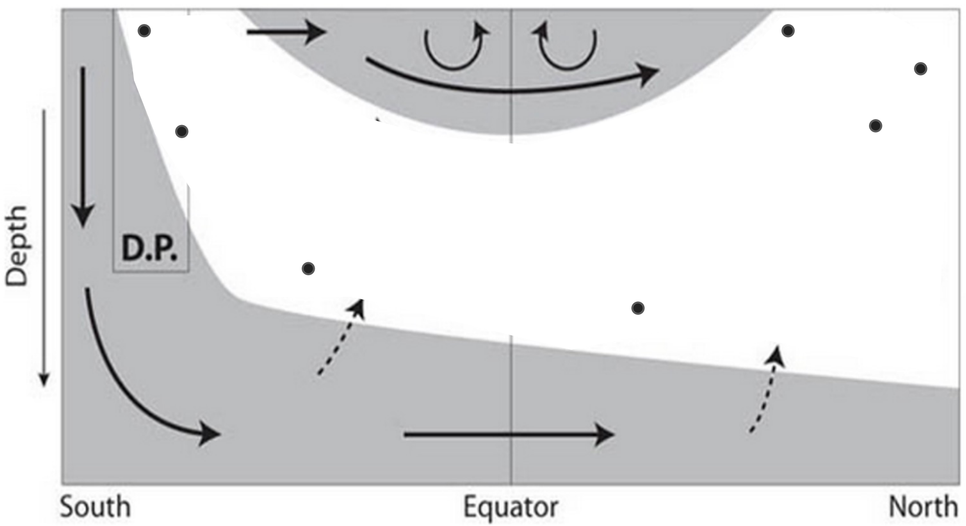


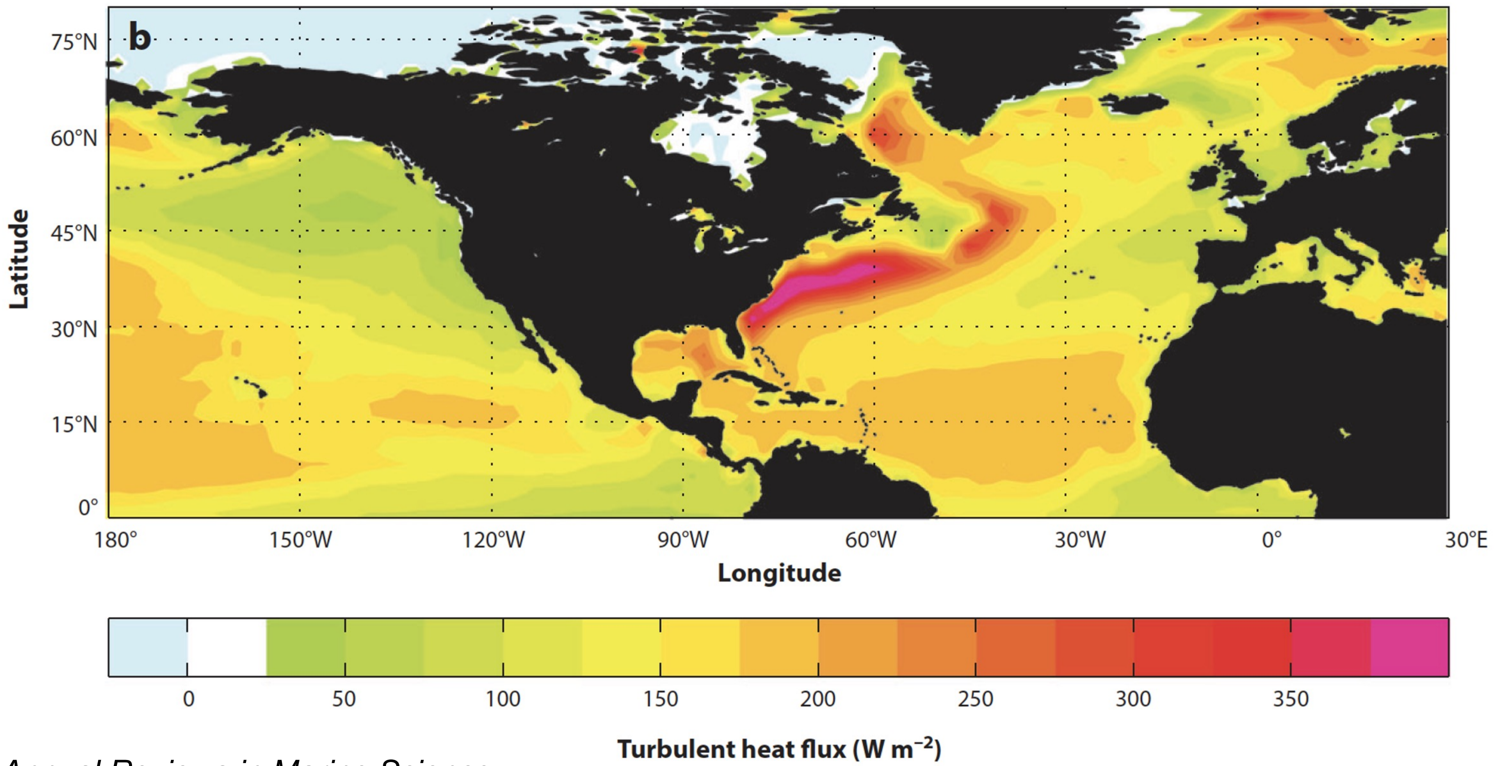
Figure 4.8. Schematic of the meridional overturning circulation, most applicable to the Atlantic Ocean (D.P. indicates the Drake Passage, the narrowest part of the ACC). The arrows indicate water flow, and dashed lines signify water crossing constant-density surfaces, made possible by mixing. The upper shaded area is the warm water sphere, including the subtropical thermocline and mixed layer, and the lower shaded region is Antarctic Bottom Water. The bulk of the unshaded region in between is North Atlantic Deep Water.

Driven by: buoyancy

Driven by: mixing

Draw the direction of motion you expect at each of the black dots on the diagram

Wind Driven Gyres Move Heat



Palter, 2015. Annual Reviews in Marine Science
DOI: 10.1146/annurev-marine-010814-015656

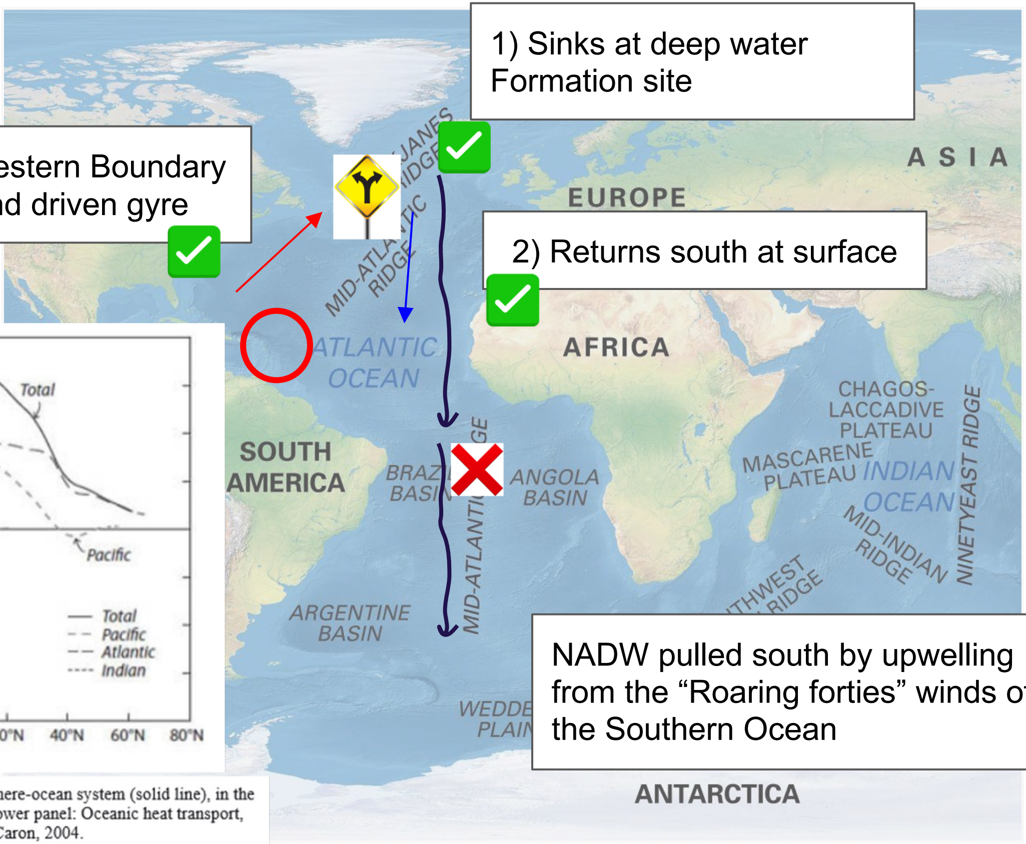
https://www.britannica.com/science/ocean-basin

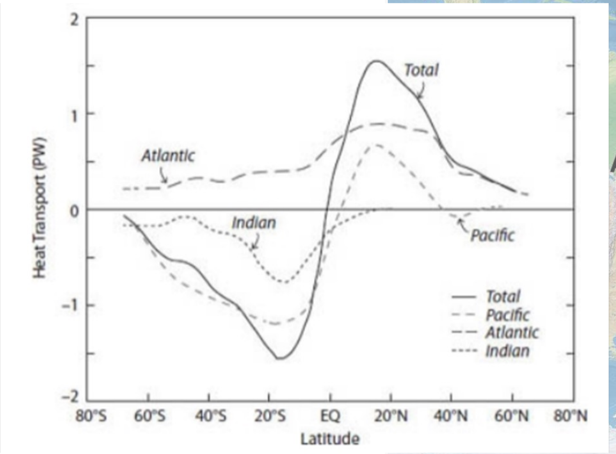
Tracing the path of some hot water at the equator

Moves north in Western Boundary Current due to wind driven gyre ✓

1) Sinks at deep water Formation site ✓

2) Returns south at surface ✓





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NADW pulled south by upwelling from the "Roaring forties" winds of the Southern Ocean ✗

Do we have deep water formation in the Pacific?

Is the heat transport poleward?

✓ = Yes

✗ = No

What are the **effects** of the ocean storing and moving heat?

Vallis (5.1)

Looking at Damping with some Math

How fast the temperature changes

heating

cooling

$$C\frac{dT}{dt} = S - \lambda T$$

Rate of cooling depends on the temperature of the object, but the heating rate does not

Looking at Damping with some Math

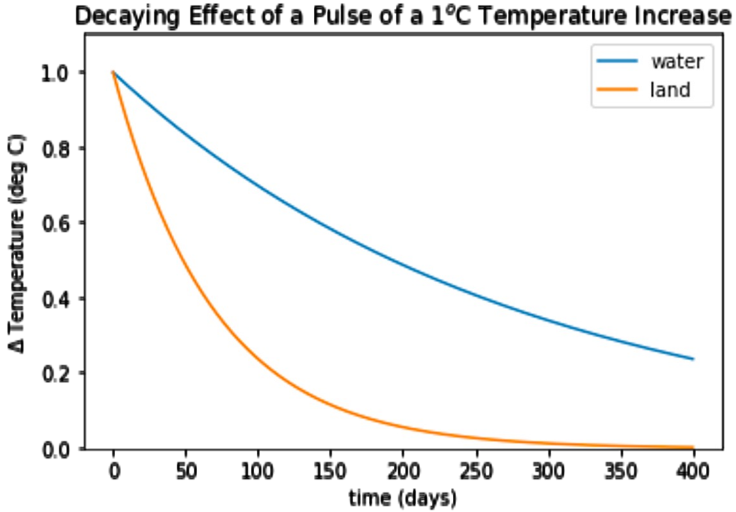
“Thermal inertia”

heating cooling

$$T = \frac{S}{\lambda} + T_o exp(-\frac{\lambda t}{C})$$

Exponential decay scale:
C/λ

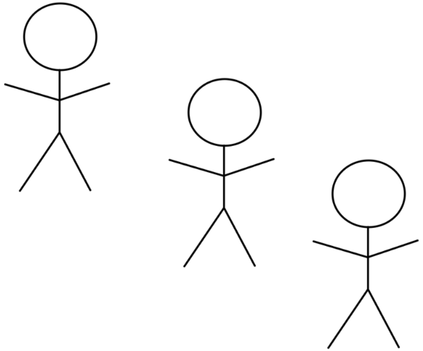
The effect of a small perturbation will take about a year to decay in the ocean



Can the Ocean Adjust? An Analogy to a Coffee Shop Line

Coffee shop makes your coffee in 2 minutes

"Heat Capacity" of the coffee shop



Whether or not the ocean can adjust to a heating source depends on the frequency of the heating source

Effect of Ocean Heat on Seasonal Cycle

Maritime climate

Continental climate

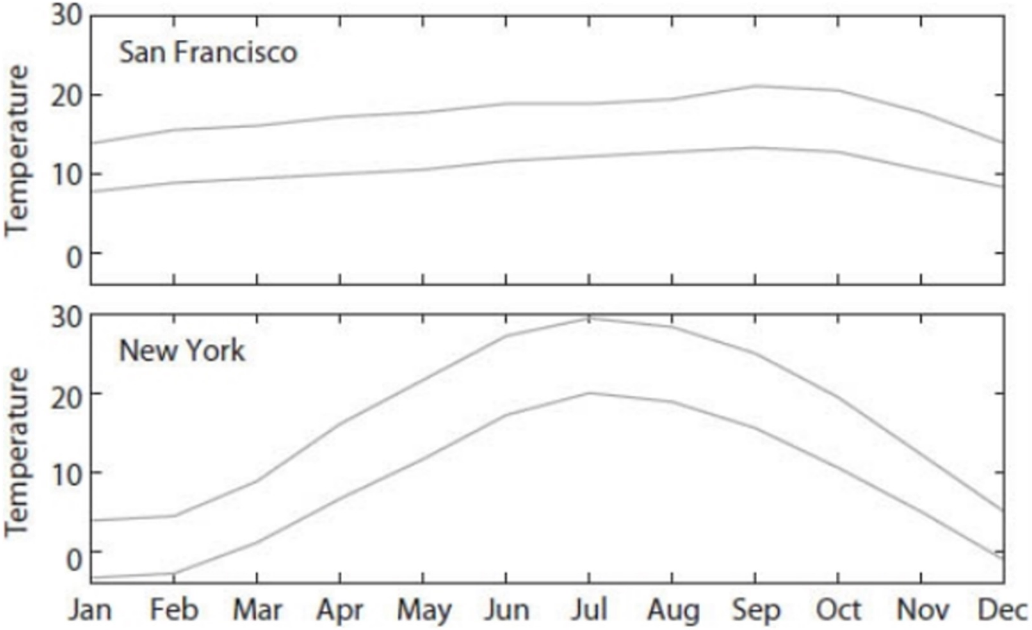


Figure 5.1. The seasonal cycle of temperature (°C) in San Francisco and New York. For each city, we plot the average low temperature and the average high temperature for each month. Note the much bigger range in New York and the maximum earlier in the year, in July rather than September.

Is the Gulf Stream responsible for Europe’s relatively moderate climate?

The Source of Europe’s Mild Climate

The notion that the Gulf Stream is responsible for keeping Europe anomalously warm turns out to be a myth

Richard Seager

If you grow up in England, as I did, a few items of unquestioned wisdom are passed down to you from the preceding generation. Along with stories of a plucky island race with a glorious past and the benefits of drinking unbelievable quantities of milky tea, you will be told that England is blessed with its pleasant climate courtesy of the Gulf Stream, that huge current of warm water that flows northeast across the Atlantic from its source in the Gulf of Mexico. That the Gulf Stream is responsible for Europe’s mild winters is widely known and accepted, but, as I will show, it is nothing more than the earth-science equivalent of an urban legend.

This is not to say that there is no climatological mystery to be explained

(Seager, 2006. American Scientist)

“the importance of the Gulf Stream in establishing Europe’s warmth relative to the zonal mean has evoked strenuous debate among oceanographers and climate scientists for more than a decade.”

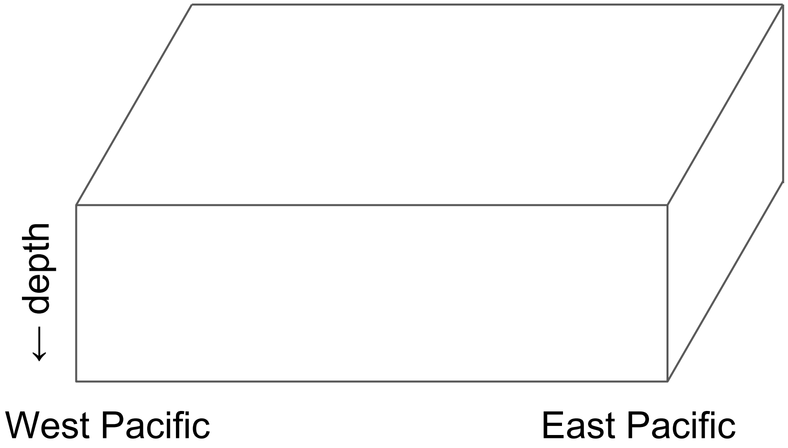
Palter, 2015. Ann. Rev. Mar. Sci.

El Niño Southern Oscillation (ENSO)

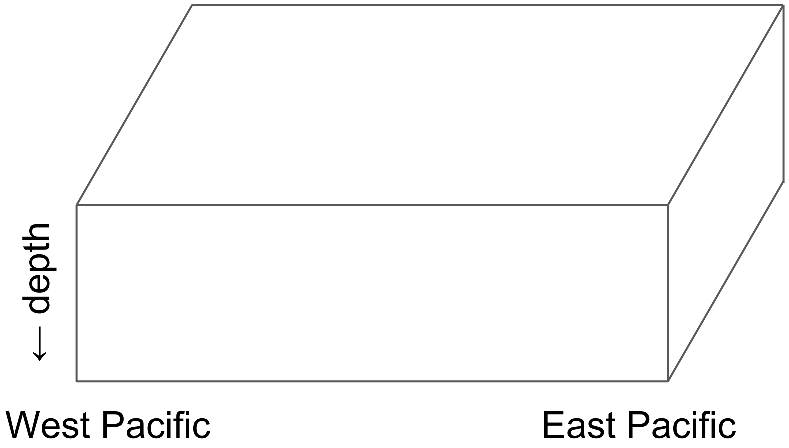
What does ENSO look like?

Label:

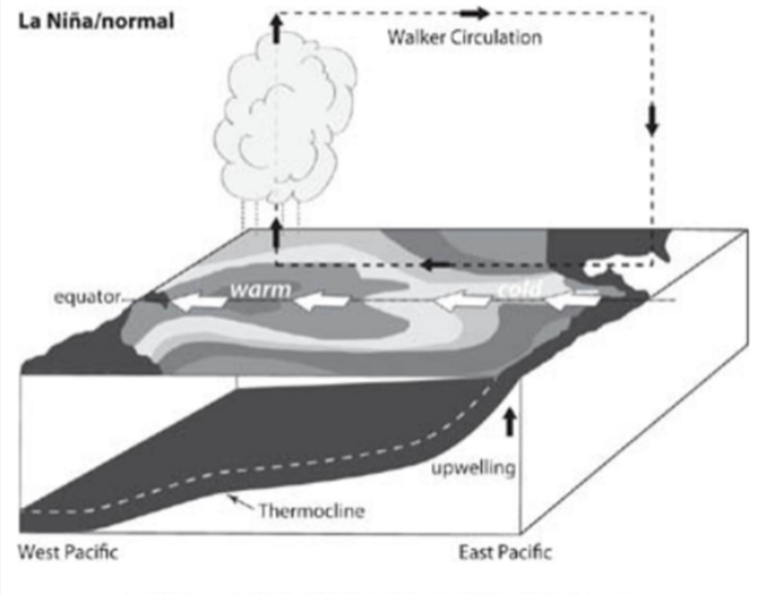
- Approximate SST contours
- Direction of surface winds
- Direction of upper level winds
- Atmospheric convective zone
- The thermocline depth

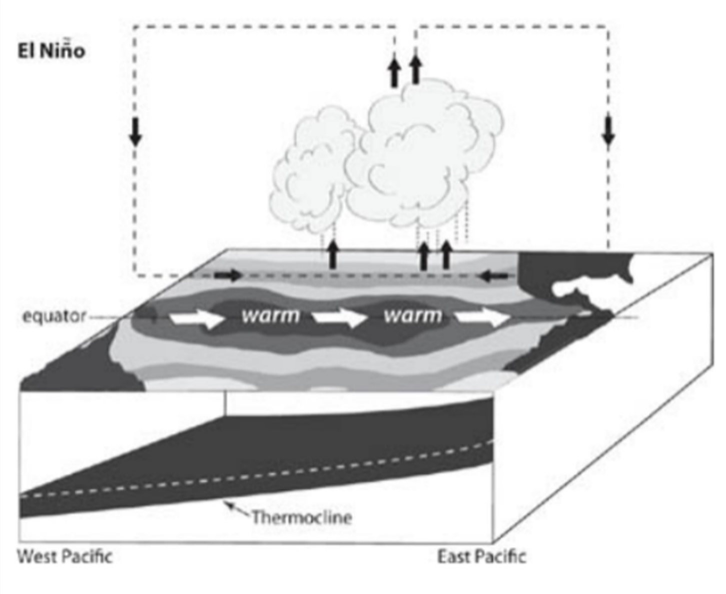


La Niña/Normal State



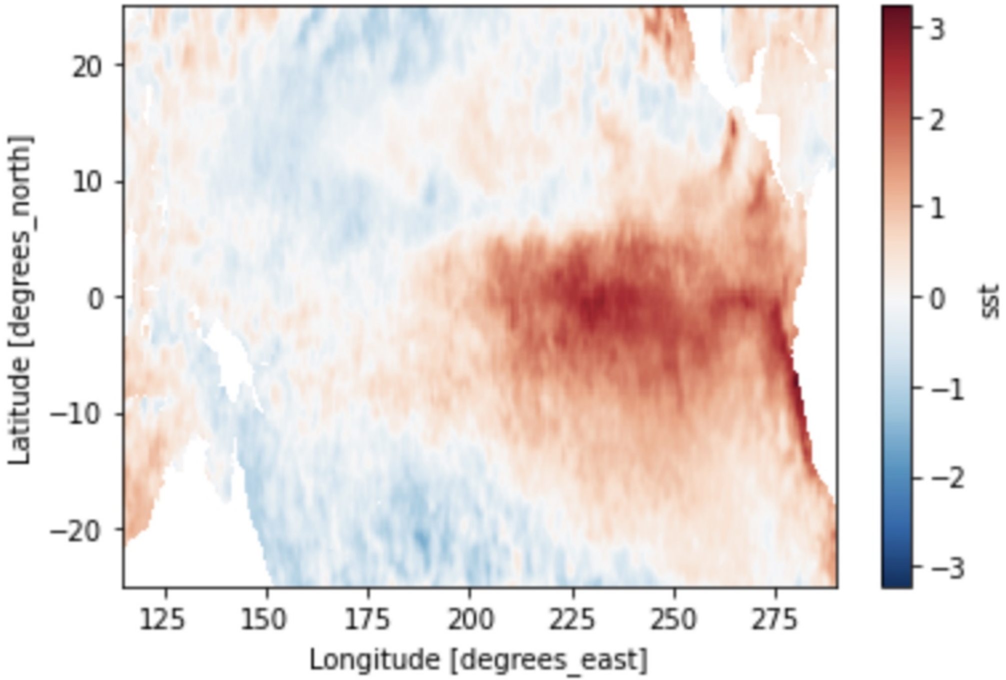
El Niño Year


La Niña/normal
Walker Circulation
warm
cold
equator
upwelling
Thermocline
West Pacific
East Pacific


El Niño
warm
warm
equator
Thermocline
West Pacific
East Pacific

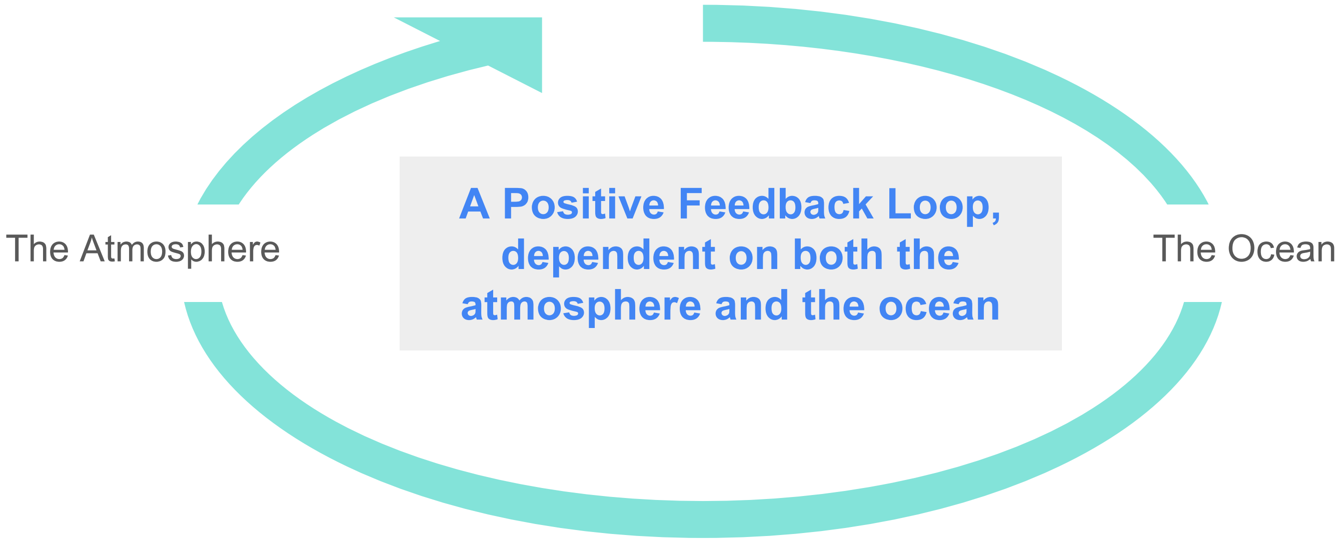
El Niño is an **Anomaly** State from the Climatological Mean

1982-1983 El Niño minus Normal state



What is the mechanism of ENSO?

ENSO is driven by



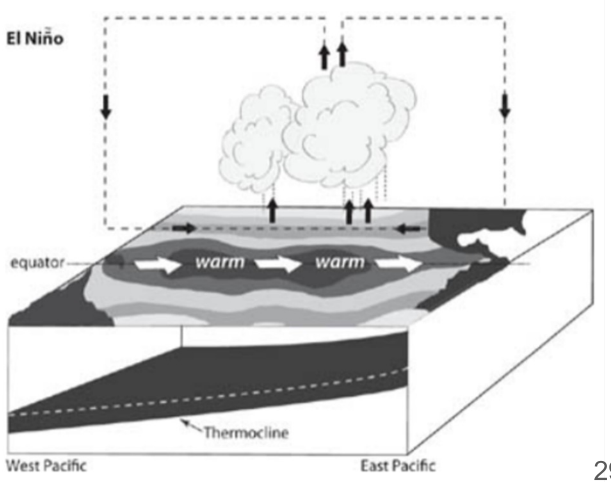
The Positive Feedback

Atmospheric effect
Oceanic effect

Trade Winds Weaken

Atmosphere affects the Ocean

Ocean affects the atmosphere

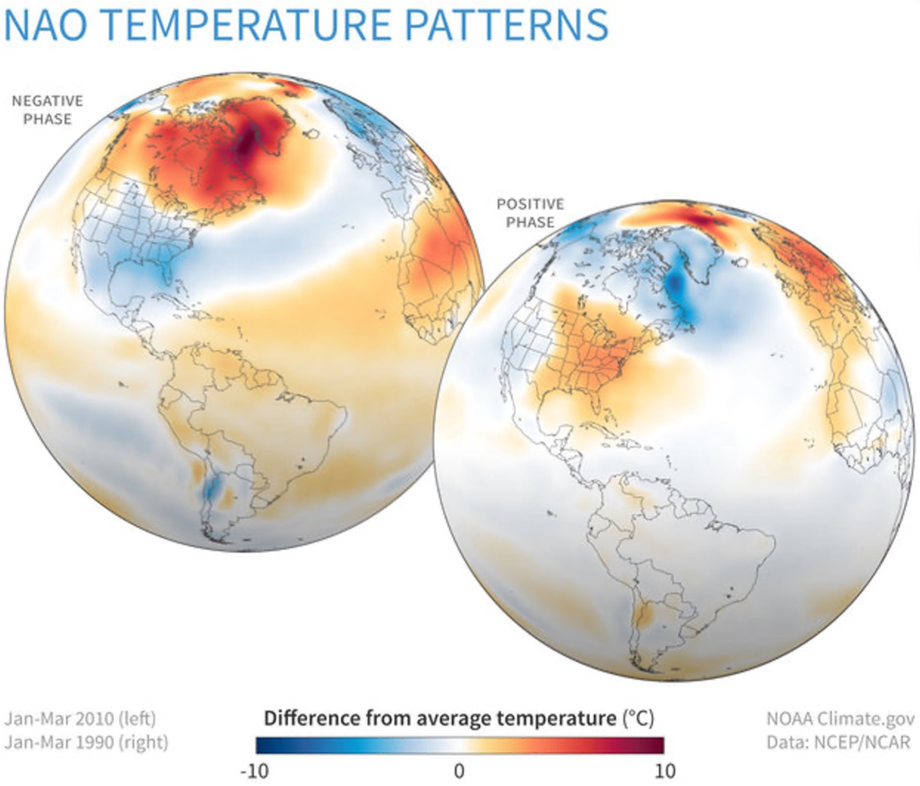


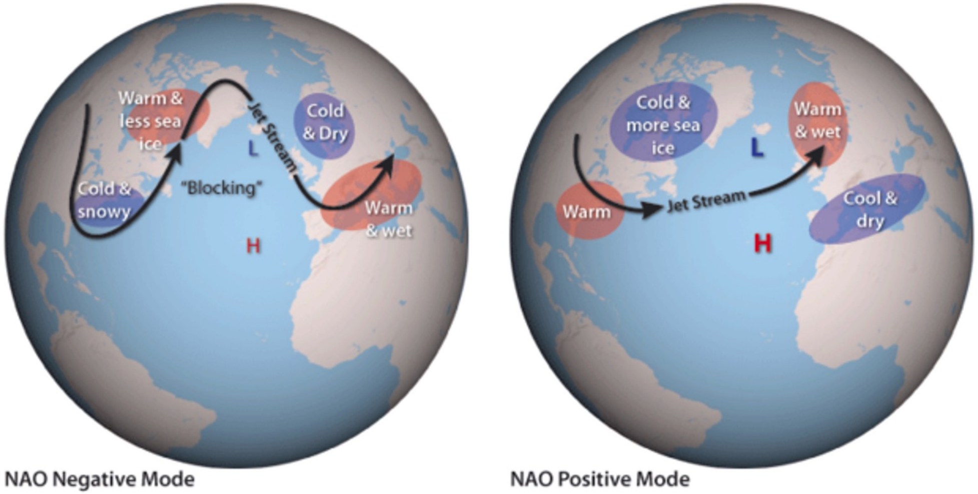
Effects of an El Niño

- Increase in global surface temperature
- Less rainfall in West Pacific; more rainfall in East Pacific
- Stronger and more southerly atmospheric storm track in the East Pacific
- Effects in the Atlantic: Suppressed hurricanes, more southerly storm track

https://www.climate.gov/news-features/understanding-climate/climate-variability-north-atlantic-oscillation

North Atlantic Oscillation (NAO)





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1) High heat capacity
2) Ocean has a mixed layer

1) Wind driven gyres
2) Meridional Overturning Oscillation (although transport isn't always equatorward!)

- Rate of temperature change depends on
  - Heat capacity of the system
  - The frequency of heating (daily cycle? Seasonal cycle?)
- The ocean moderates heating with a frequency up to a year. Beyond that the ocean adjusts

- An El Niño state is an anomaly from a climatology
- An El Niño state is driven by a positive feedback between the ocean and the atmosphere