Today's Lecture (Lecture 8): General circulation of the oceans

## Reference

Hartmann, *Global Physical Climatology* (1994), Ch. 2, 3, 6
Peixoto and Oort, Ch. 4, 6, 7, 14, 15
Kuhlbrodt et al. (2007), linked from course webpage

# 5.3 – General circulation of the oceans

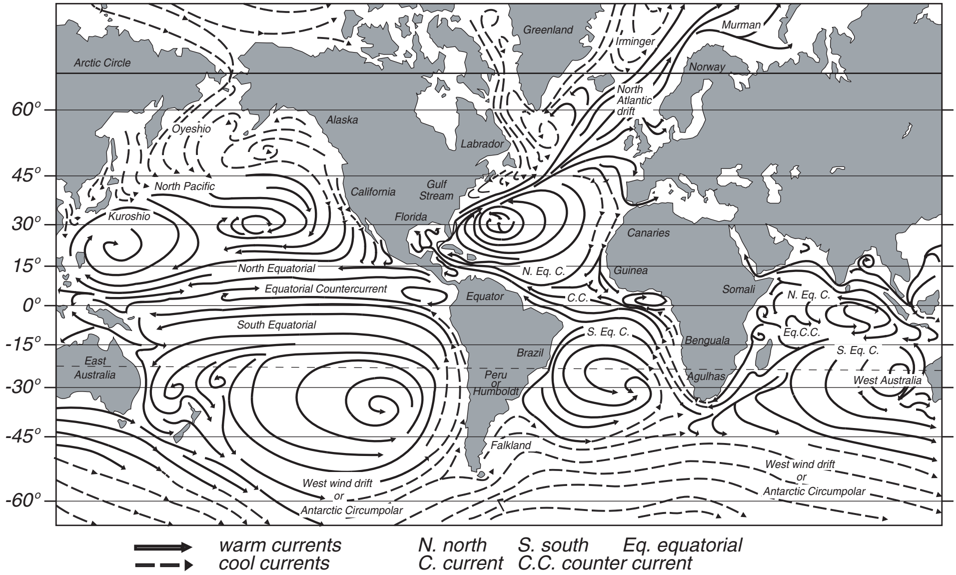



Figure: Stewart 2008

# Meridional overturning circulation

- Definition: meridional–vertical circulation ("meridional overturning circulation" or "thermohaline circulation")
- Function:

| | |
|---|---|
| meridional | heat transport |
| vertical | heat storage (also $CO_2$ storage) |

- Structure:
  - Upwelling processes that transport volume from depth to near the ocean surface
  - Surface currents that transport relatively light water toward high latitudes
  - Deepwater formation regions where waters become denser and sink
  - Deep currents closing the loop
- Timescales: millennial

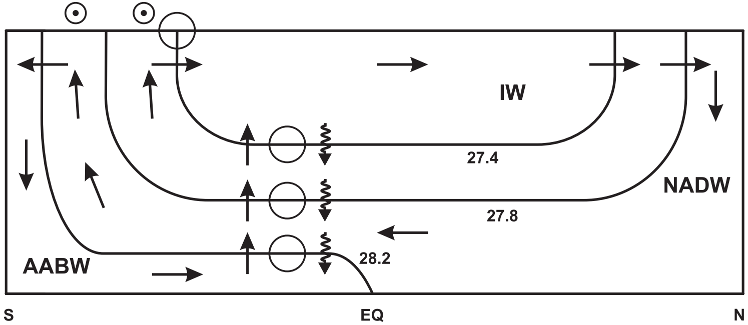
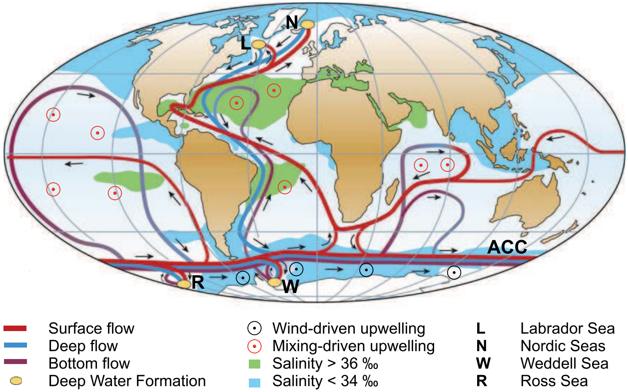



Figure: Kuhlbrodt et al., 2007

# The global conveyor belt

## Meridional overturning circulation

- Upwelling processes that transport volume from depth to near the ocean surface
- Surface currents that transport relatively light water toward high latitudes
- Deepwater formation regions where waters become denser and sink
- Deep currents closing the loop




## Deepwater formation

- Density dictates vertical motion
- Temperature of all oceans is approximately $-2^{\circ}$C at the poleward boundary (ice formation)
- Whether water is dense enough to sink is decided mainly by salinity
- Sufficient salinity is reached in the north Atlantic and under the Antarctic ice sheets (due to brine production during freezing)

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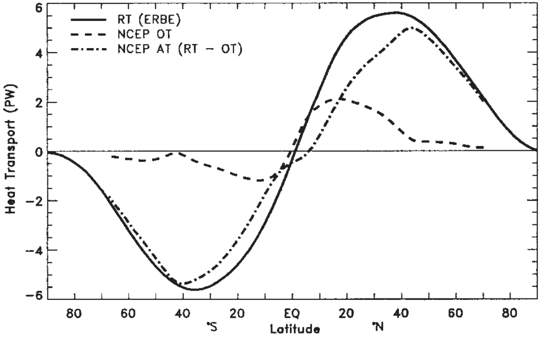
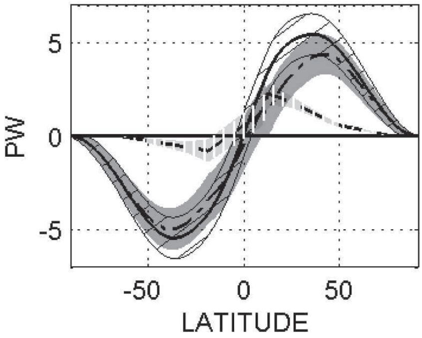
Figure: Kuhlbrodt et al., 2007

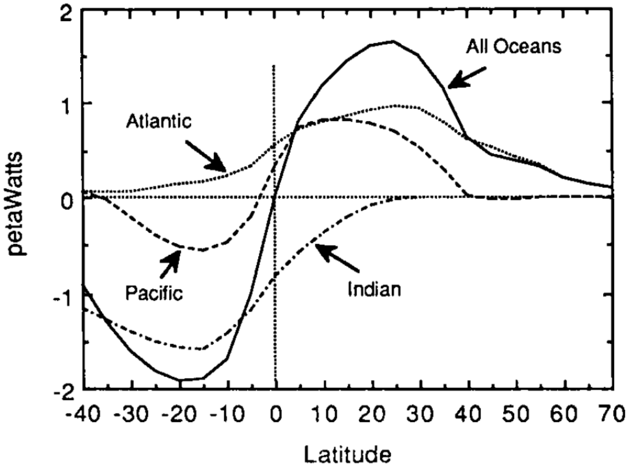
# Partitioning between atmospheric and oceanic transport




Figures: Trenberth and Caron (2001), Wunsch (2005)

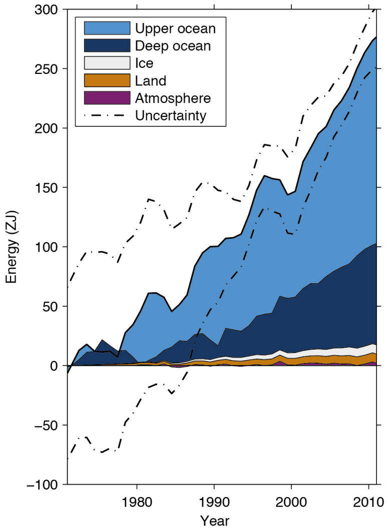
# Partitioning of meridional transport between oceans




Note the anomalous equatorward transport in the South Atlantic Ocean

Figure: Hartmann (1994)

# Oceanic heat uptake




- Ocean warming dominates the global energy uptake
- Warming of the ocean accounts for about 93% of the energy uptake between 1971 and 2010
- Warming of the upper (0 to 700 m) ocean accounts for about 64% of the total
- Energy uptake is equivalent to 0.4 W $m^{-2}$ (global average), or 0.55 W $m^{-2}$ (ocean average)

Figure: IPCC AR5

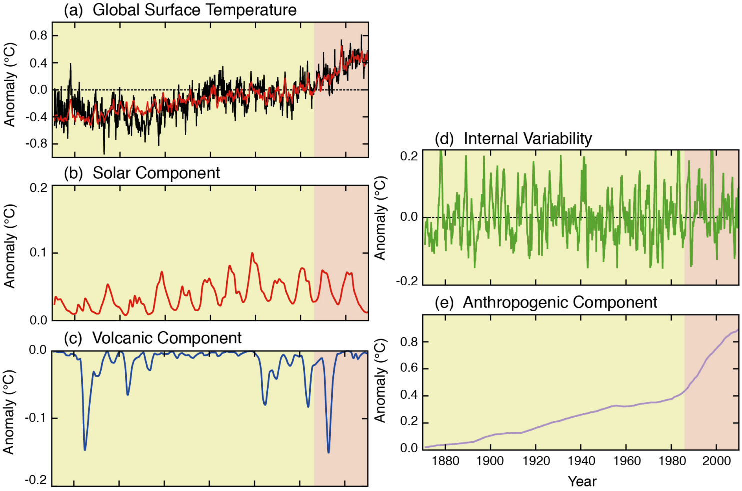
# 6 – Internal variability



## Reference

IPCC AR5, Ch. 14
Holton, Ch. 11
COMET *Introduction to tropical meteorology*, linked from course webpage

# 6.1 – Departures from temporal average




Classification of fluctuations about the climatological mean:

- Time scale: for example, diurnal, annual cycles in solar forcing
- Periodic or trend?
- Natural or anthropogenic?
- Forcing or internal variability?

Figures: IPCC AR5, Holton (unless otherwise noted)

# Forcing or internal variability?

## Forcing

- Change in net energy exchange between the climate system and the environment
- Examples:
  - Solar intensity cycles
  - Orbital parameter cycles
  - Volcanic eruptions
  - Anthropogenic emissions of greenhouse gases, aerosols

## Internal variability

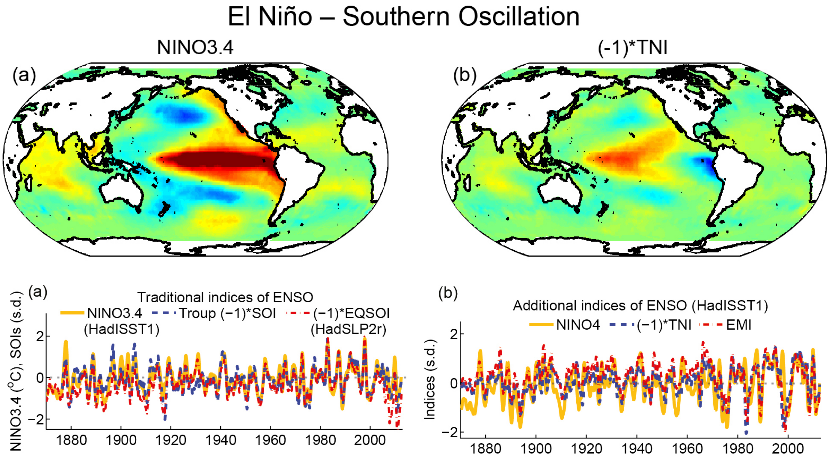
- Many aspects of the climate system
  - are described by nonlinear differential equations
  - couple systems with different time scales
  - have positive feedback
- This leads to transitions between states (example: the attractors in the Lorenz system) on various time scales
- Examples (with time scales):

| | |
|---|---|
| Days–weeks | Midlatitude storm systems |
| Months | Madden–Julian oscillation (MJO) |
| Interannual | El Niño–southern oscillation (ENSO) |
| Decadal | Pacific decadal oscillation (PDO) |
| Multidecadal | Atlantic multidecadal oscillation (AMO) |

# 6.2 – Modes of internal variability

## What is a mode?

A *mode* describes the space–time structure of the variability. Often it is defined as a product of a characteristic spatial *pattern* (of one or more variables) and a time-varying *index*. In next week's homework, we will look at two methods for determining modes.



# Modes of internal variability