Density-Driven Downwelling and Thermohaline Circulation

The Great Ocean Conveyor

Deep circulation
- Deep waters form in the high North Atlantic and around Antarctica.
- Intermediate waters form in the Mediterranean Sea (MIW) and the Southern Hemisphere polar front region (AAIW).
- Deep water masses, like near-surface currents, are influenced by the Coriolis effect.
  - As deep waters flow equatorward, they hug the lower continental slopes and rise on the western sides of the ocean basins.
  - They are also channeled by topographic features on the seafloor.

Surface vs. deep circulation
- Near-surface waters move independently of deep and intermediate waters because of the pycnocline that separates them.
- Downwelling & upwelling link the surface & deep ocean.

The Global Conveyor
The global conveyor describes the complete circuit of global ocean circulation involving the horizontal & vertical flow of near-surface and deep waters.

Net import of near-surface water into the Atlantic
Net export of deep water out of the Atlantic
Cold water holds more dissolved oxygen than warm water.

Why is there so much variation in dissolved O$_2$ across the ocean surface?

Cold water holds more dissolved oxygen than warm water.

Deep waters lose O$_2$ over time due to animal respiration and the decomposition of organic matter. The older the water mass, the lower its O$_2$ content and the higher its CO$_2$ content.

Deep & intermediate waters acquire their physical & chemical characteristics at the surface.

Better views of the conveyor

- Note the Gulf Stream in its proper position.
- Note upwelling of NADW in the Weddell Sea and subsequent formation of AABW.
- Note formation of bottom water in the Ross Sea also.

NADW formation and clihmate

The evidence suggests that glacial periods flip more frequently and abruptly. The likelihood means that these flips may be a transitional position in the North Atlantic ocean.

A few decades at most – YIKES!

Can you translate the terms in this diagram (even without knowing German)?

Hint: think “deep”
Oceanic gateways and climate

- long-term changes (millions-of-years time scale) which re-organized global ocean circulation
- 3 oceanic gateways (remember Ma = “Mega-annums” = millions of years ago)
  1) Drake Passage (opened ~34 Ma)
  2) Central American seaway (closed ~5 Ma)
  3) Indonesian seaway (moved north ~3-4 Ma)

Drake Passage opening

- prior to ~40 Ma …
  - isthmus of land existed which connected southern tip of South America to Antarctic Peninsula
  - Brazil Current acted like Gulf Stream today
    - swift, strong, warm, poleward-flowing
    - kept Antarctica warm
- after 34 Ma (Eocene-Oligocene boundary) …
  - Drake Passage opened, land bridge disappeared
  - Antarctic Circumpolar Current began to flow
    - isolated Antarctic continent
    - allowed glacial ice sheets to form on Antarctica
- or was it something else?
  - maybe changes in atmospheric CO$_2$ did it
  - DeConto and Pollard, 2003 modeling paper in Nature

Central American Seaway closure

- prior to ~5 Ma …
  - open passage existed between North and South America
  - allowed exchange of tropical water between ancient Pacific and Atlantic
    - salinity in both was similar
  - no (or very weak) Gulf Stream existed
- after ~2.7 Ma …
  - Isthmus of Panama fully formed, closed Central Am. Seaway
  - salinity increased in Atlantic, decreased in Pacific
  - Gulf Stream intensified
    - warm, saltier waters north
    - ocean conveyor started
    - onset of Northern Hem.
    - ice sheets & glacial cycles
- wait a second …
  - Gulf Stream warms N. Hem.
  - so why ice sheets???

Gulf Stream and Northern Hemisphere Glacial Cycles

- intensified Gulf Stream carried not only more heat, but also more moisture to the Northern Hemisphere
- rain, snow fell on Eurasia
- great rivers flowed into Arctic Ocean, freshening water and forming sea ice
- fresh water short-circuited ocean conveyor
- ice reflected sunlight
- both cool the N. Hem., resulting in an ice age
- when conveyor on again, get a warm (and fuzzy) interglacial period

See: http://www.whoi.edu/oceanus/viewArticle.do?id=2508
Indonesian Seaway switch

- prior to ~4 Ma ...
  - New Guinea farther south
  - allowed warm South Pacific water to flow through Indonesian Seaway
  - persistent El Niño-like state
    - moved warm water from tropics to high latitudes
    - kept N. Hemisphere ice-free
- after ~3 Ma ...
  - northward displacement of New Guinea
  - switched the source of flow through Indonesia
  - relatively cold North Pacific waters
  - persistent La Niña-like state
    - reduced transfer of heat from tropics to high lat’s
    - onset of Northern Hem. ice sheets & glacial cycles

Cane and Molnar, 2001 paper in Nature

So the question is …
What happens next ???

OR…