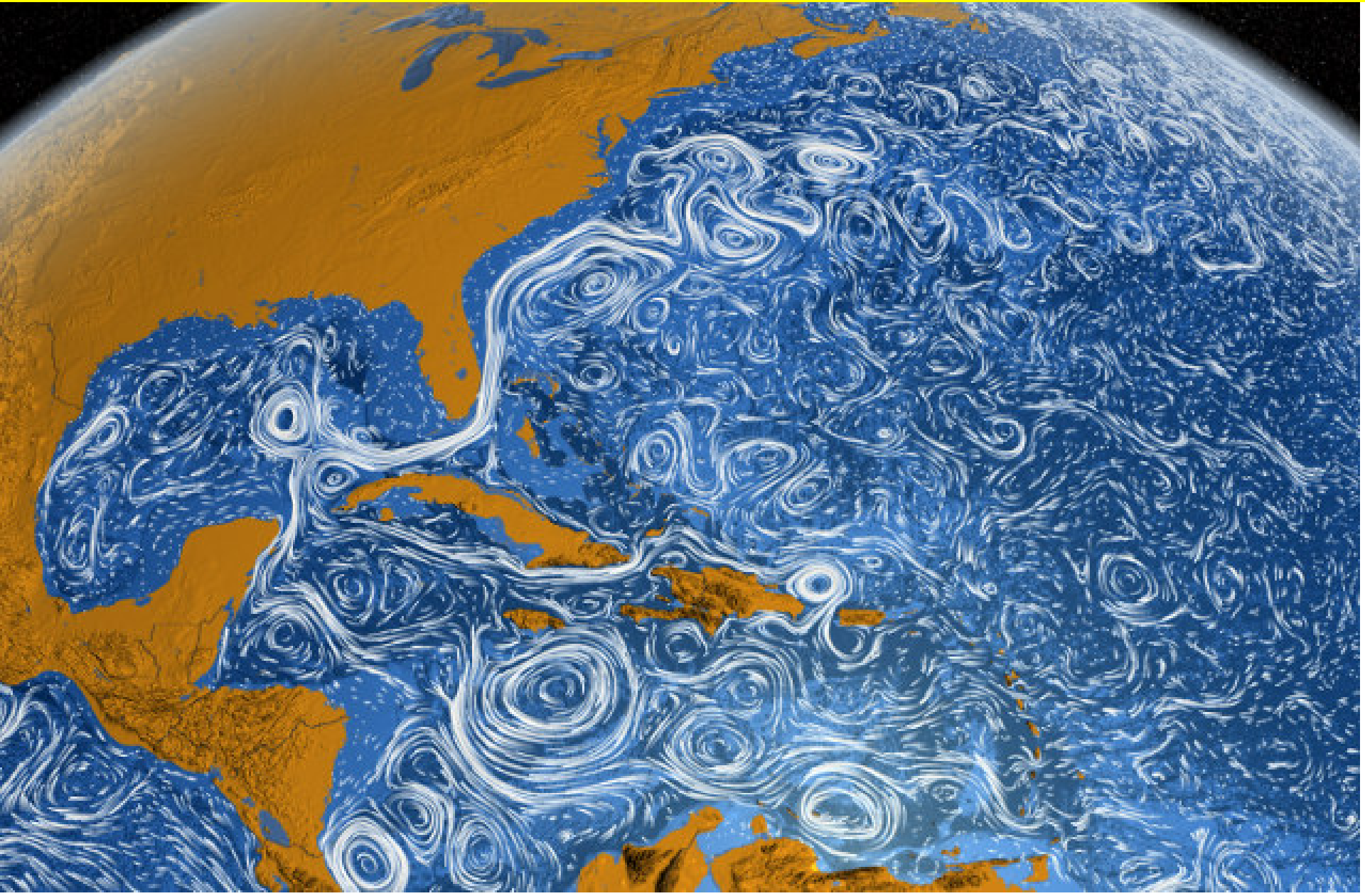
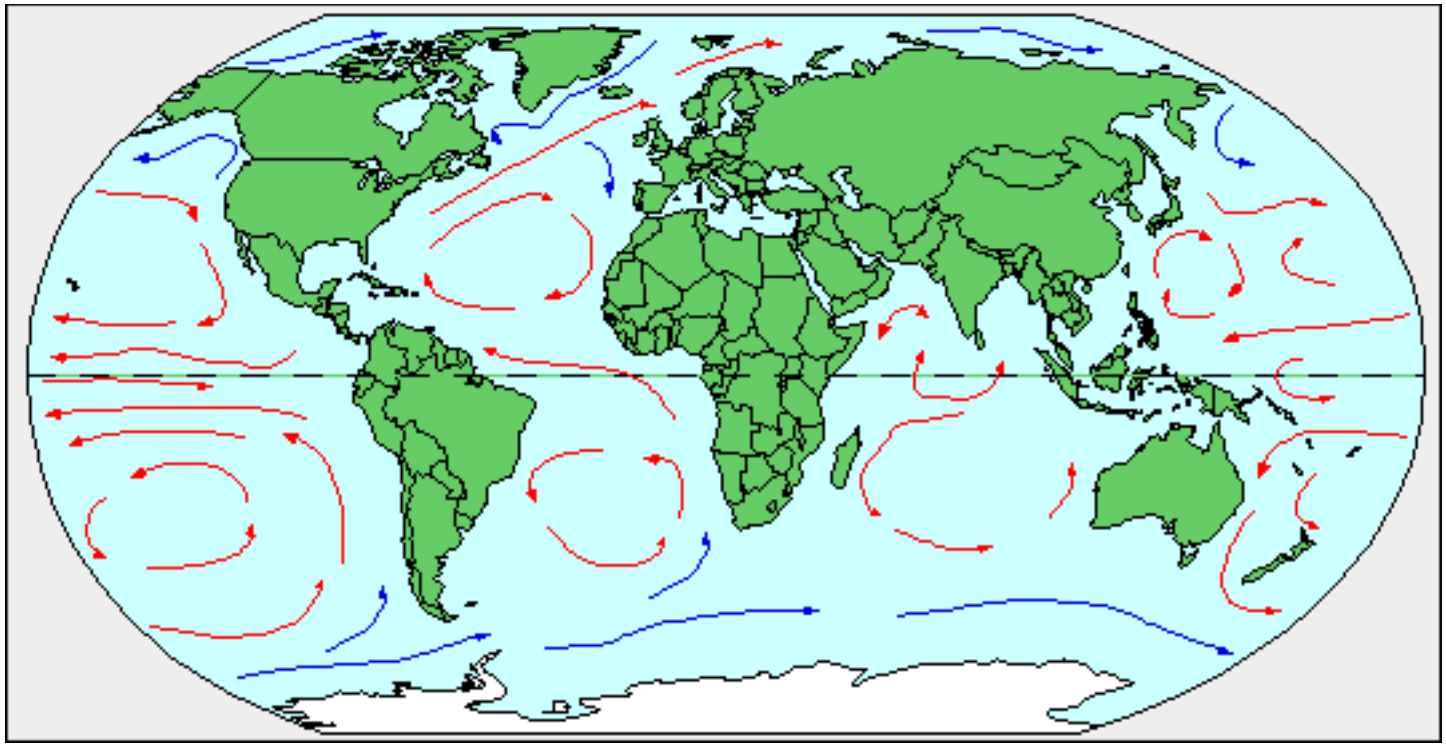
Ocean circulation



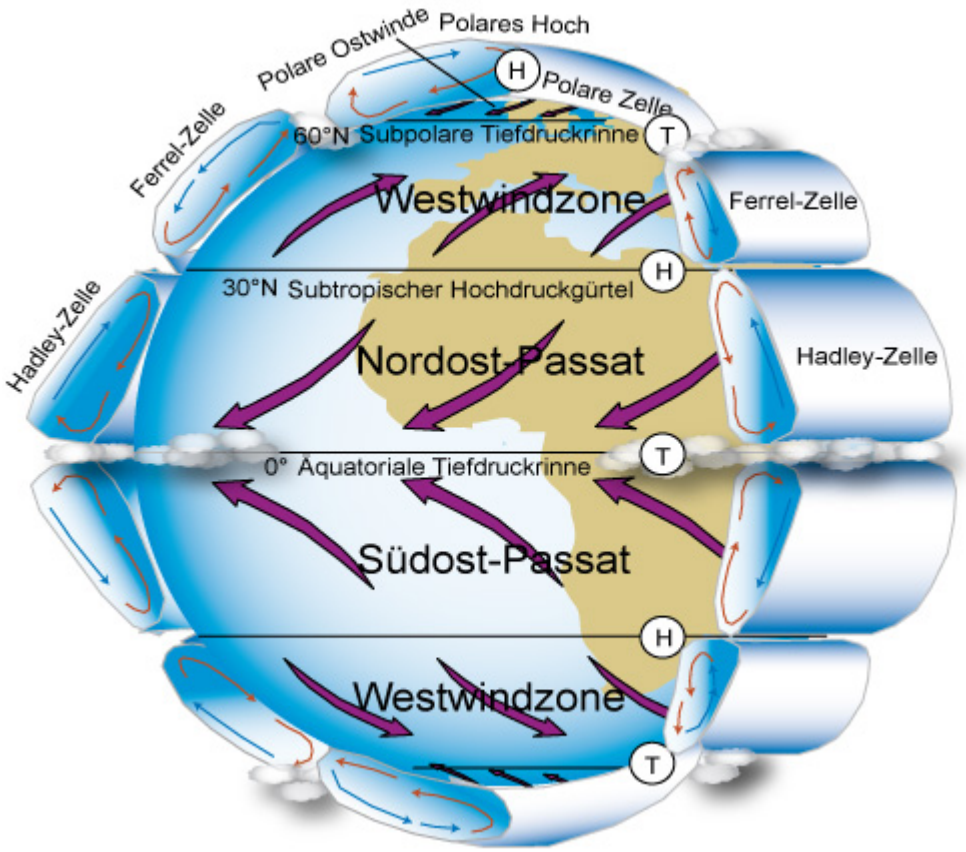
Ocean circulation

- Vertical and horizontal circulation of the oceans results in seawater being well mixed in terms of its major constituents
- This is because of the **wind** and **thermohaline-driven circulation** of the oceans



Global wind patterns

Ocean Gyre



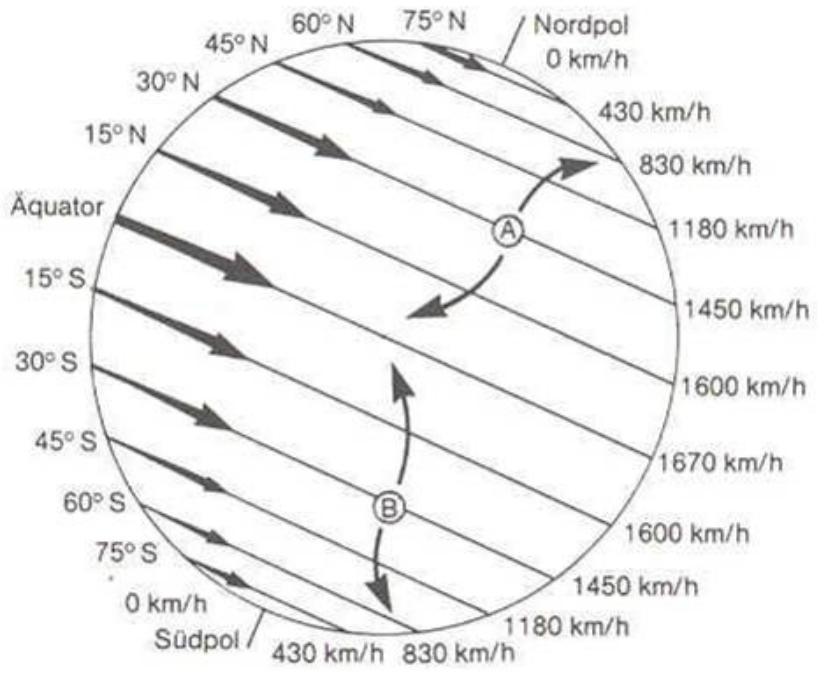
Hadley cell
Hot air rises at the **doldrums** and flows north at a high altitude and descends at the **horse latitudes** and flows back to the equator

Westerlies and **trade winds** blow in opposite directions

These winds contribute to the formation of **circular ocean currents**

Coriolis force
This effect bends the westerlies and trade winds slightly clockwise in the northern hemisphere and counterclockwise in the southern hemisphere.

Global wind patterns



Ocean surface currents are driven by wind. When the wind blows over the ocean, energy is transferred to the ocean surface through friction between the air and the water. In the Northern Hemisphere this energy results in movement of the water in a direction to the right of the wind direction because of the **Coriolis force**

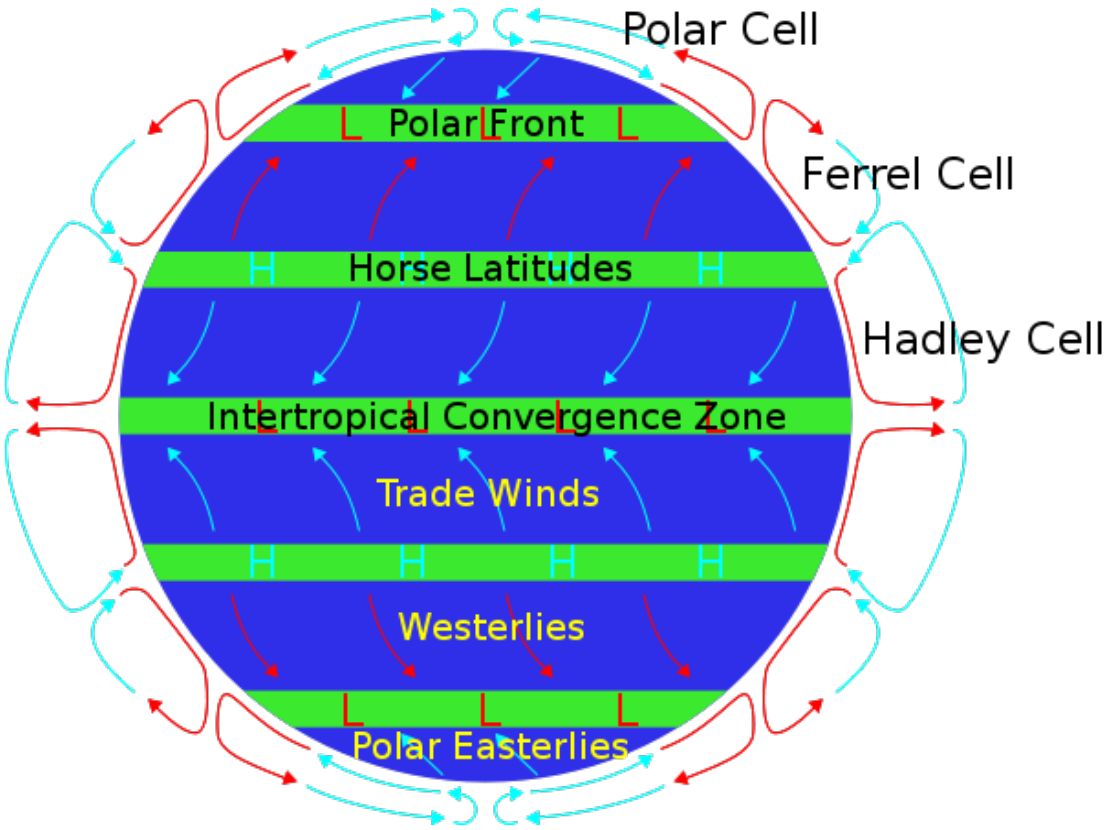
Hadley cell
Hot air rises at the **doldrums** and flows north at a high altitude and descends at the **horse latitudes** and flows back to the equator

Westerlies and **trade winds** blow in opposite directions

These winds contribute to the formation of **circular ocean currents**

Coriolis force
This effect bends the westerlies and trade winds slightly clockwise in the northern hemisphere and counterclockwise in the southern hemisphere

Global wind patterns



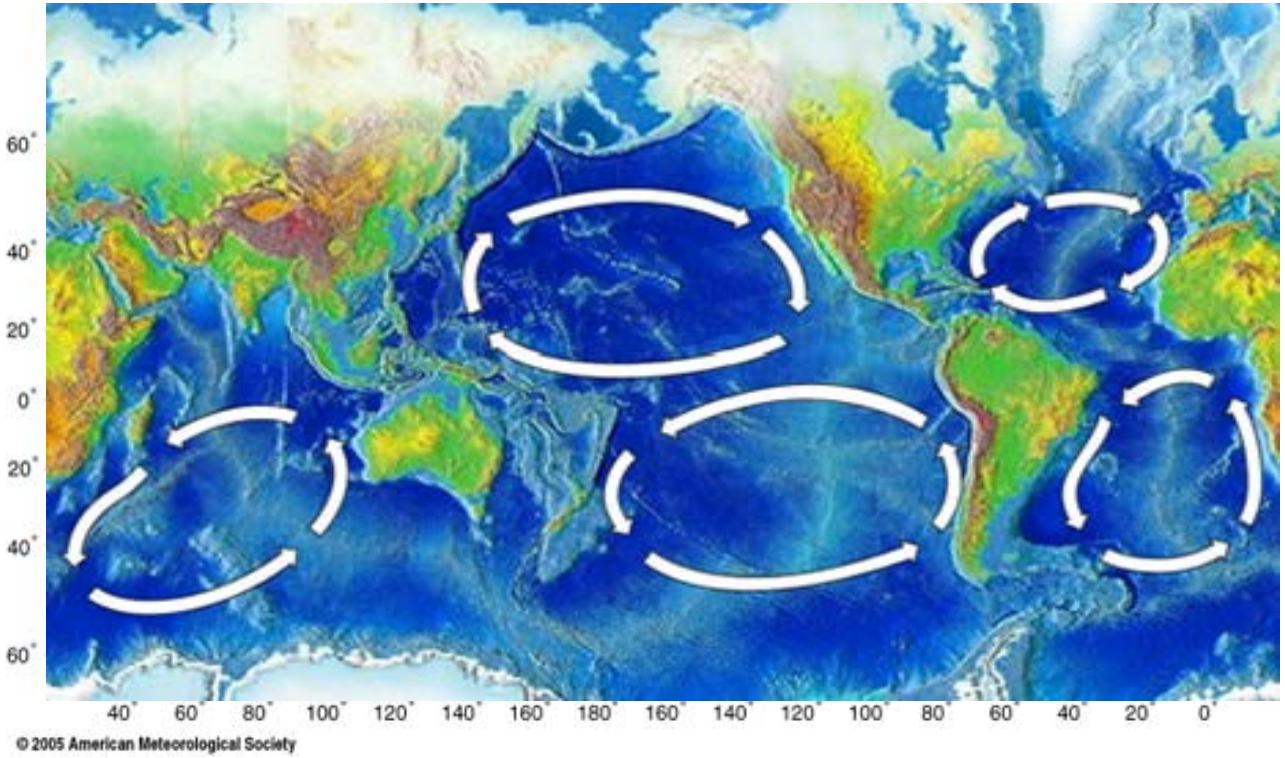
Hadley cell
Hot air rises at the **doldrums** and flows north at a high altitude and descends at the **horse latitudes** and flows back to the equator

Westerlies and **trade winds** blow in opposite directions

These winds contribute to the formation of **circular ocean currents**

Coriolis force
This effect bends the westerlies and trade winds slightly clockwise in the northern hemisphere and counterclockwise in the southern hemisphere.

Ocean surface currents



Ocean surface currents

Gulf stream
Western boundary current
N Atlantic

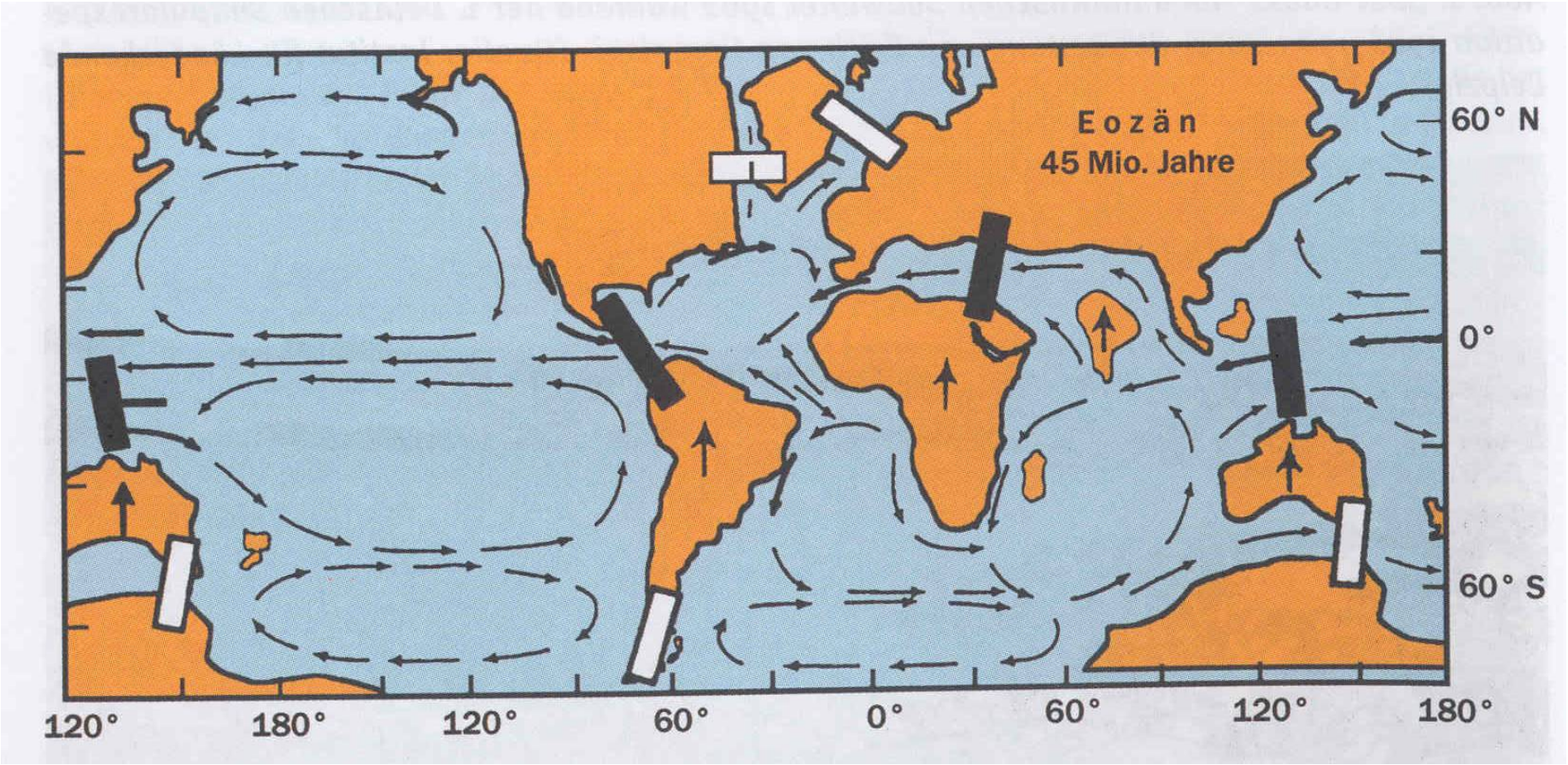
Kuroshio-Strom
Western boundary current
NW Pacific

Antarctic Circumpolar current (ACC)
Southern hemisphere
(West Wind Drift)

ACC:

- flows clockwise from west to east around Antarctica
- largest ocean current: 100-150 Sverdrups (Sv, million m^3/s)
- circumpolar due to the lack of any landmass
- keeps warm ocean waters away from Antarctica

Ocean circulation & climate



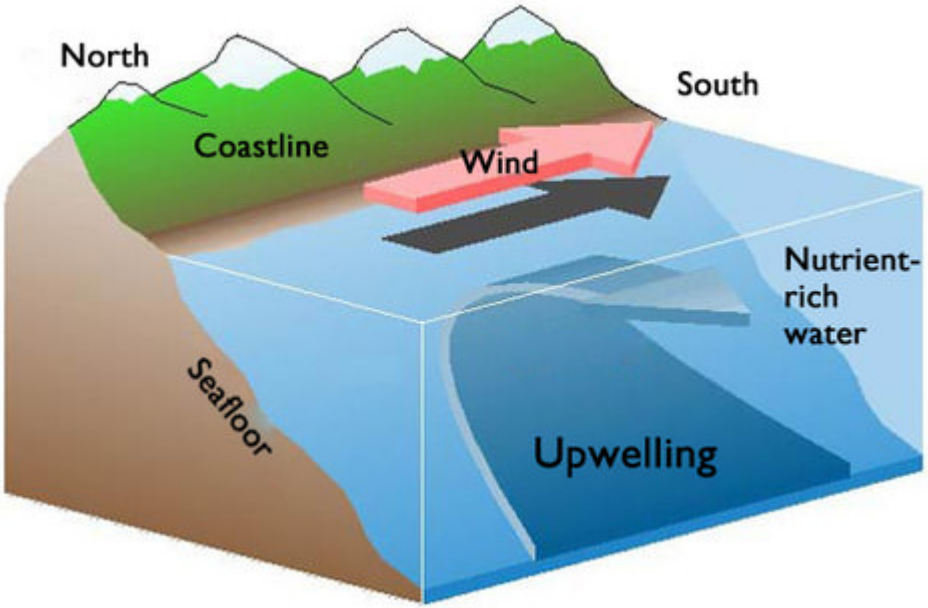
Major seaways during the Cenozoic times, c. 45 million years ago

black rectangular: seaway closed since Eocene

White rectangular: seaway opened since Eocene

(Wefer & Berger 2001, Huch 2005)

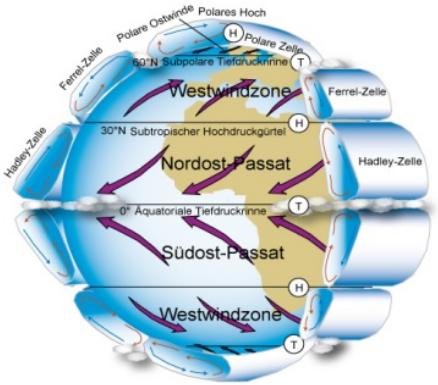
Upwelling and Ekman transport

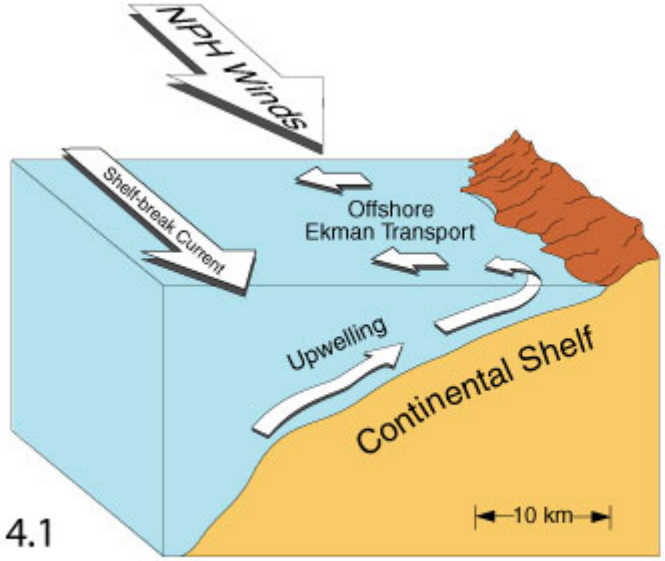


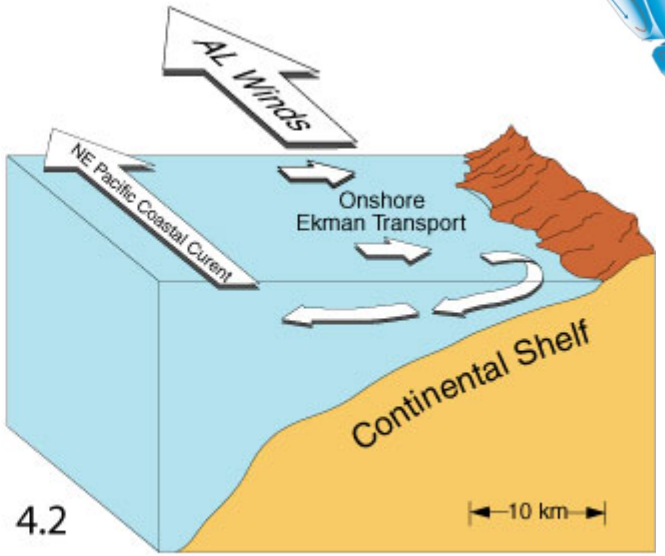
Ekman transport

Along the equator trade winds create a divergence of surface water /related to Coriolis force)

Upwelling, downwelling and Ekman transport







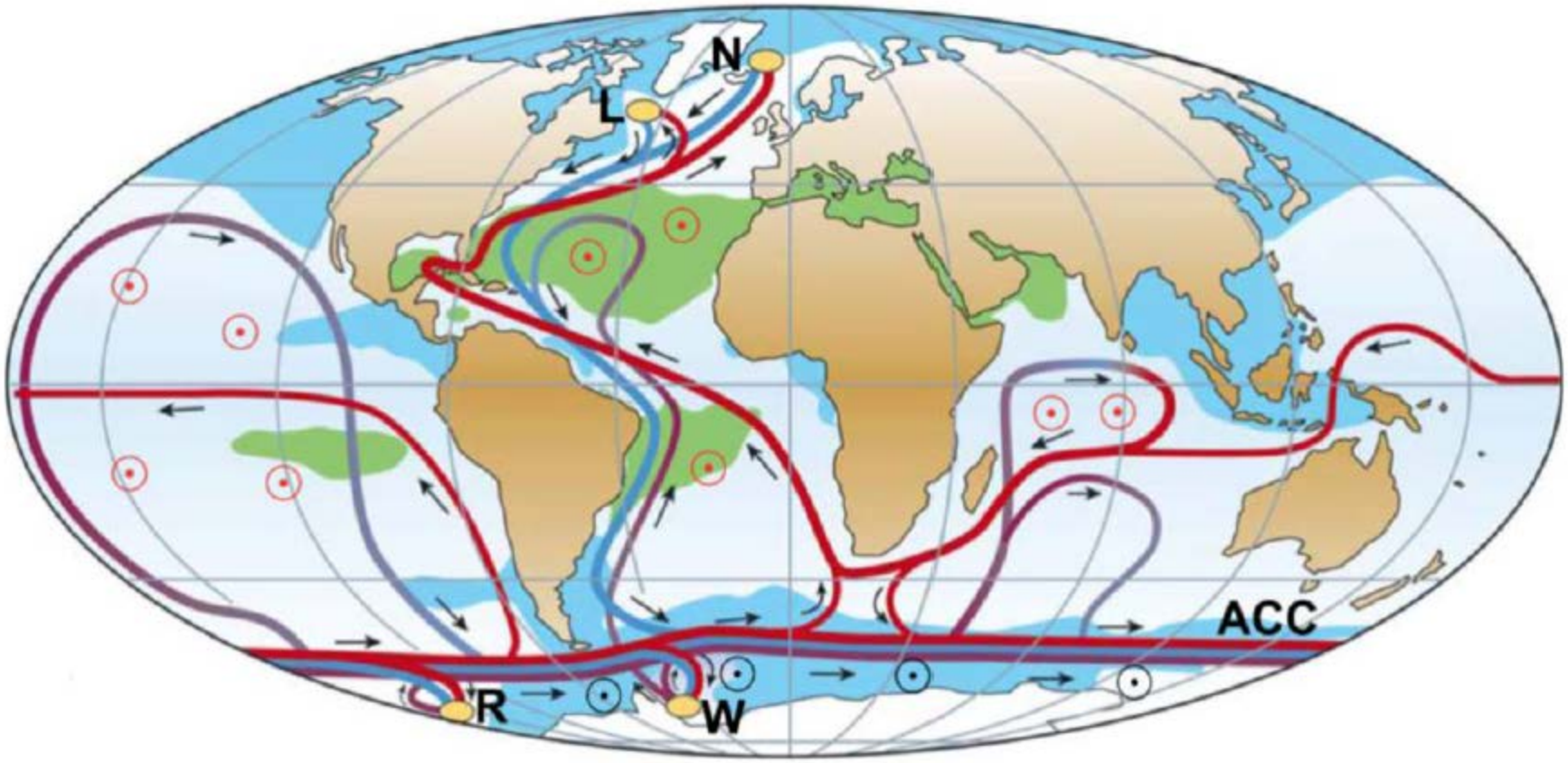
http://palaeo-electronica.org/2004_1/fish2/fig4.htm

west coast of Vancouver Island during summer. Northerly North Pacific High (NPH) winds generate a southward surface flow and offshore Ekman transport inducing **upwelling**

west coast of Vancouver Island during winter. Southerly Aleutian Low (AL) winds generate a northward drift and onshore Ekman transport wind-induced **downwelling**

Thomson (1981)

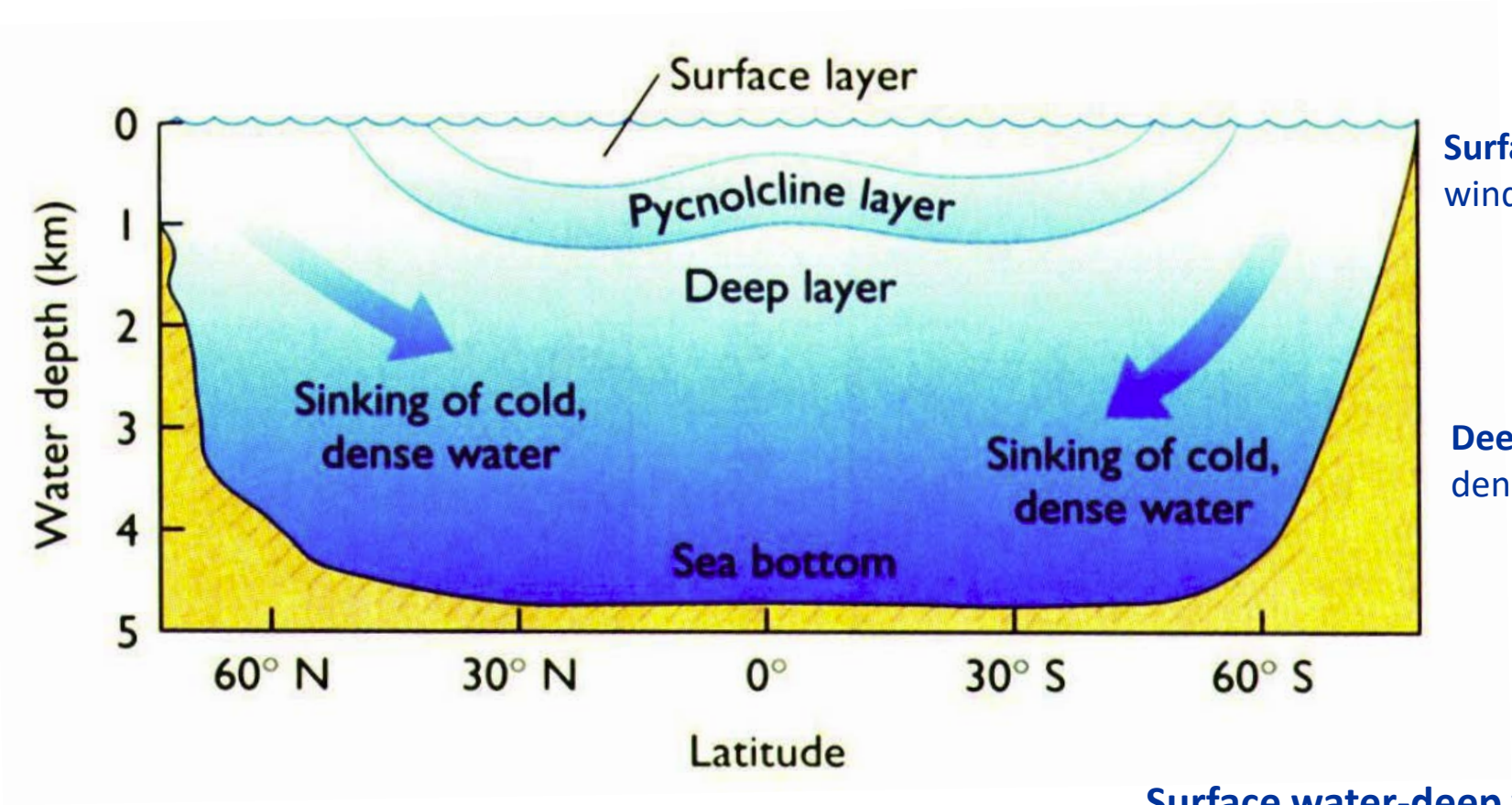
Global ocean circulation



Kuhlbrodt et al. (2007)

Sea water circulation in the Atlantic ocean

Water flow across the pycnocline occurs only at limited regions

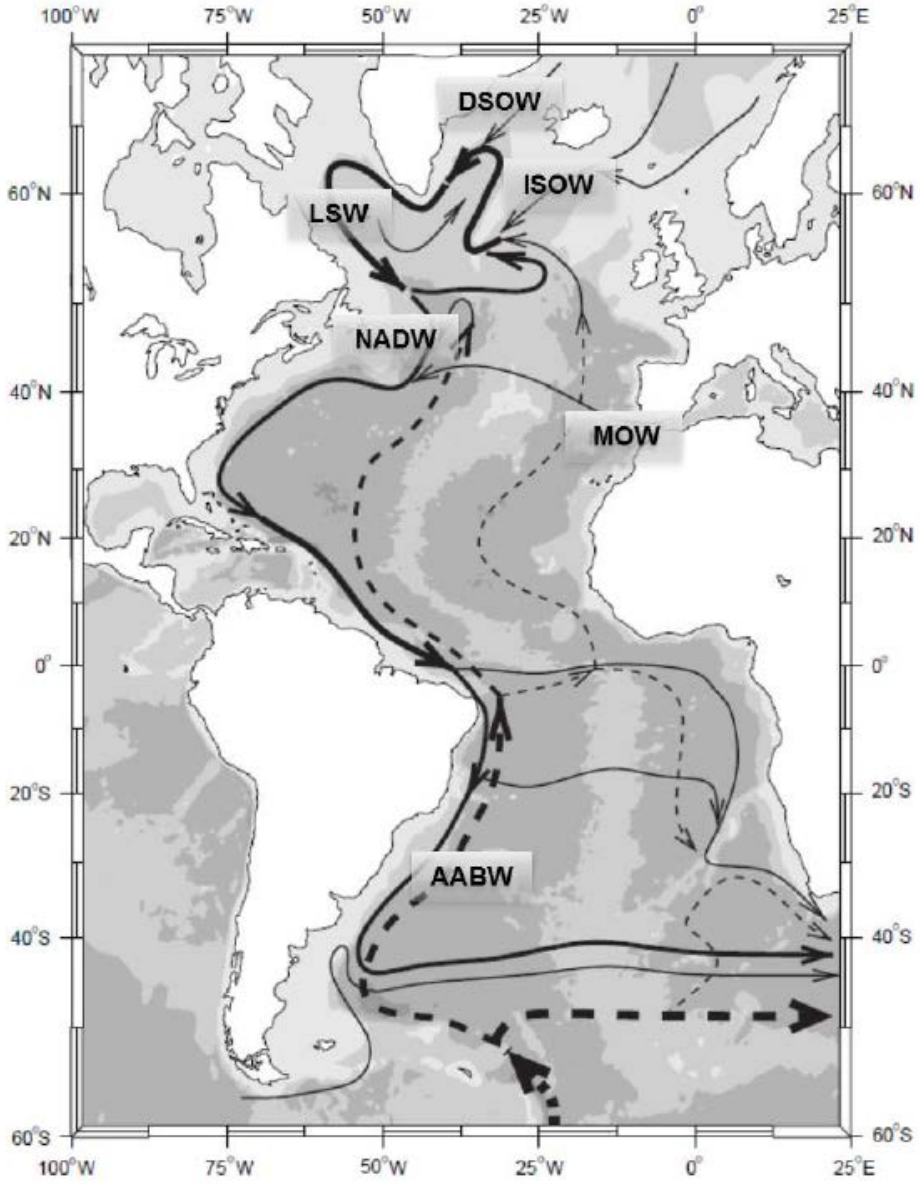


Surface water
wind driven

Deep water
density driven

Surface water-deep water
circulation coupling

Atlantic Meridional Overturning Circulation (AMOC)



NADW
North Atlantic Deep Water

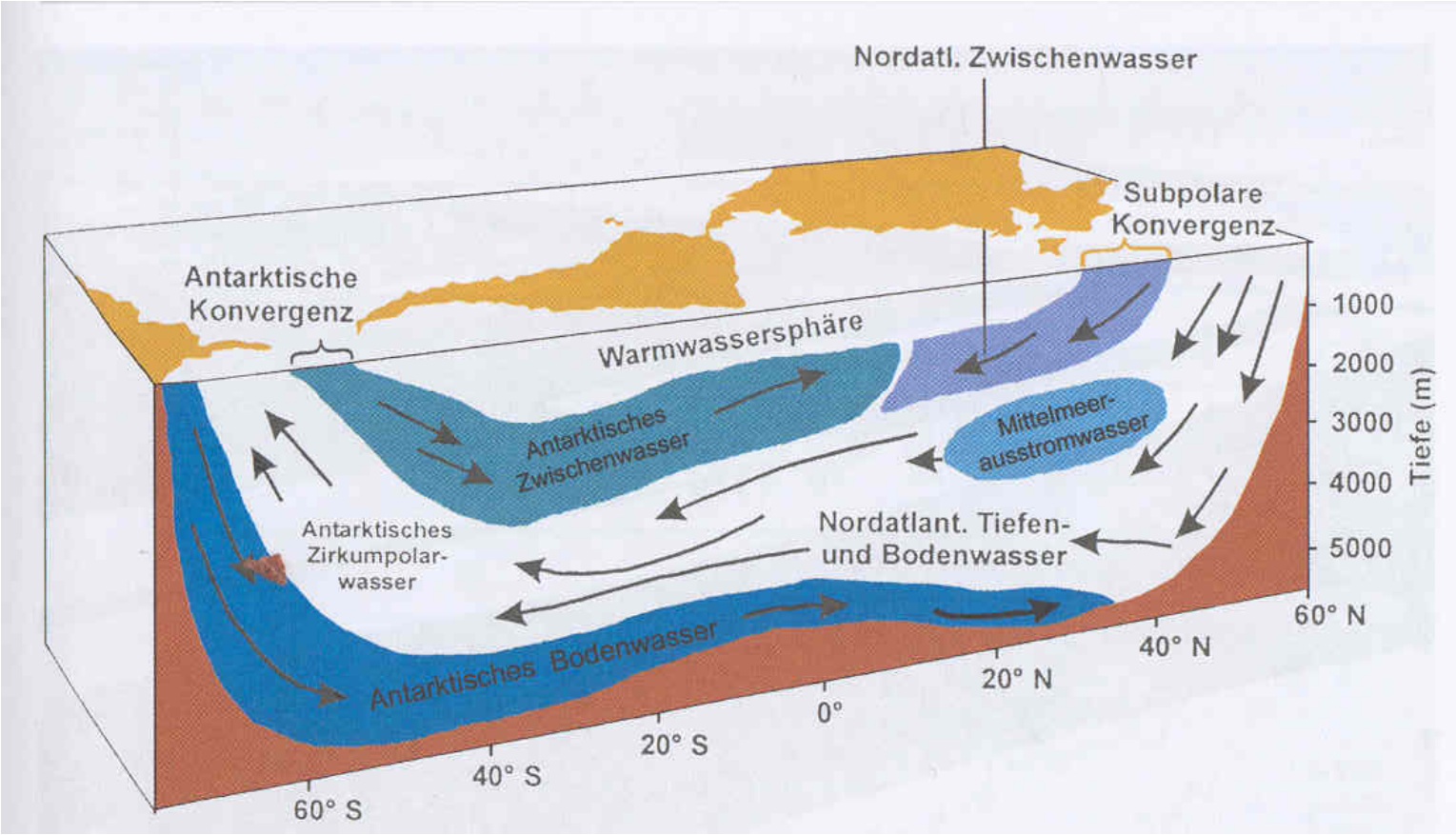
MOW
Mediterranean Outflow Water

AABW
Antarctic Bottom Water

Sources: Strama (2001)

Sea water circulation in the Atlantic ocean

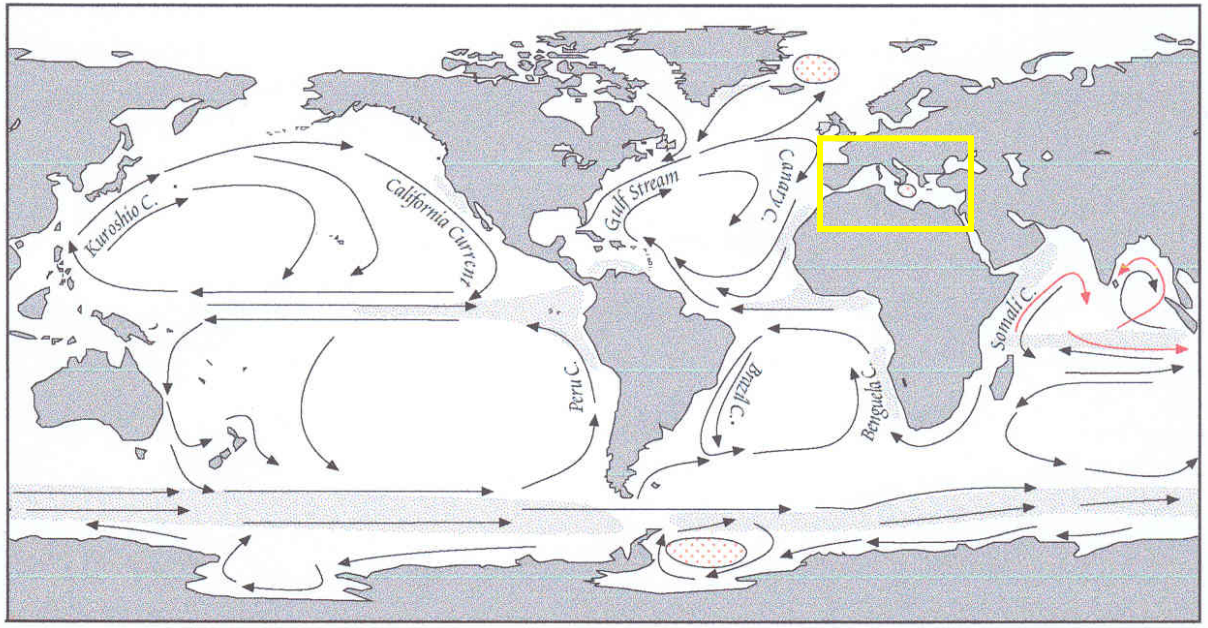
Atlantic ocean: exports deep water and imports surface water

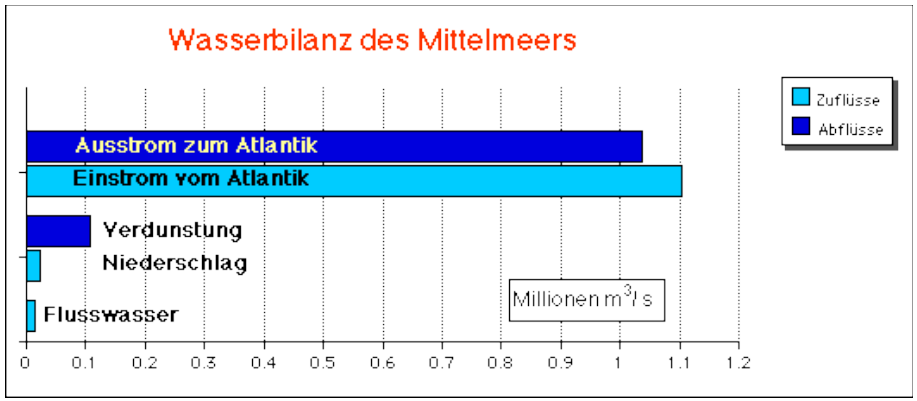


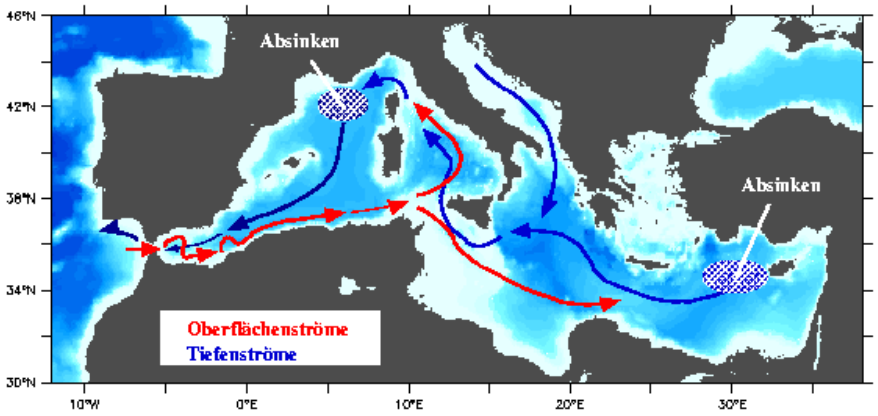
(Wefer & Berger 2001, Huch 2005)

Mid-depth (intermediate) water

1. **Mediterranean** (MIW)

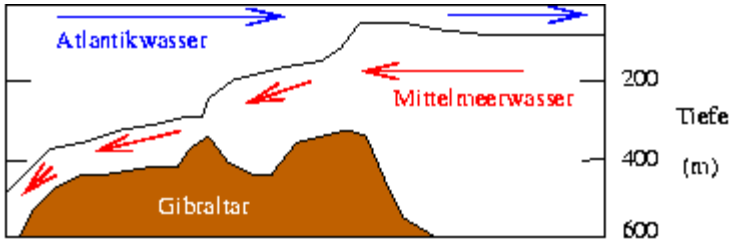


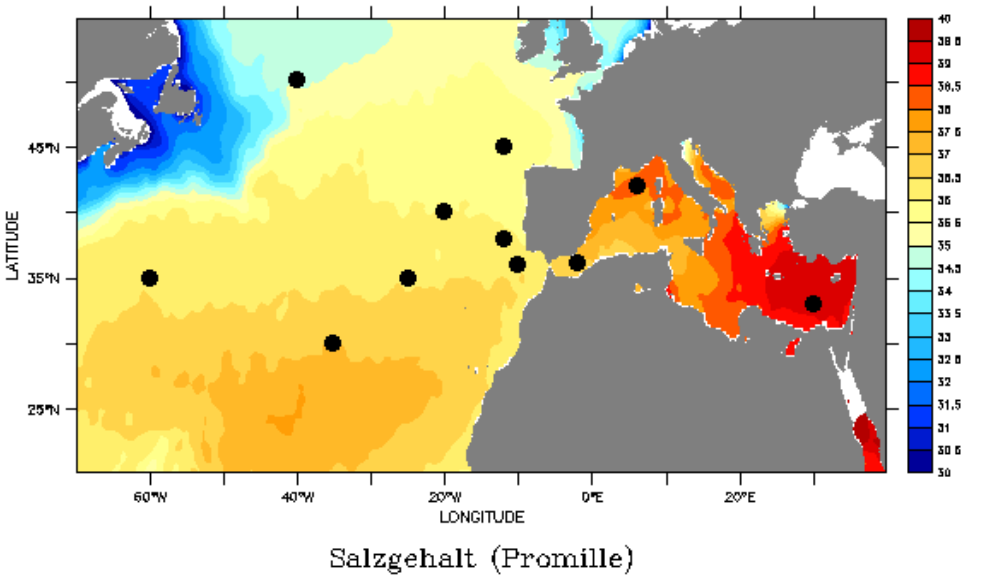




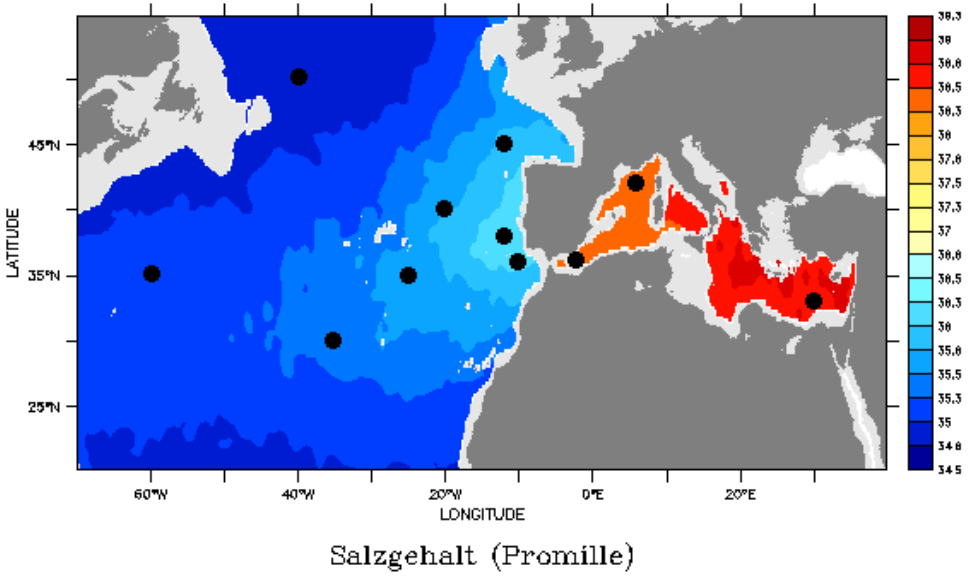
Mid-depth (intermediate) water

Sea surface

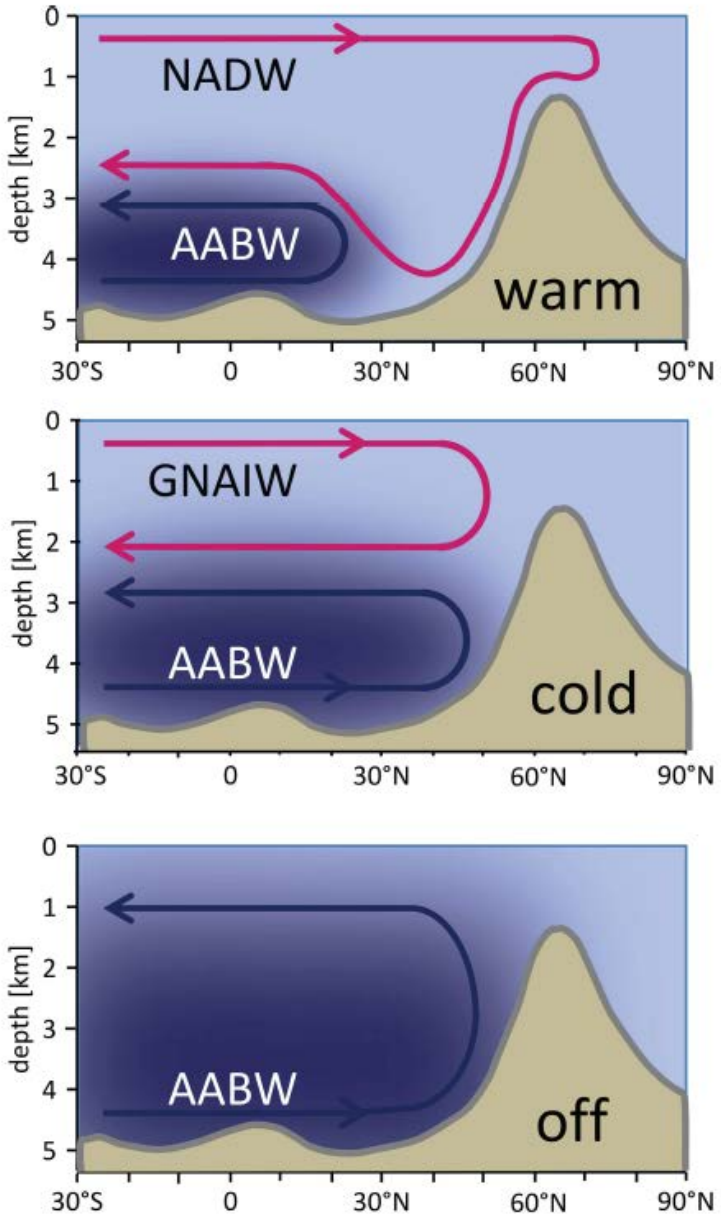




1000 m depth



Sea water circulation in the Atlantic ocean

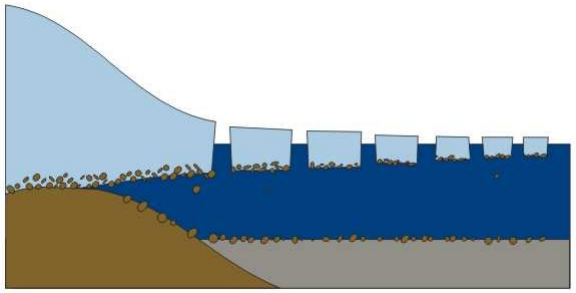


Modes of ocean circulation that prevailed during different times of the last glacial period

a) Present situation (interglacial period)

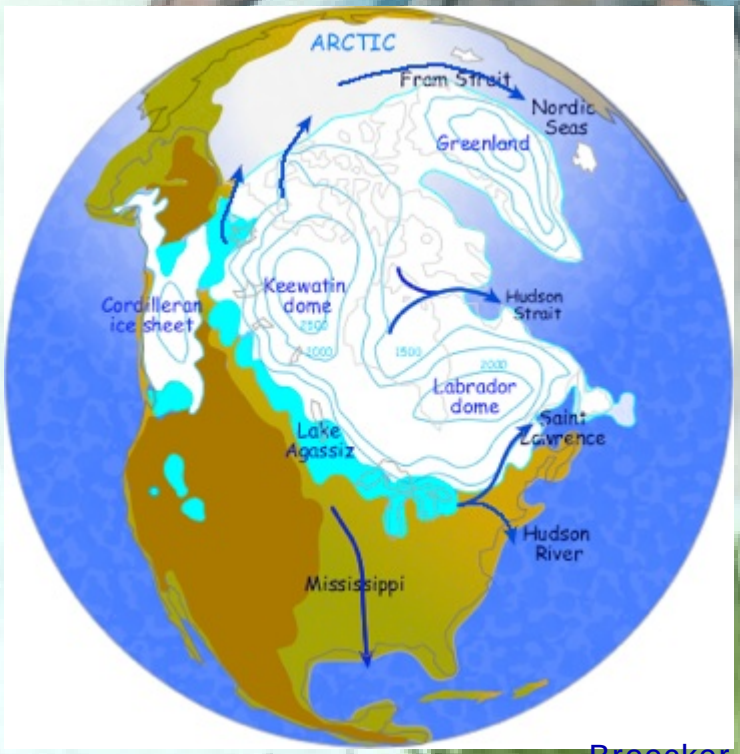
b) Changes in surface air temperature caused by a shutdown of North Atlantic Deep Water (NADW) formation (interstatial period)

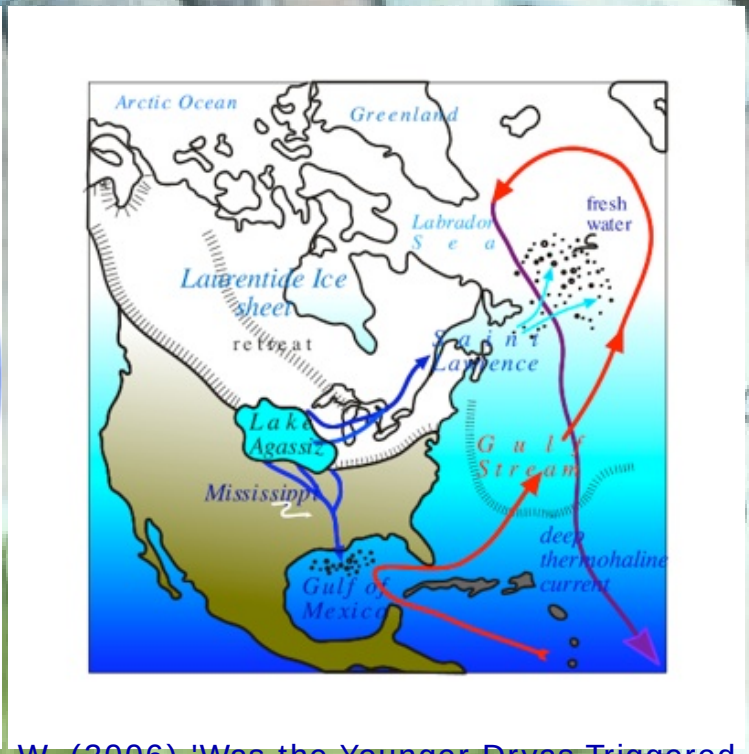
c) Heinrich mode
during Heinrich events



Sources: Rahmstorf (2002); Diss. Böhm (2014)

Younger Dryas (~10850 - 9620 BP) Bond event





sudden increase in freshwater flux modified North Atlantic thermohaline circulation, reducing northward heat transport in the Atlantic and causing significant North Atlantic cooling

Broecker, W. (2006) 'Was the Younger Dryas Triggered by a Flood?', Science 312

Eldigio Press is the phonetic pronunciation of "LDGO", the acronym for Lamont-Doherty Geological Observatory and was created as a logo for Wally's self-published books.

Books by Wally (click on 'PDF' to download)

Wally's Carbon World (2015 Revised Edition, Eldigio Press) This book is aimed at challenging further thought and debate regarding how Earth's carbon cycle has influenced climate over the last 800 million years (PDF)

What Drives Glacial Cycles? (2015 Revised Edition, Eldigio Press) This book outlines an alternate explanation for the tie between orbital cycles and glaciation. (PDF)

How to Build a Habitable Planet: The Story of Earth from the Big Bang to Humankind C.H. Langmuir and W.S. Broecker (2012 Princeton University Press) An Introduction to the origin and evolution of Earth, from the Big Bang through the rise of human civilization. It provides and understanding of Earth in its broadest context, as well as a greater appreciation of its possibly rare ability to sustain life over geologic time. *(This book was inspired by my much shorter 1987 book with the same title. However, it was written entirely by Charlie Langmuir using bits of the original. So in a sense, Broecker is an honorary author.)*

The Carbon Cycle and Climate Change: Memoirs of my 60 years in Science (2012 Geochemical Perspectives) Science mixed with personal experience (PDF)

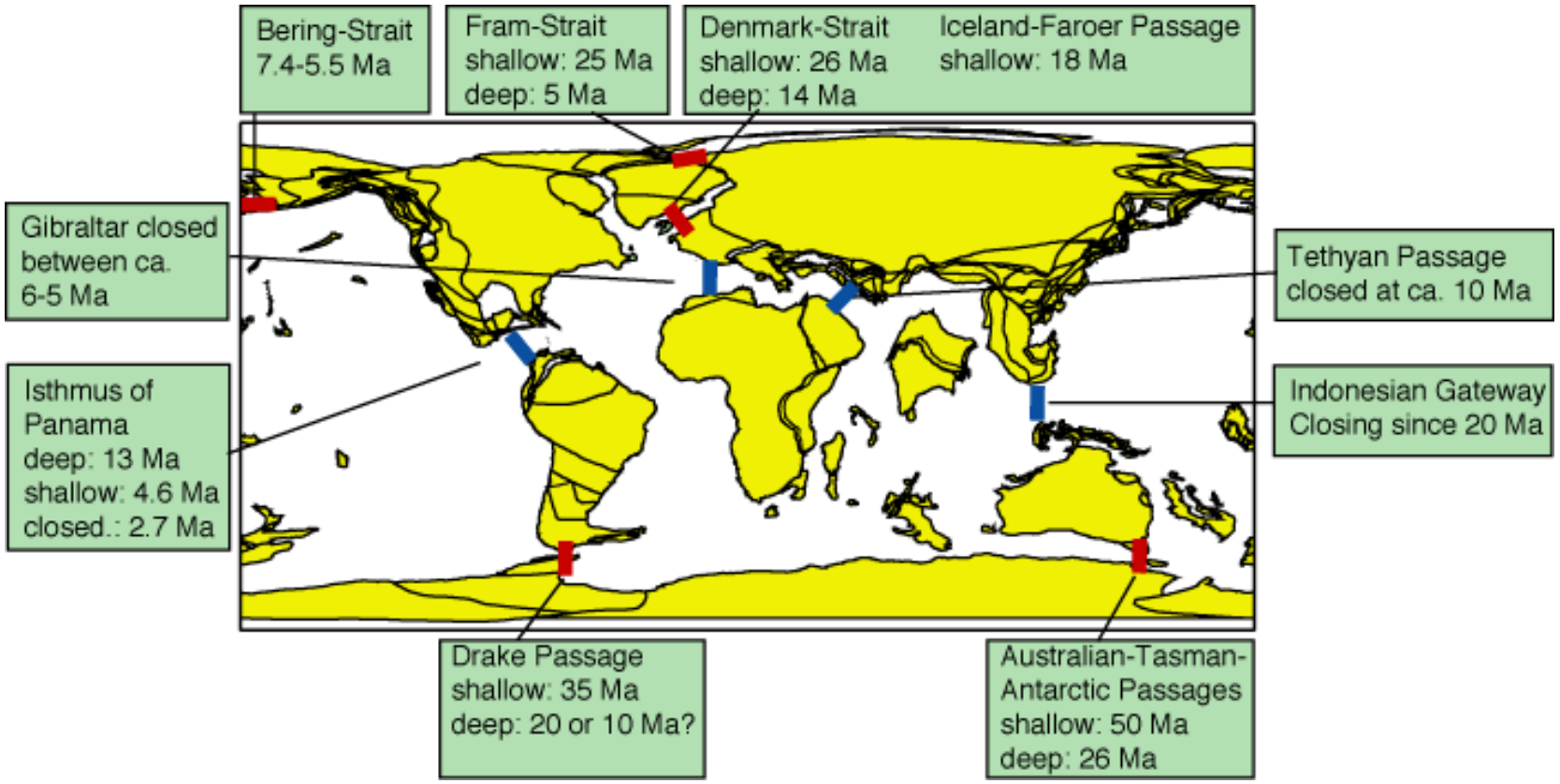
The Fate of Greenland: Lessons from Abrupt Climate Change P. Conkling, R. Alley, W.S. Broecker, G. Denton (2011 The MIT Press) A documentation of Greenland's warming and investigation of the episodes in Greenland's climate history for clues about what happens when climate change is abrupt rather that gradual. Illustrated with photographs taken by Land's End founder, Gary Comer.

The Great Ocean Conveyor: Discovering the Trigger for Abrupt Climate Change (2010 Princeton University Press) This book deals with the discovery of the link between ocean circulation and climate change. It introduces readers to the science of abrupt climate change while providing a first-hand account of the field's history and development.

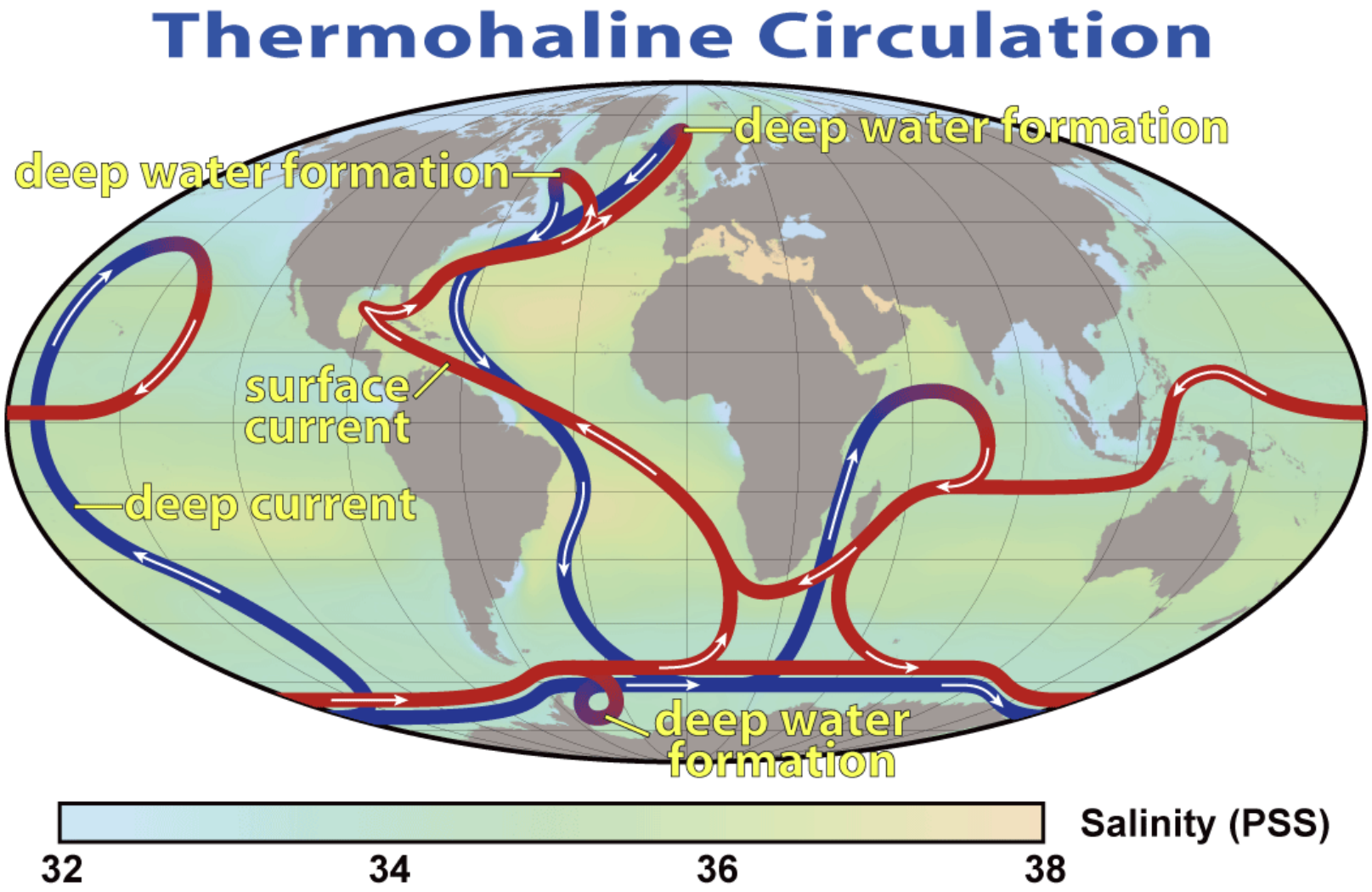
Ocean circulation

- Opening and closure of seaways → change in ocean circulation and heat transport

- Opening of Tasman See and Drake Passage → ACC → thermal isolation of Antarctica



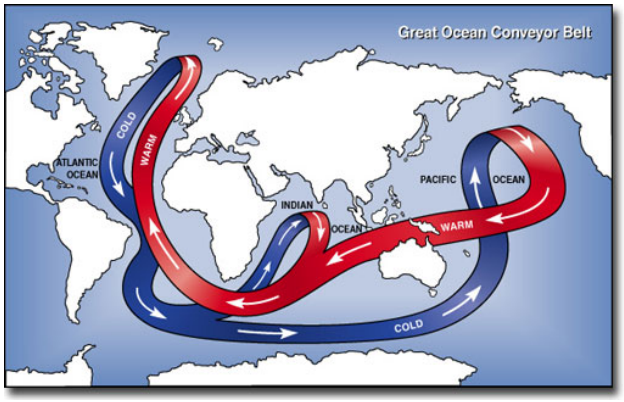
The great conveyor belt “grant tour”



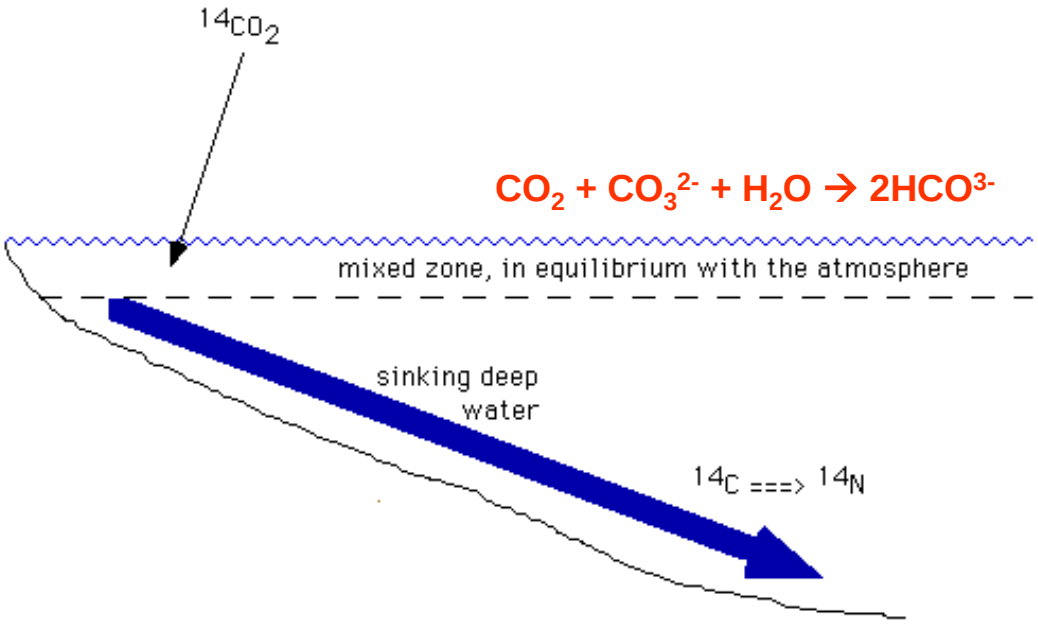
Based on models from Stommel (1958), Gordon (1986), Broeker (1987)

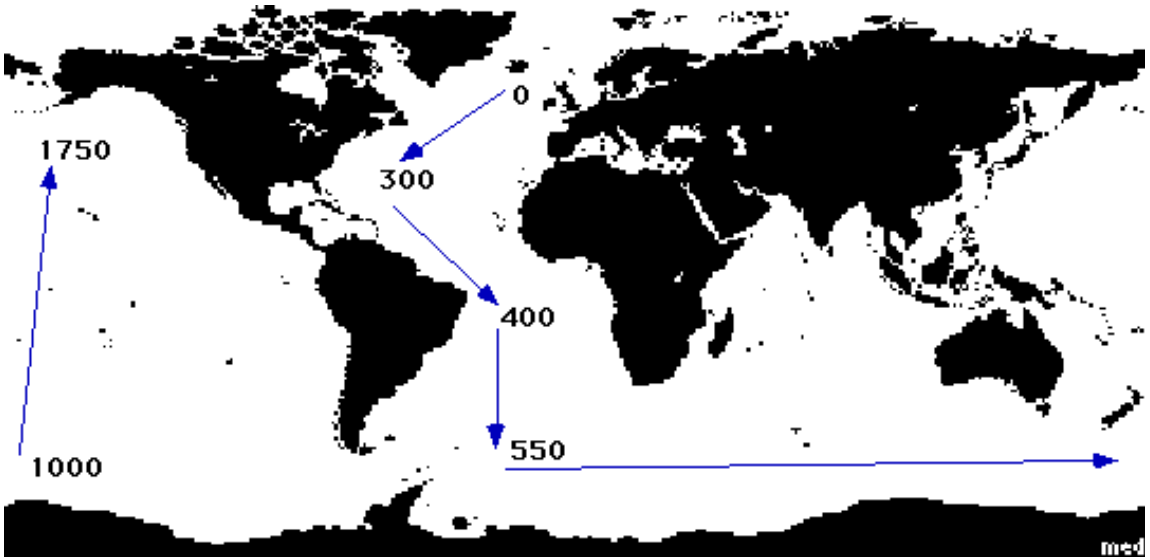
Tracing the circulation of sea water

Great Ocean Conveyor



major source of this bottom water in the North Atlantic





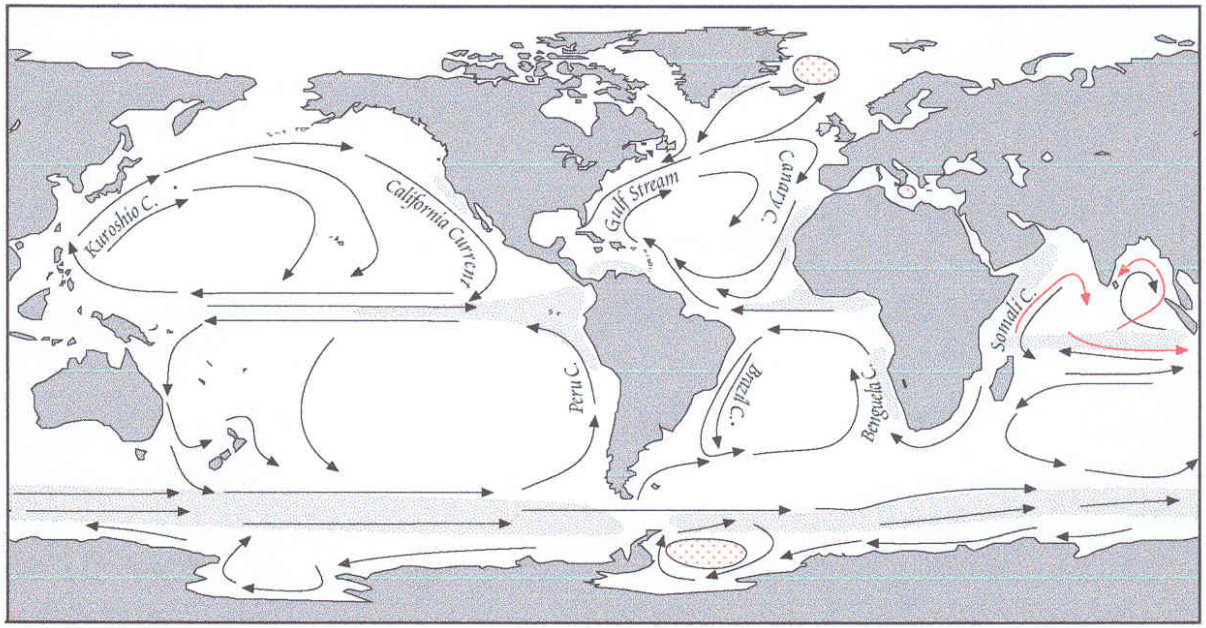
Upwelling zones

Seasonal or permanent

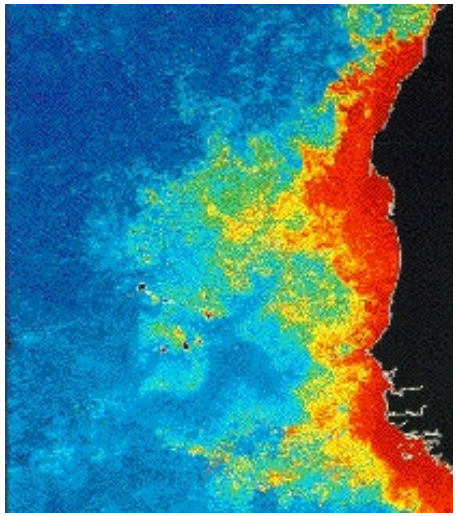
Upwelling provides nutrients, primarily nitrate and phosphate

High phytoplankton productivity zones

Occurs along equatorial regions of the oceans

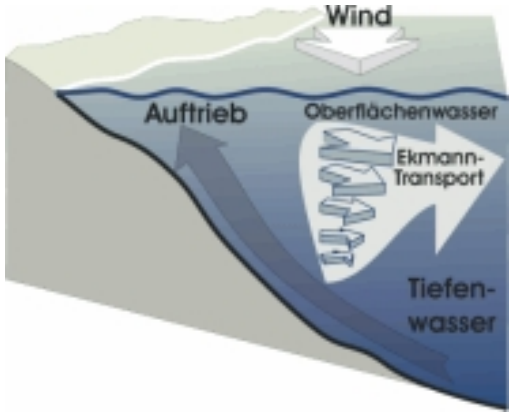


Gray areas are regions of upwelling. Red stippled areas are regions of deep water production



Chlorophyll image

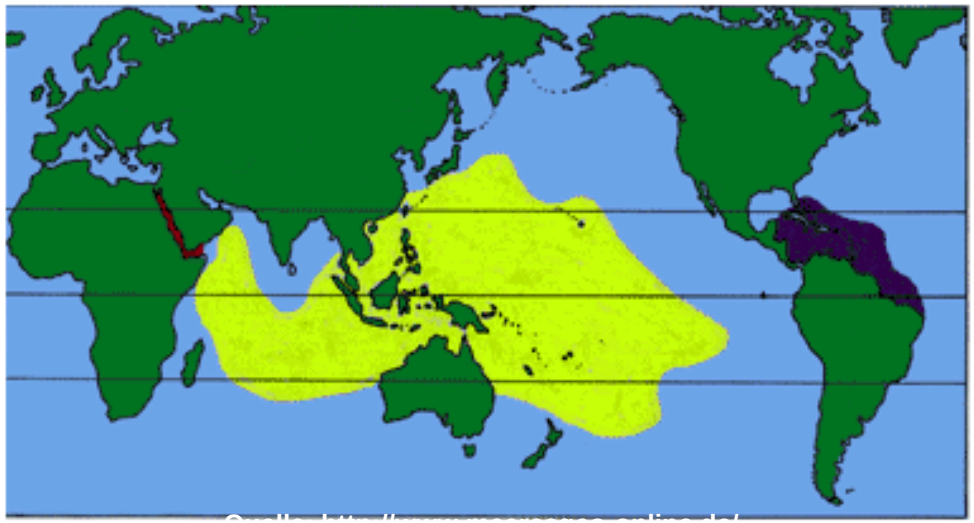
Examples: Benguela upwelling zone

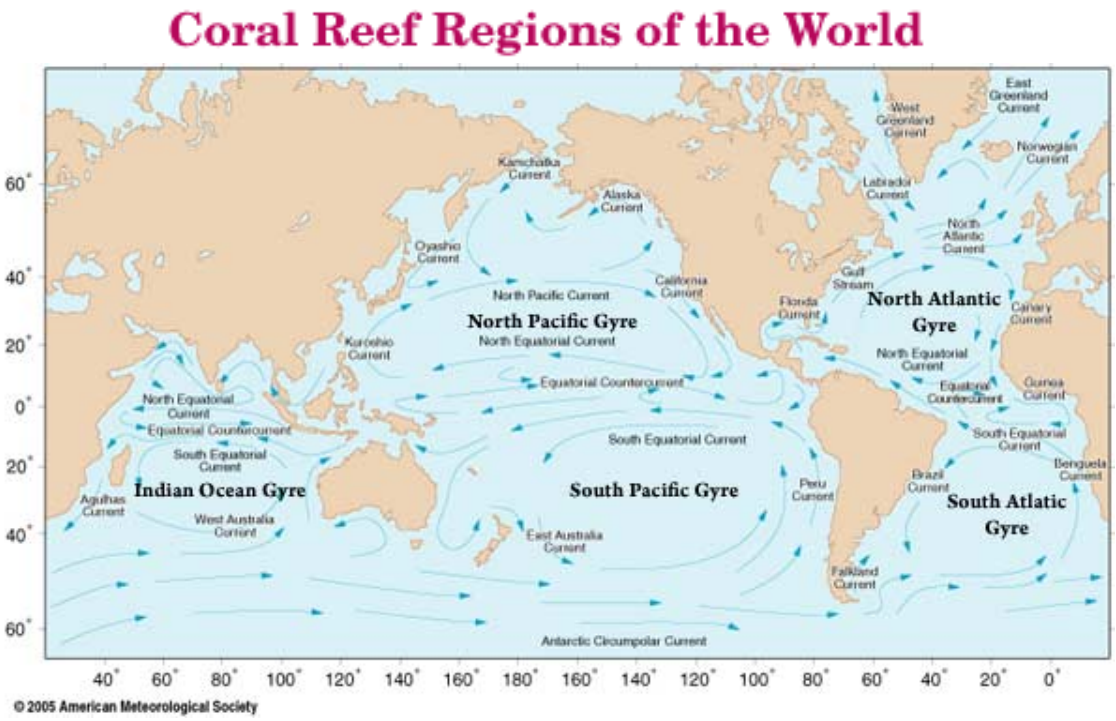


Effects of ocean circulation

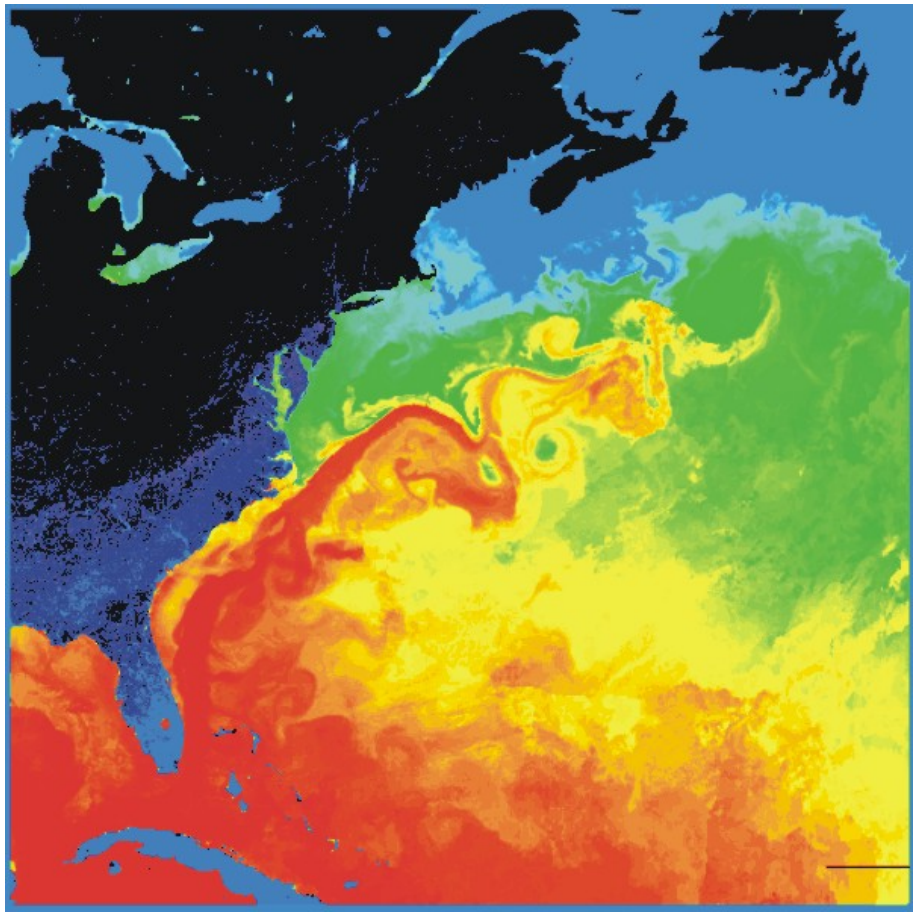
Distribution of ocean sediments

Asymmetry in faunal distribution (e.g. coral reefs)

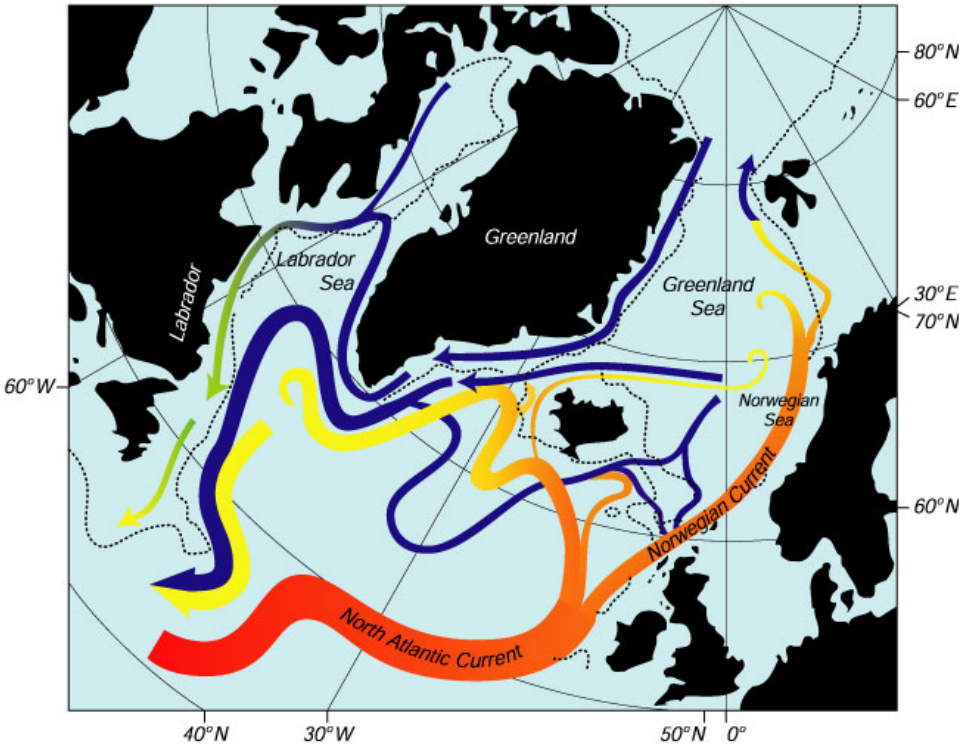




Gulf stream

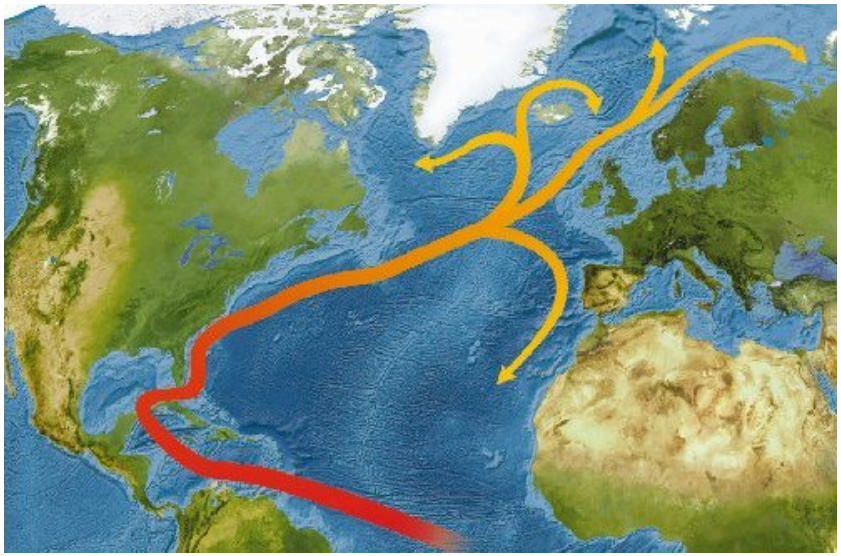


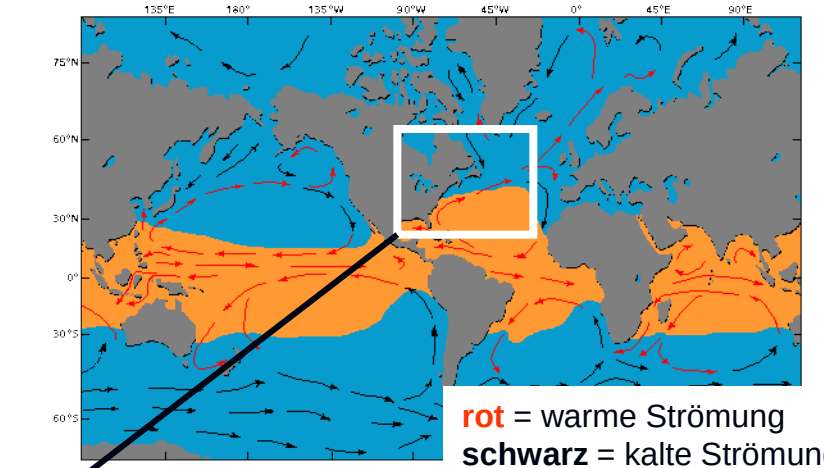
source: http://www.meeresgeo-online.de/



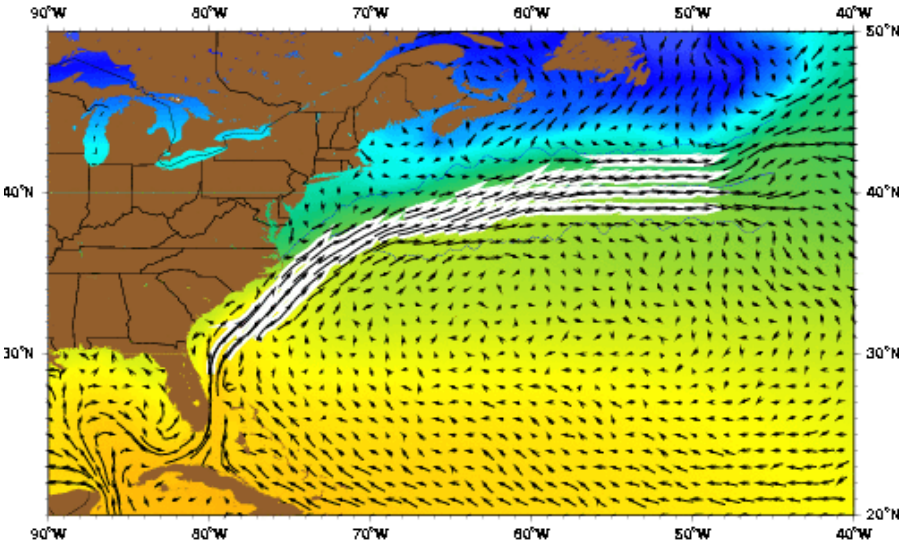
Gulf Stream meanders and produces eddies, small offshoots from the current with a rotating circulation. something like whirlpools.

Gulf stream



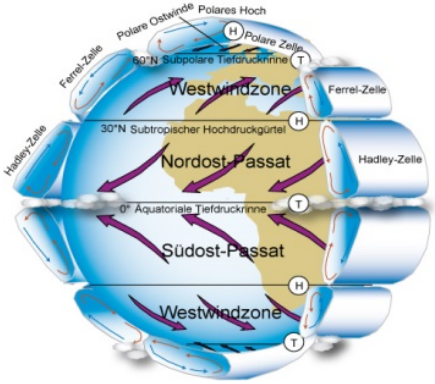


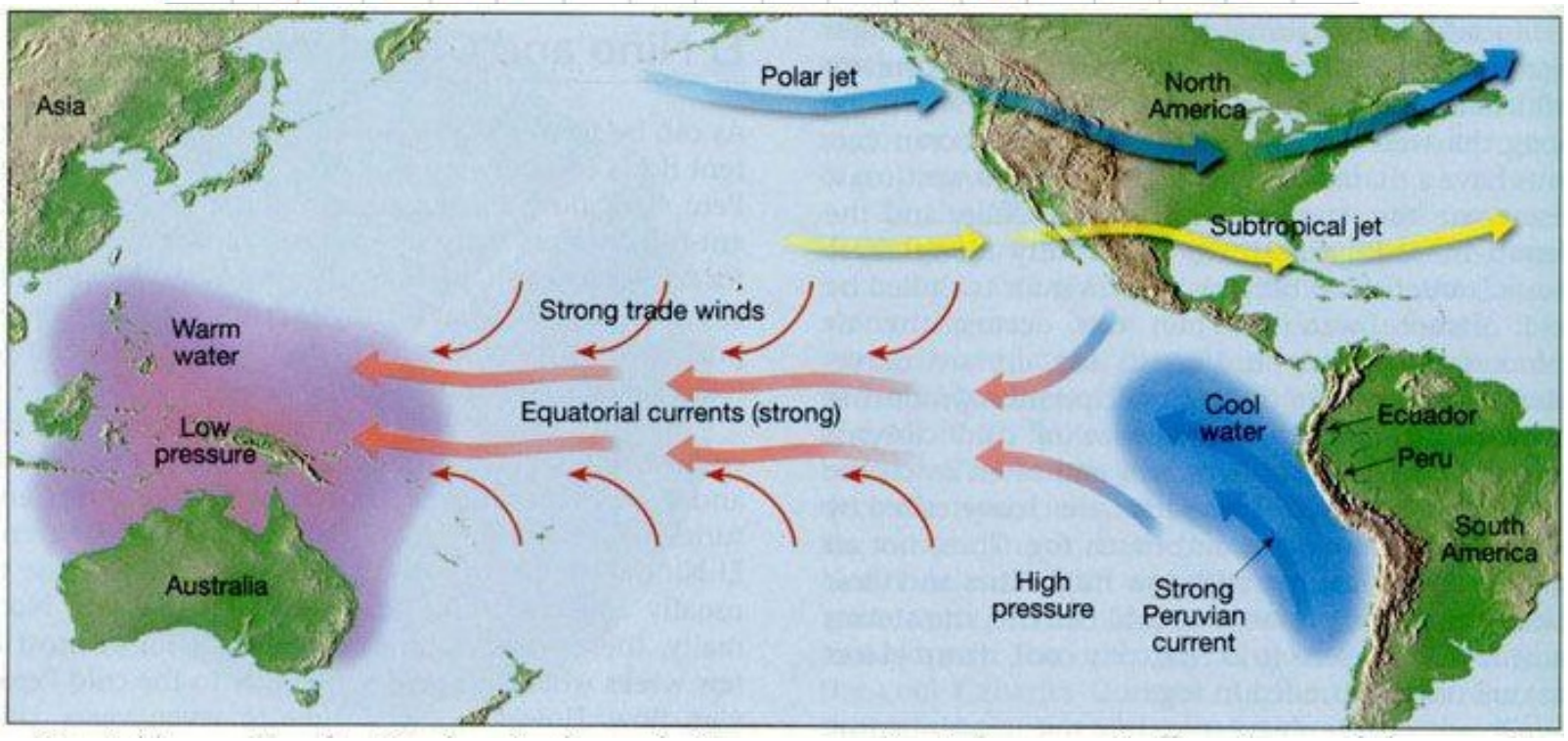
rot = warme Strömung
schwarz = kalte Strömung
Orange = Wasser im 20 ° Bereich



Gulf stream: core area (white)
flow velocity 2 m/s.
source: Gyory, Mariano, Ryan, CIMAS
http://oceancurrents.rsmas.miami.edu/

Humboldt (Peru) Current





Humboldt (Peru) Current

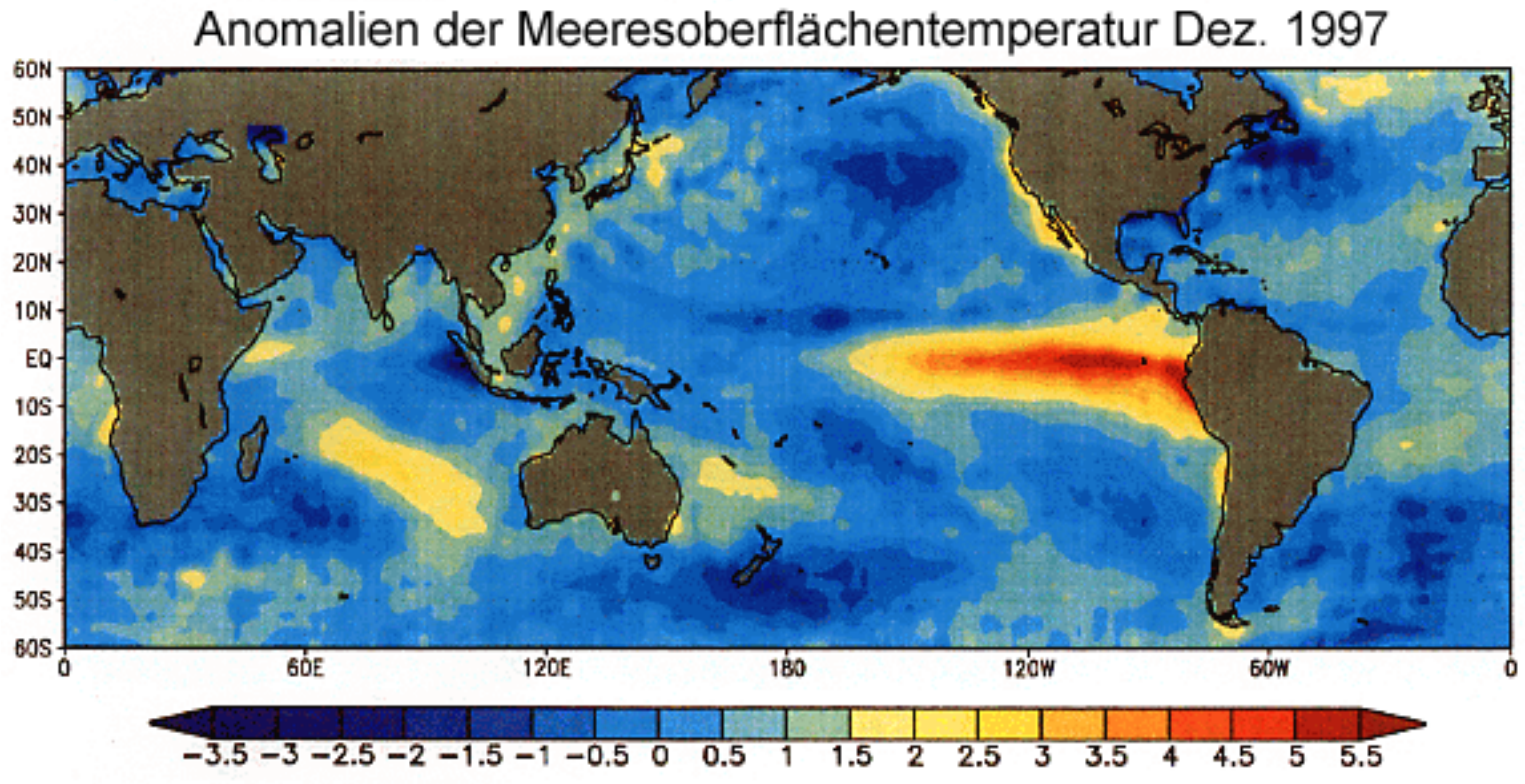
Humboldt (Peru) Current

Camanchaca - dense cloud banks in front of the Chilean coast (do not produce rain)

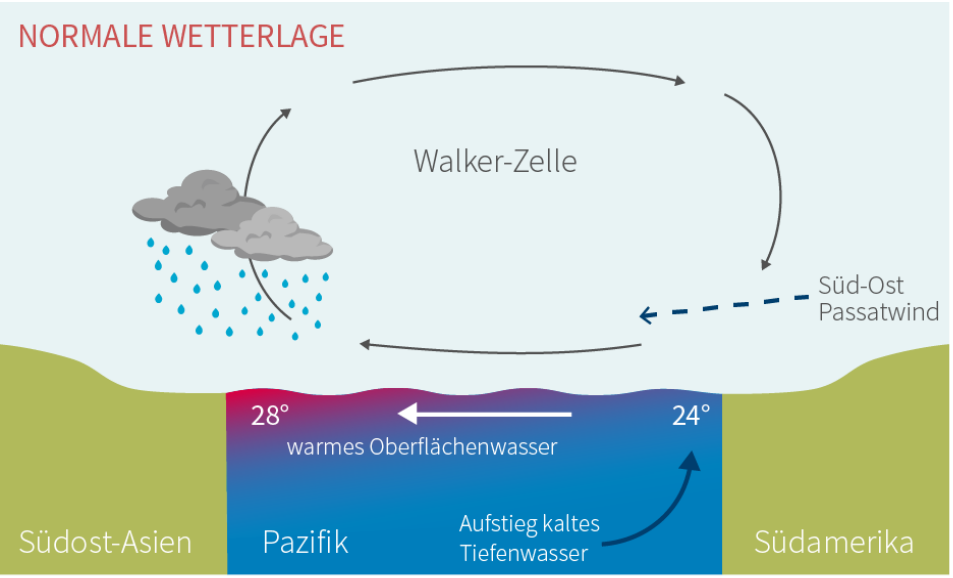
Humboldt current cools the warm air above it producing clouds of fog which blow over the land in the mornings

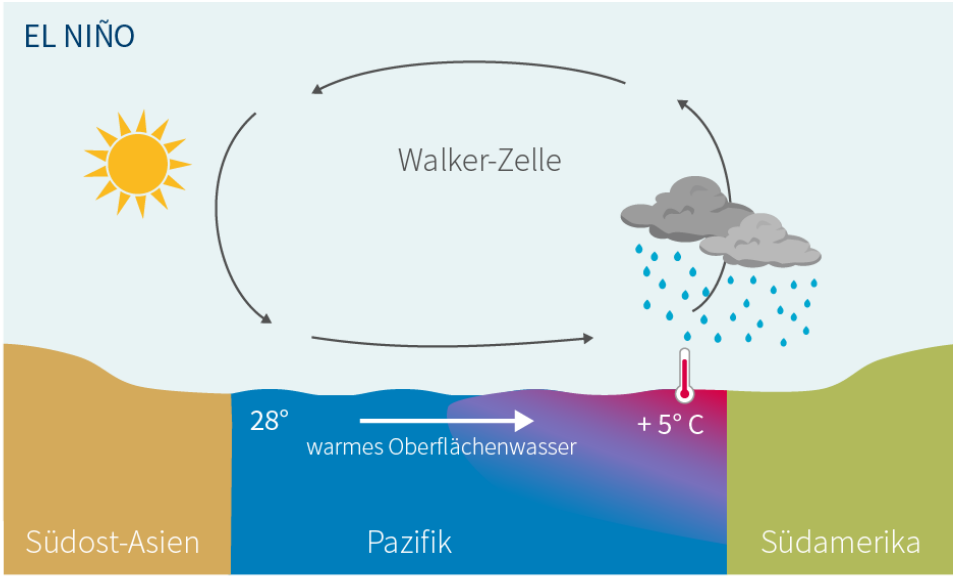
Camachaca allow plants, and animals such as guanacos to survive in an area that would otherwise be too dry

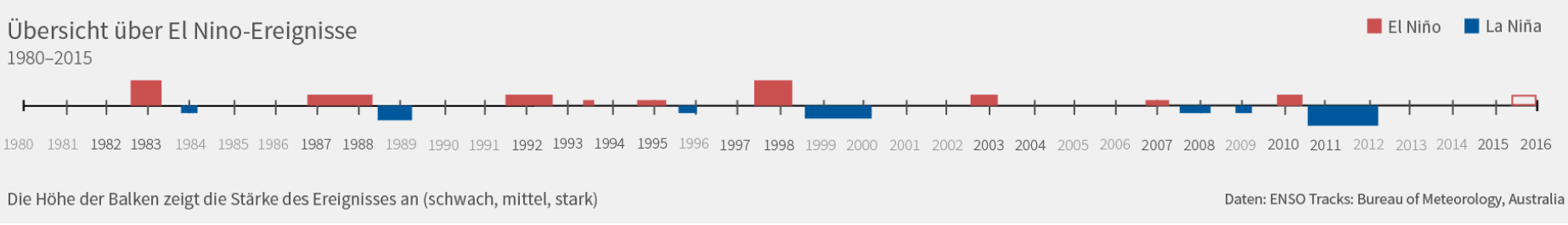
El Niño Southern Oscillation (ENSO)



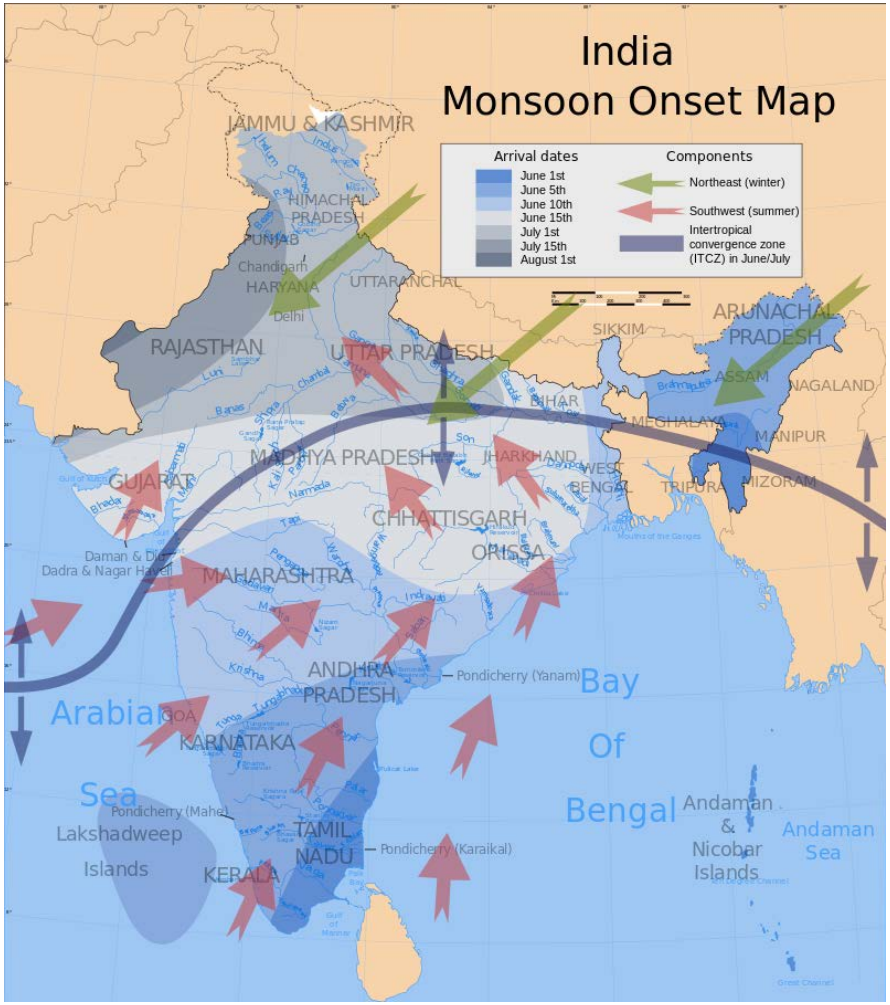
El Niño Southern Oscillation (ENSO)

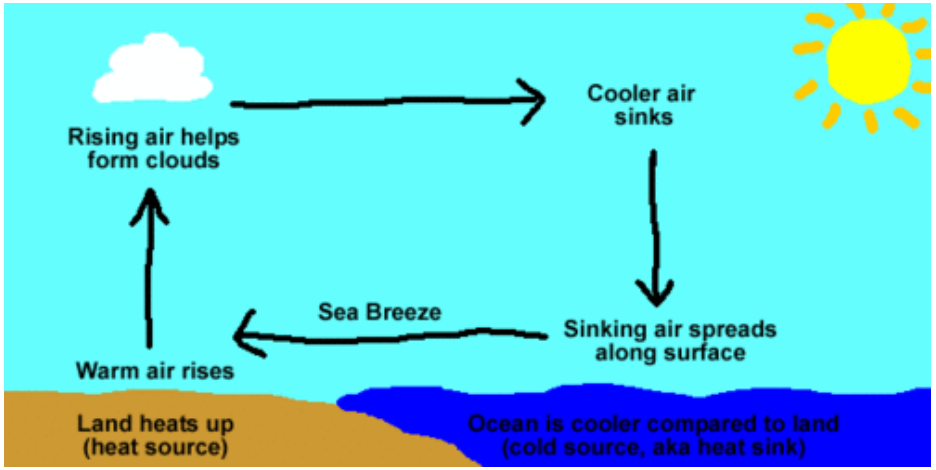


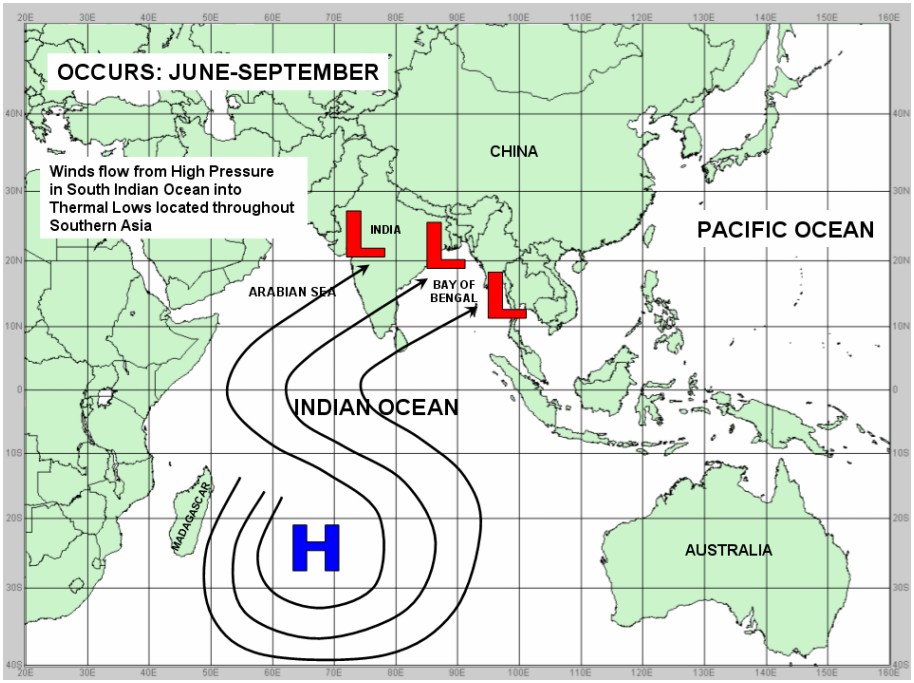




Indian monsoon current



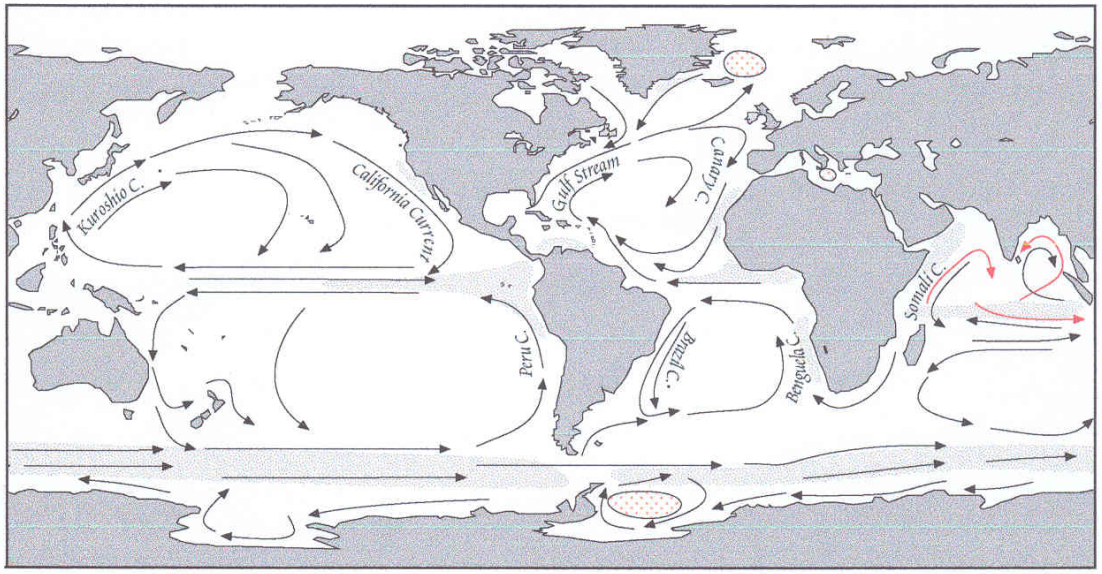




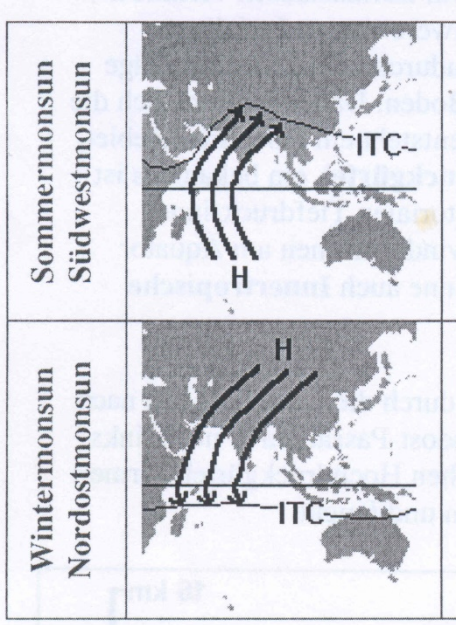
Southwest Monsoon

Indian monsoon current

Surface water circulation



from: White *Geochemistry*



Circulation in Indian Ocean undergoes radical seasonal changes in response to the Monsoons

Somali Current, which flows to the southwest along the African Coast in northern hemisphere winter, reverses direction to flow northeastward in northern hemisphere summer (red)