# 11857 Extreme Climate & physical nature
# 21/2-2018

## Oceanograhpy

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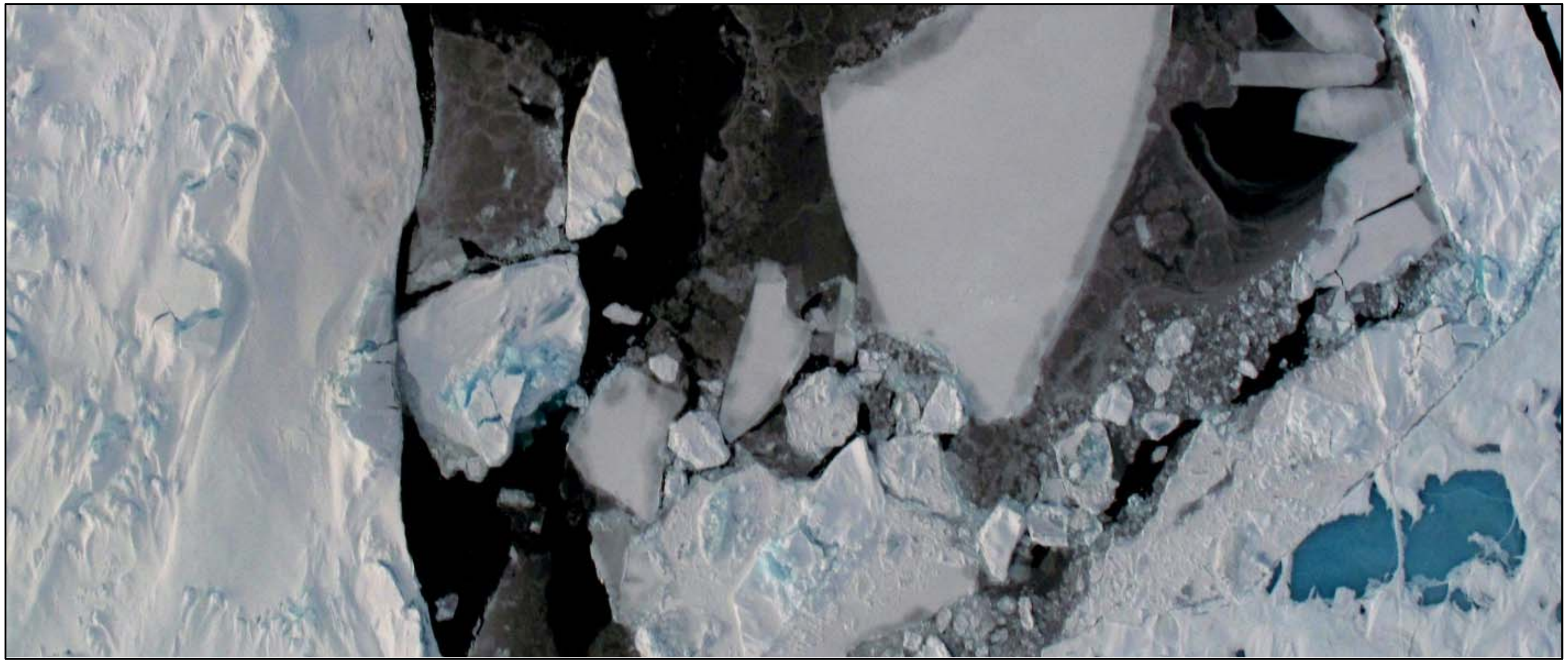
Prepared by: Henriette Skourup



# Overview of today

Content:

Paper presentation: Firn compaction (Nicolaj)
Repetition questions from last lecture
Goal of today
My background
Sea ice in global and local perspective
Sea ice extent, type and drift
Paper presentation: Sea ice (Evelina)
Satellite observations if extent, type and drift
Exercise

# Goals

- Sea ice mass balance
- Knowledge of sea ice definitions (new words ☺)
- Explain sea ice extent, type, and drift
- Observation methods
- Exercise in sea ice remote sensing of extent, type, and drift

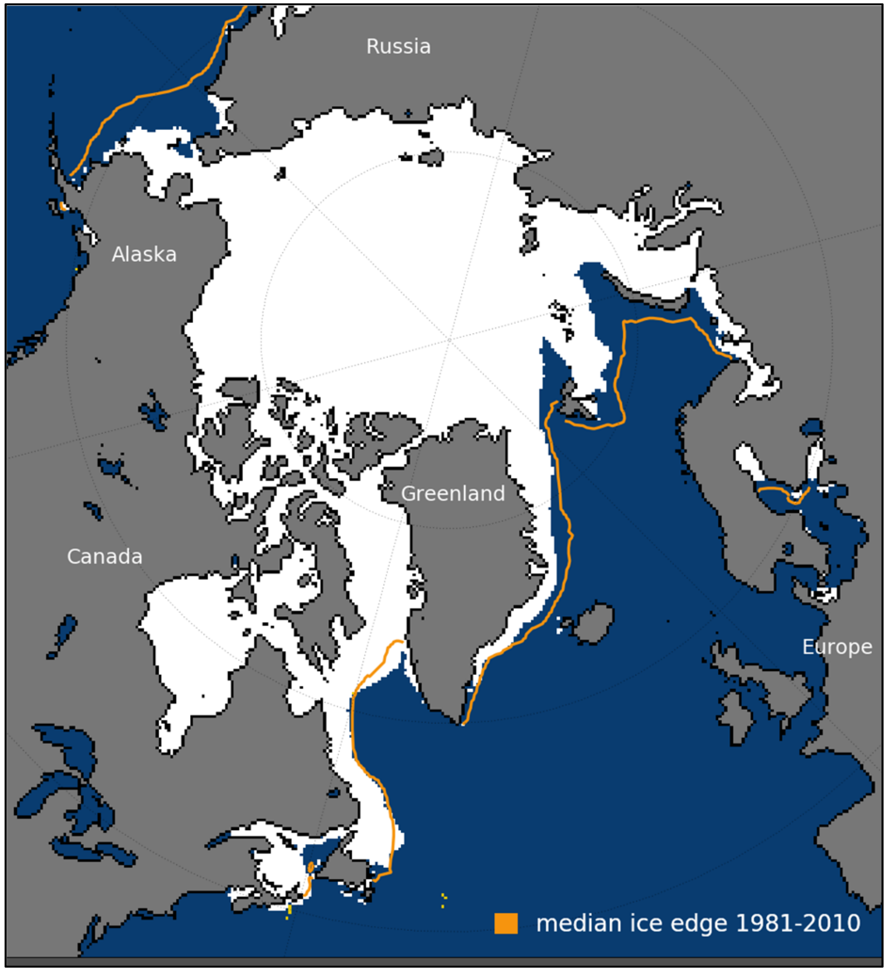
- Feedback: What was good/not so good ?!? Did we reach our goals ?!?

# Oceans of the Arctic


*National Snow and Ice Data Center, Boulder, Colorado, US*

# Sea ice

Sea ice extent, February 12, 2018




*National Snow and Ice Data Center, Boulder, Colorado, US*

# Ocean circulations

1) Thermohaline (temperature and salt content)
2) Wind driven

# Thermohaline circulation

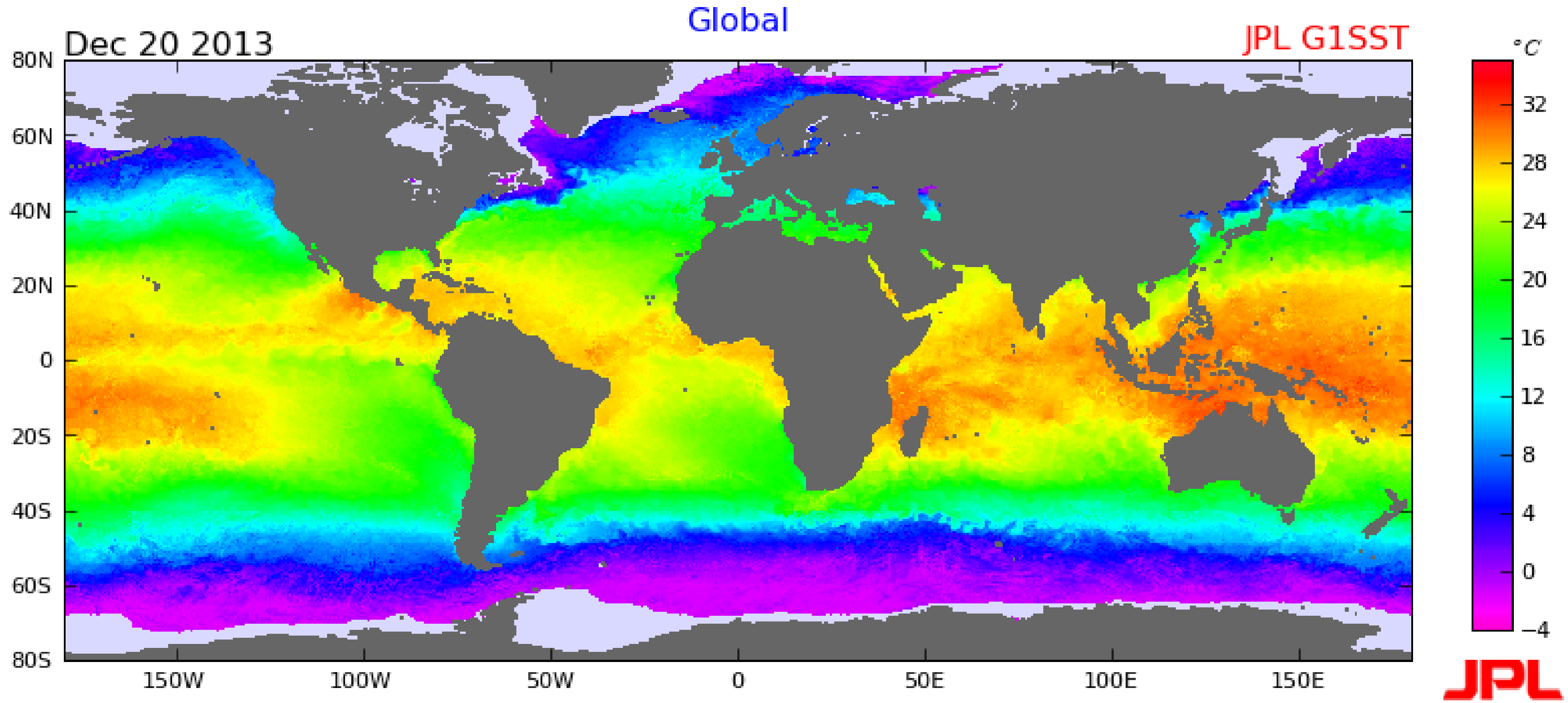
The thermohaline circulation is driven by sinking of dense ocean water

Changes in density depends on changes in:

- Temperature
- Salinity

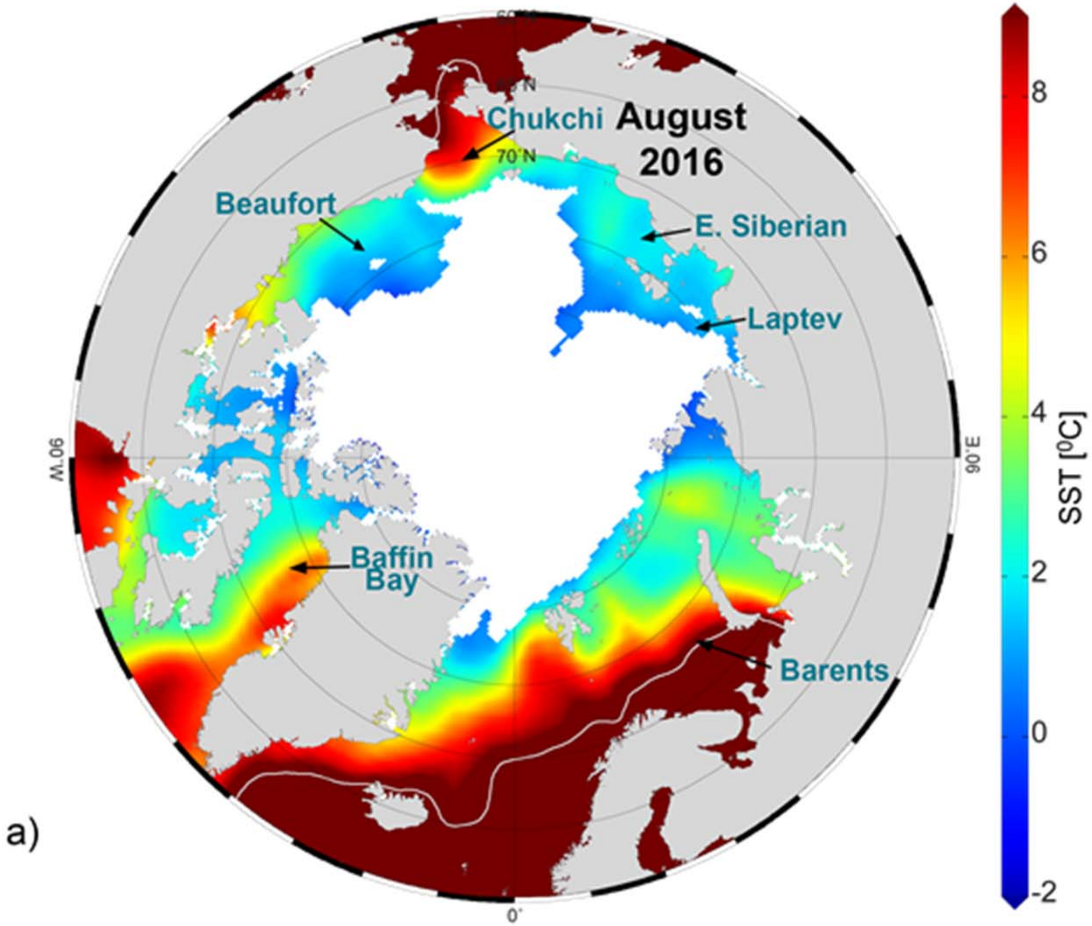
Cold and salty water sinks

# Global sea surface temperature (SST)




This is a daily, global Sea Surface Temperature (SST) data set produced on December 20th, 2013 at 1-km resolution (also known as ultra-high resolution) by the JPL ROMS (Regional Ocean Modeling System) group.

# Arctic sea surface temperature (SST)

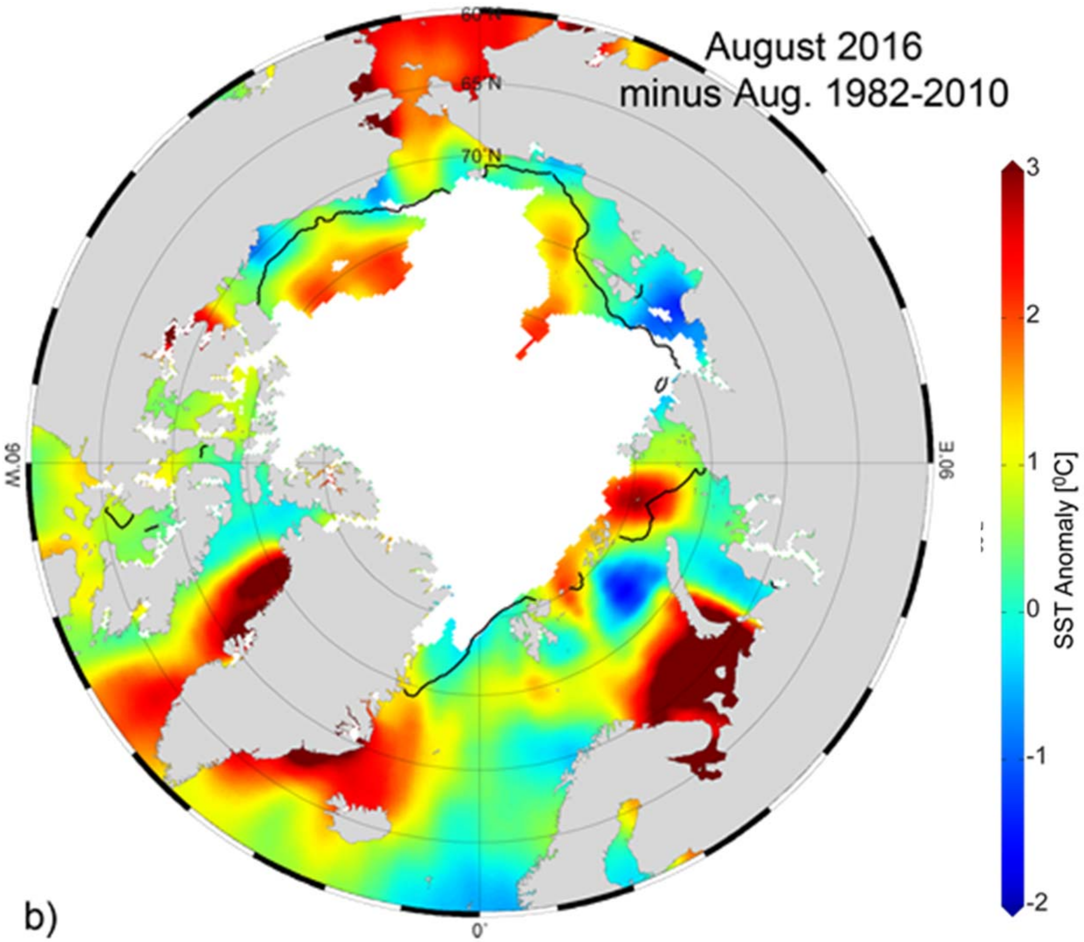



*http://www.arctic.noaa.gov/Report-Card/Report-Card-2016/ArtMID/5022/ArticleID/285/Sea-Surface-Temperature*

Summer sea surface temperatures in the Arctic Ocean are set by absorption of solar radiation into the surface layer. In the Barents and Chukchi seas, there is an additional contribution from advection of warm water from the North Atlantic and Pacific Oceans (for a recent assessment of this in the Chukchi Sea, see Serreze et al., 2016).

SST data from the NOAA Optimum Interpolation (OI) SST Version 2 product (OISSTv2), which is a blend of in situ and satellite measurements (Reynolds et al. 2002, 2007).

# Arctic sea surface temperature (SST)



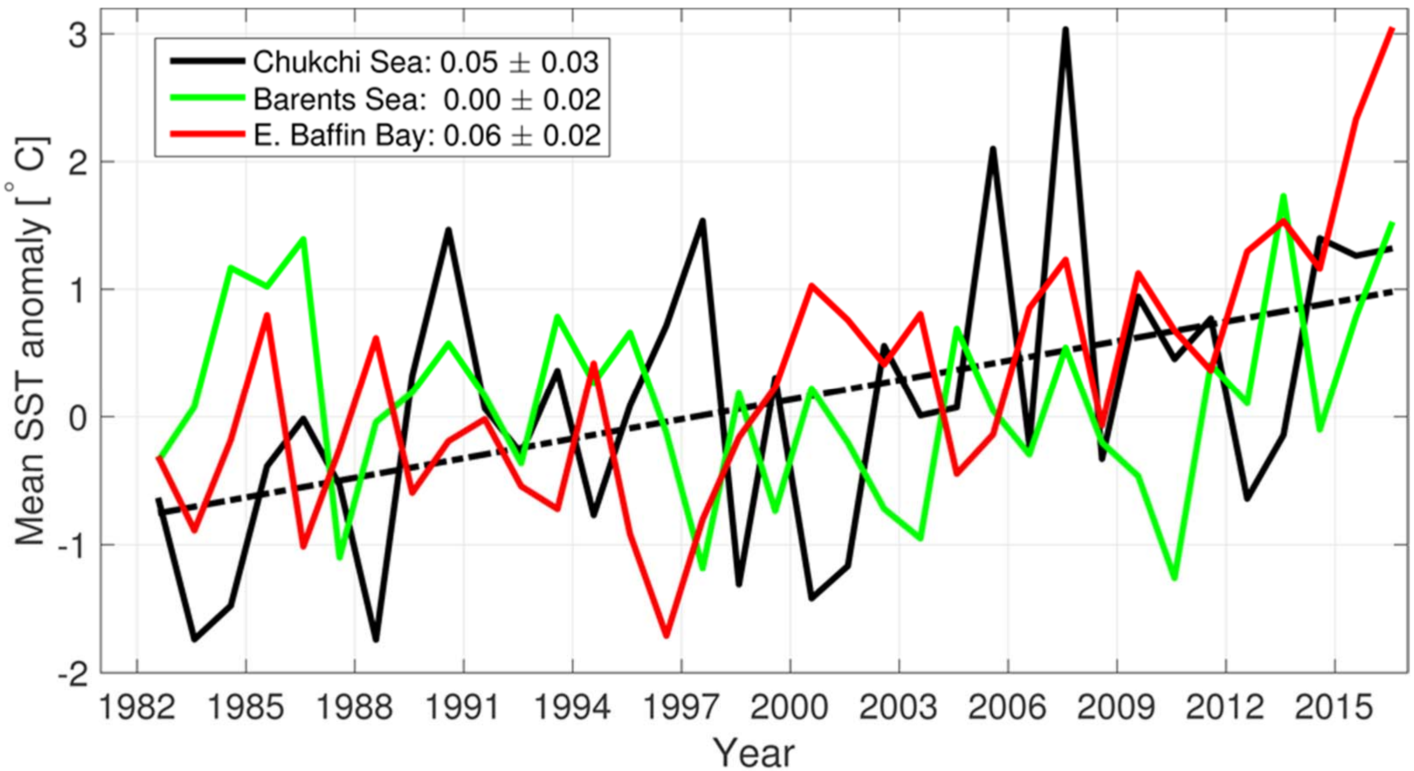

*http://www.arctic.noaa.gov/Report-Card/Report-Card-2016/ArtMID/5022/ArticleID/285/Sea-Surface-Temperature*

Sea surface temperatures (SSTs) in August 2016 were up to +5° C warmer than the 1982-2010 August mean in regions of the Barents and Chukchi seas, and off the east and west coasts of Greenland.

In the Arctic Basin, spatial patterns of August 2016 SST anomalies relative to the 1982-2010 August mean are linked to regional variability in sea-ice retreat, regional air temperature, and advection of waters from the Pacific and Atlantic oceans.

# Arctic sea surface temperature (SST)

The Chukchi Sea and eastern Baffin Bay show significant ocean surface warming trends; linear trends over 1982-2016 indicate August SSTs are increasing at ~0.5° C/decade in these regions.



# Salinity

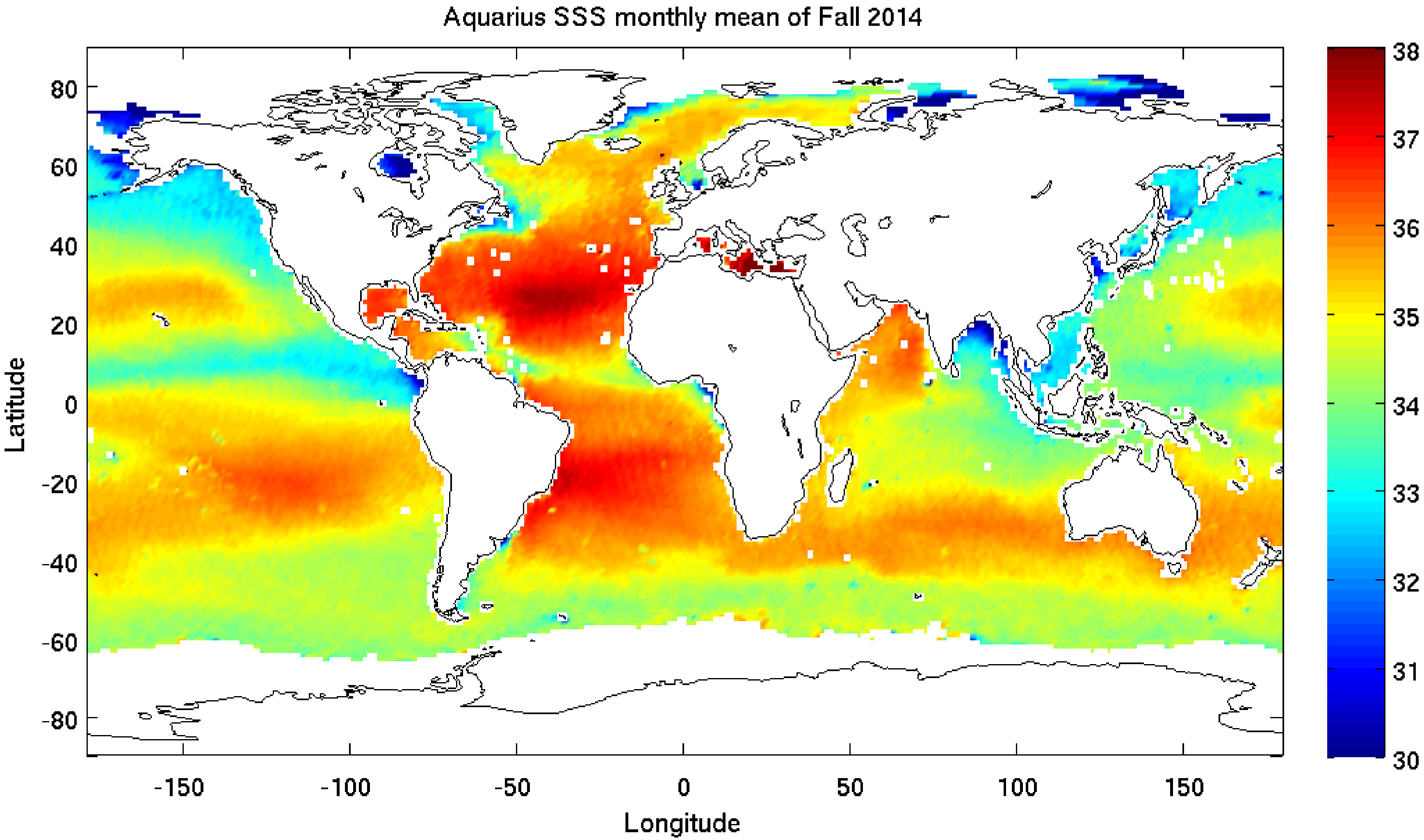
Salinity is a measure of the concentration of dissolved salts in water.

Until recently, a common way to define salinity values has been *parts per thousand (ppt)*, or kilograms of salt in 1,000 kilograms of water.

Today, salinity is usually described in *practical salinity units (psu)*, a more accurate but more complex definition.

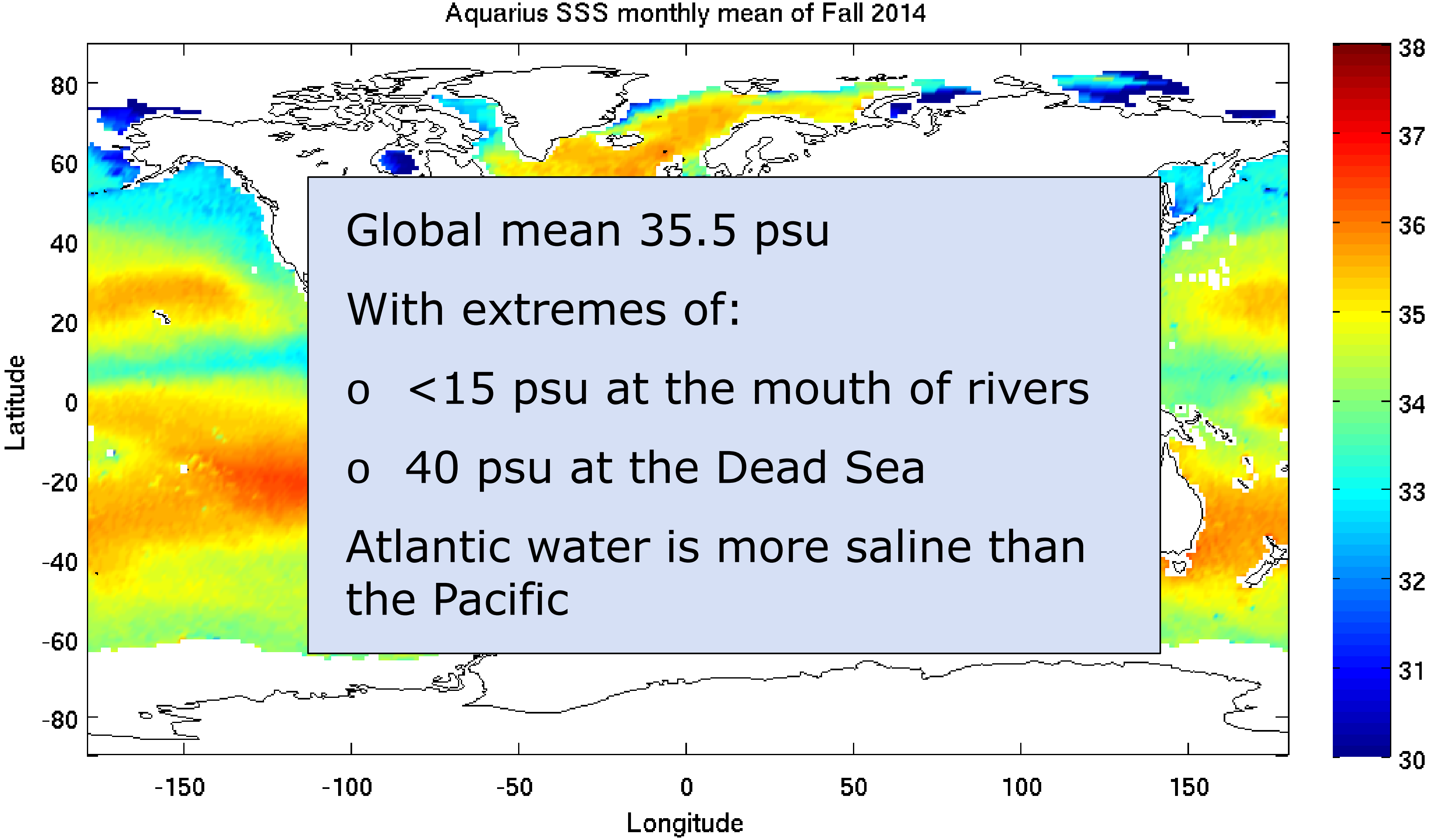
Nonetheless, values of salinity in ppt and psu are nearly equivalent.

# Global surface salinity




*https://aquarius.umaine.edu/cgi/ed_aq_datatool.htm*

# Global surface salinity




Global mean 35.5 psu

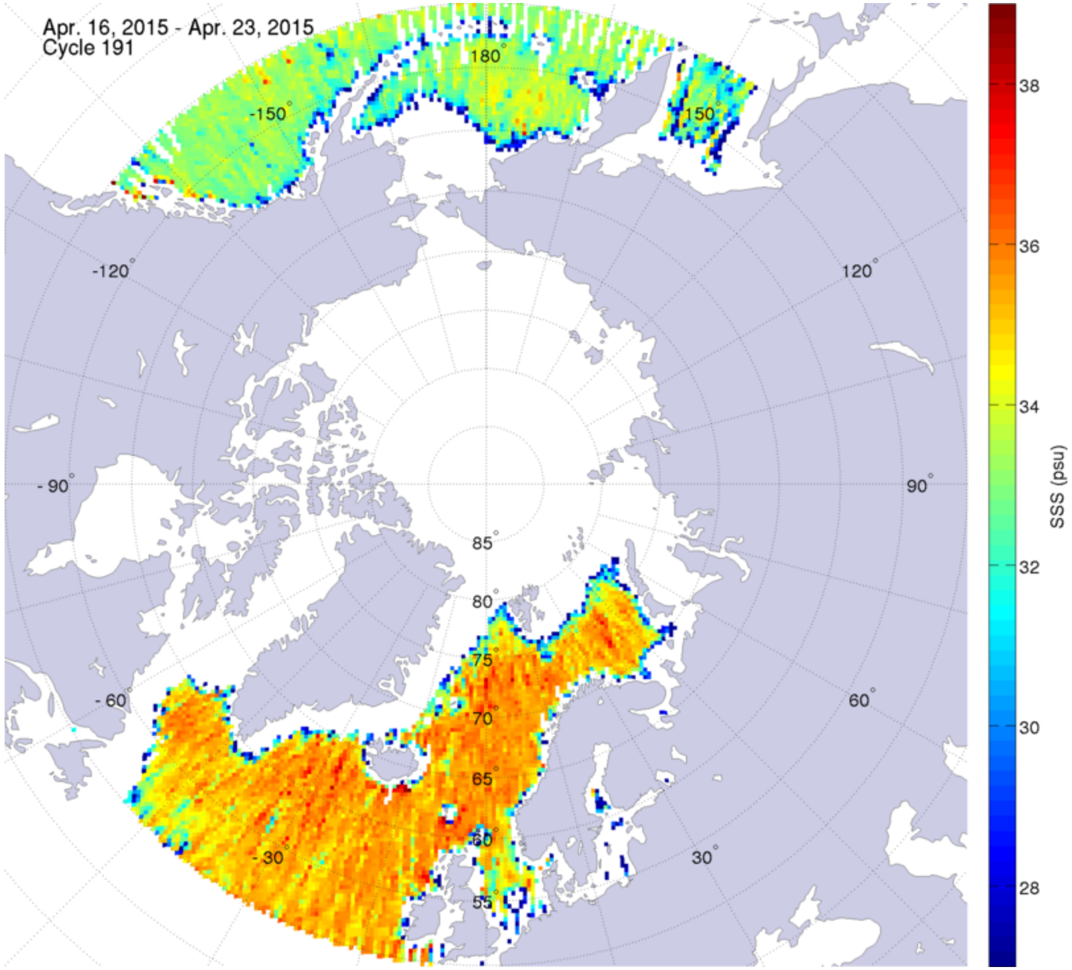
With extremes of:

- <15 psu at the mouth of rivers
- 40 psu at the Dead Sea

Atlantic water is more saline than the Pacific

*https://aquarius.umaine.edu/cgi/ed_aq_datatool.htm*

# Arctic Surface Salinity




*https://aquarius.umaine.edu/cgi/gal_latitudes_sss.htm?id=2014#northern*

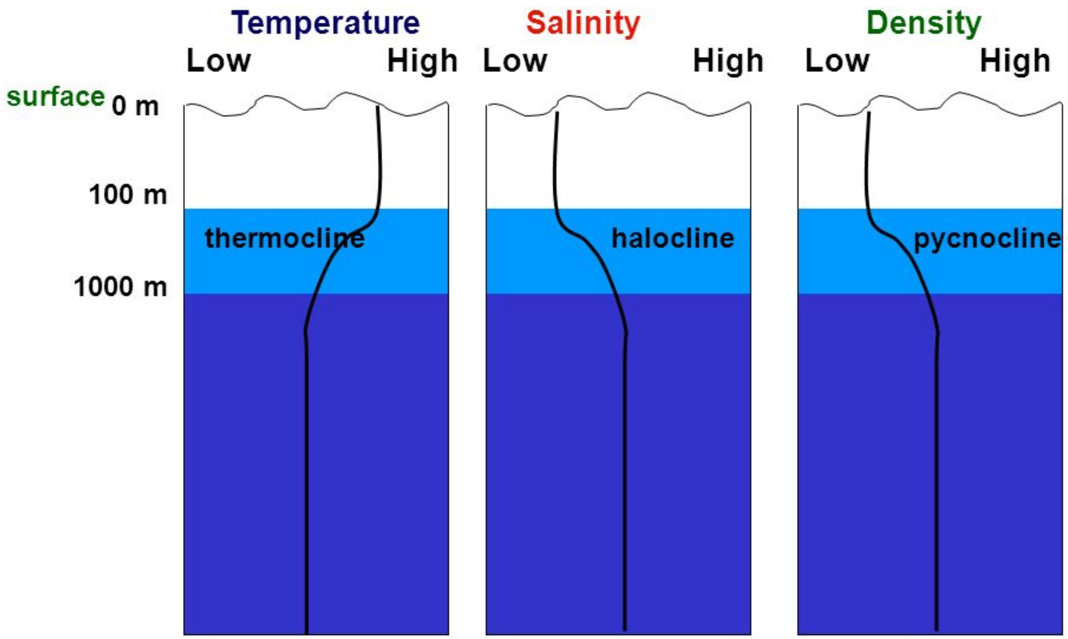
# … clines

A relative thin (about 100 m) intermediate layer of rapidly changing

- temperature is called a thermocline

- salinity is called a Halocline

The sum of the two results in a layer of changing density called a pycnocline




Thermocline + Halocline = Pycnocline

# Exercise - Satellite observations

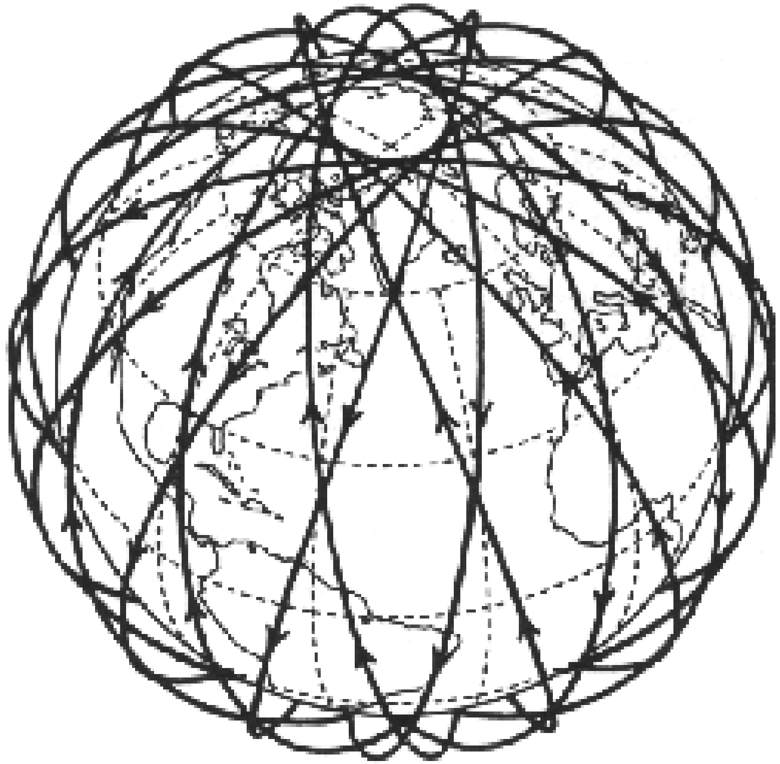
- ➢ Surface temperatures
- ➢ Surface salinities

- o What are the techniques
- o Missions ?
- o What are the limitations ?

# Exercise - Satellite observations

- What are the techniques
- Missions ?
- What are the limitations ?

# Satellite observations – Polar Gap



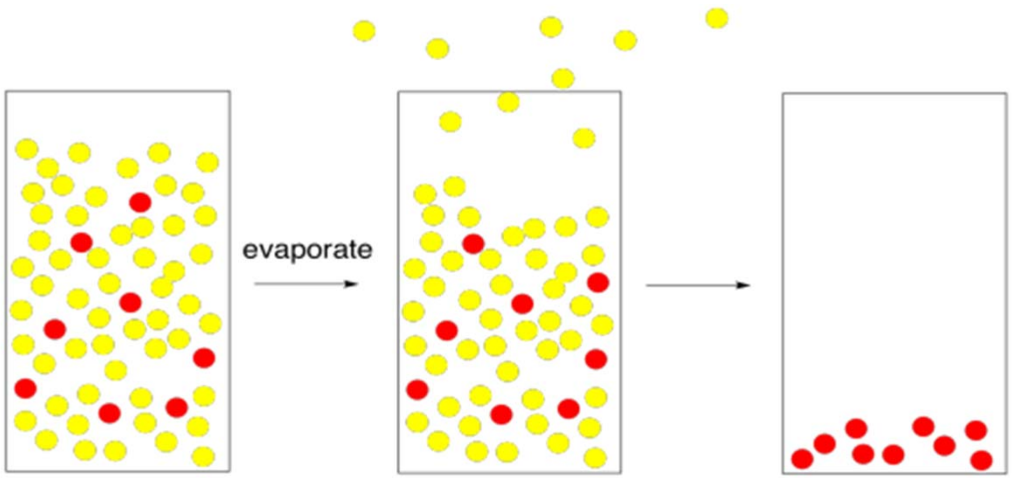
# Thermohaline circulation

In Polar regions:

- Processes which increases the density driving the thermohaline circulation depends critically on the water being sufficiently cold and salty.
- Changes in salinity affect ocean density more than changes in temperature.
- The increase in salinity can be obtained by either of the two processes:
  - Evaporation by cooling
  - Formation of sea ice

# Evaporation by cooling

It is only the water molecules which evaporates, the salt molecules stay behind and increses the density of the surface layer, which sinks



# Formation of sea ice

- As the ocean water begins to freeze, ice crystals form.
- **The crystals expel salt into the water increasing the water's salinity.**
- Some salty liquid called brine is trapped in the ice crystals.
- Depending on age, the salinity of sea ice varies between 2-5 psu.
- Older ice is less saline, as the as the brine is drained out by gravity over time leaving empty air pockets in the older ice.

A photograph in natural light showing elongated tubes that form as brine pockets trapped between the ice crystals. The image is 5 millimeters in width.

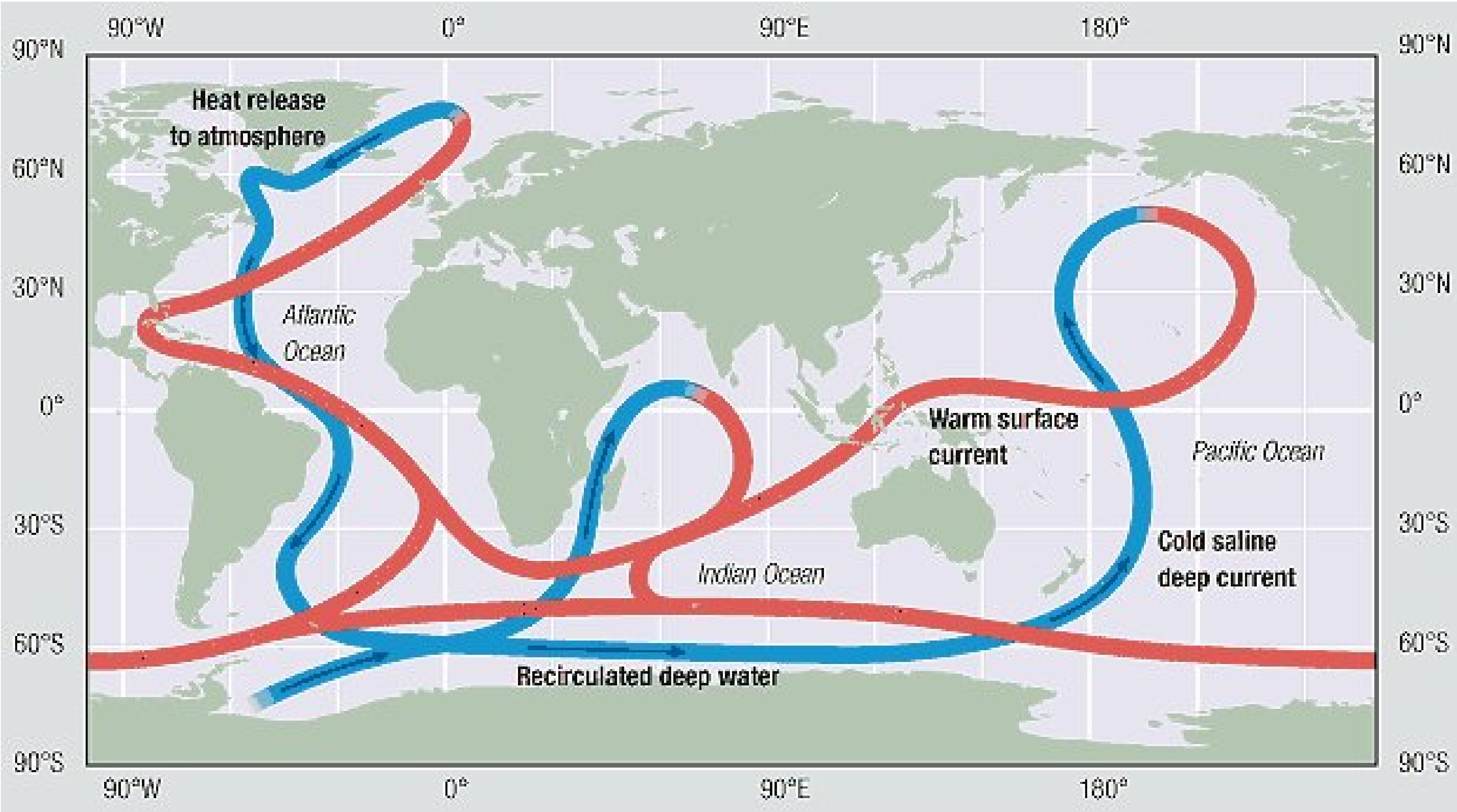
—Photo courtesy of Ted Maksym, United States Naval Academy.

# Polar drivers of the thermohaline circulation

The main thermohaline circulation is primarily driven by increase in salinity by:

- Evaporation by cooling in the Arctic forming the North Atlantic Deep Water (NADW)
- Formation of sea ice in Antarctica

# Thermohaline circulation




*Source: IPPC 2001*

# Thermohaline circulation

Any factor that changes the state of the conditions for circulation, can result in a slow-down of the thermohaline circulation, and thereby dramatically influence the climatic state and driving further climate change.

# Thermohaline circulation

Thermohaline circulation can be disrupted if the ocean surface receives a layer of fresh water.

How might this happen? One mechanism involves changes in Arctic winds that move sea ice from the Arctic Ocean through Fram Strait into the North Atlantic.

When the ice moves south through the Fram Strait into the North Atlantic, it melts, creating a layer of fresh water over the ocean surface. This fresh water is less dense than salty water, so it tends to stay at the top of the ocean. This lower density discourages the normal process of sinking at high latitudes (poles) that supports thermohaline circulation, which makes it harder to move the warm water north from the equator.

Strong evidence shows that this stagnation process happened over a period of several years in the late 1960s and early 1970s, when extra fresh water entered the North Atlantic and affected the climate of northern Europe. Scientists call this event the "Great Salinity Anomaly."

National Snow and Ice Data Center ... https://nsidc.org/cryosphere/seaice/environment/global_climate.html

# Thermohaline circulation

- A decrease in salinity can be obtained by:
  - Melting of sea ice
  - Melting of icebergs
  - Precipitation
  - Run-off from rivers

# Arctic Ocean – Surface currents

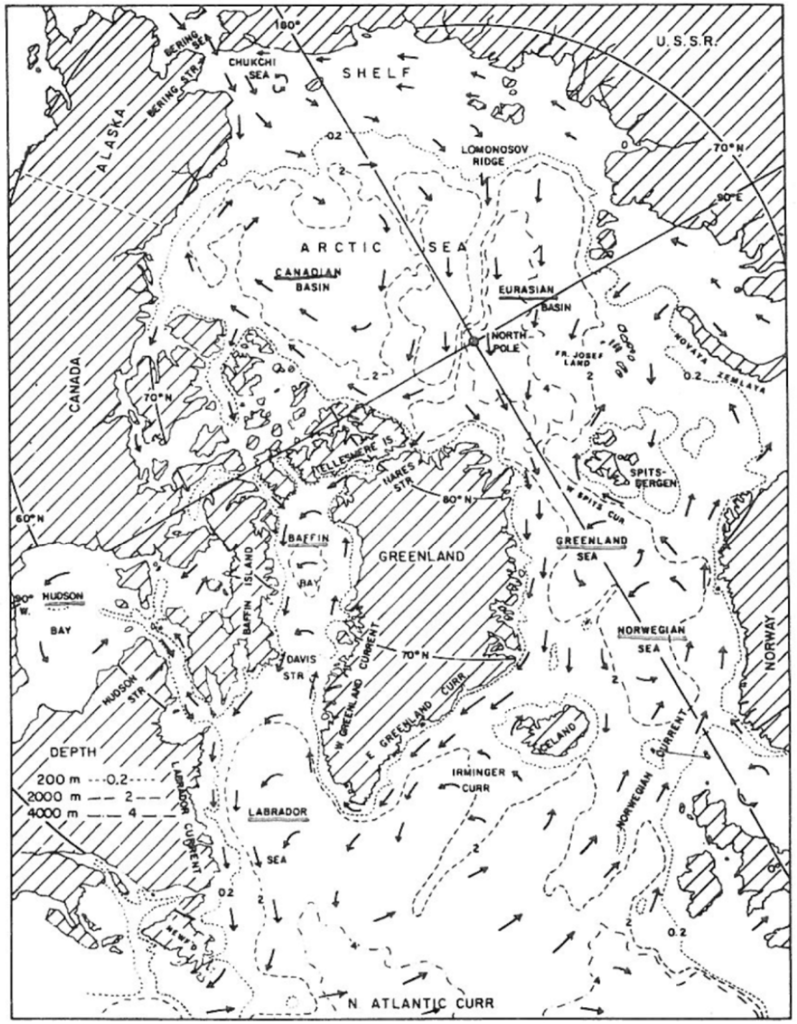



FIG. 7.26. Arctic Sea and North Atlantic adjacent seas: bathymetry and surface currents.

Main surface currents:

- Beaufort Gyre
- Transpolar drift stream
- East Greenland Current
- West Greenland Current

# Currents

In oceanography the volumetric rate of transport of ocean currents are often given in Sverdrup (Sv)

$$1 \text{ Sv} = 1 \times 10^6 \text{ m}^3/\text{sec}$$

# Geostrophic current

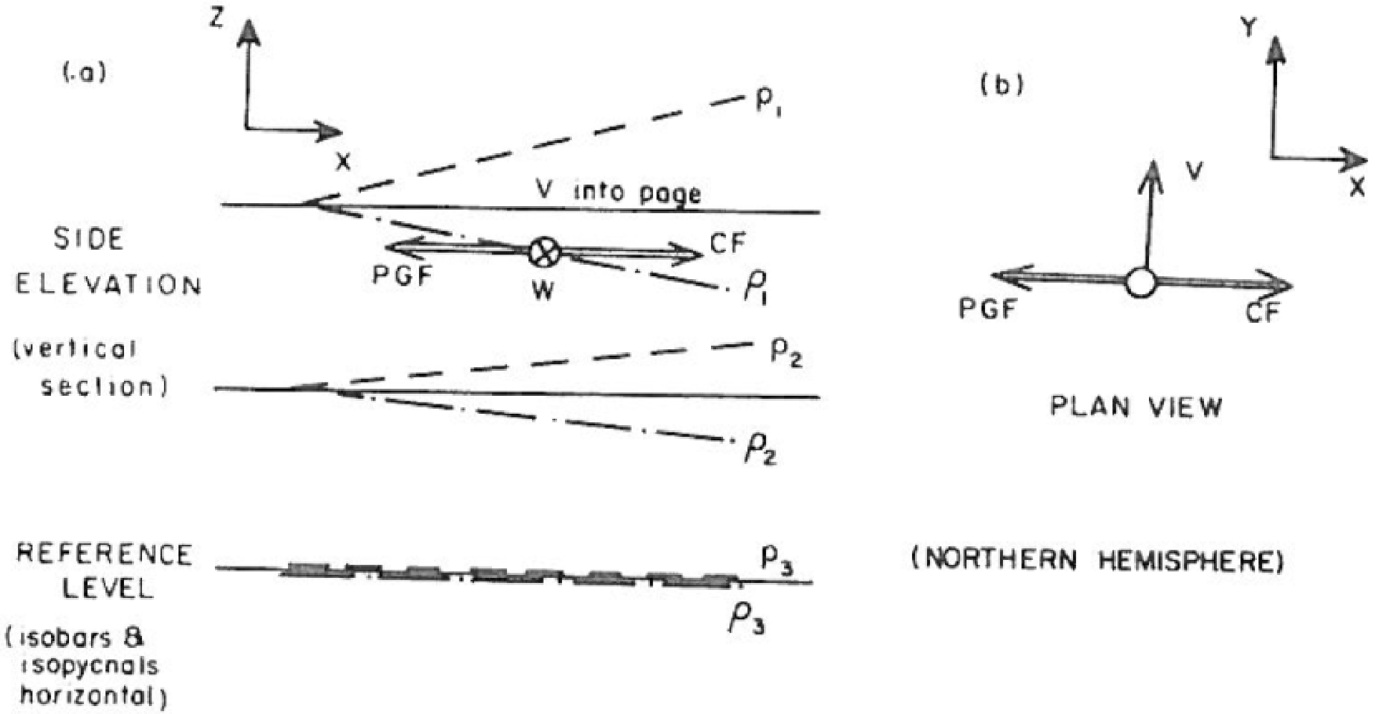
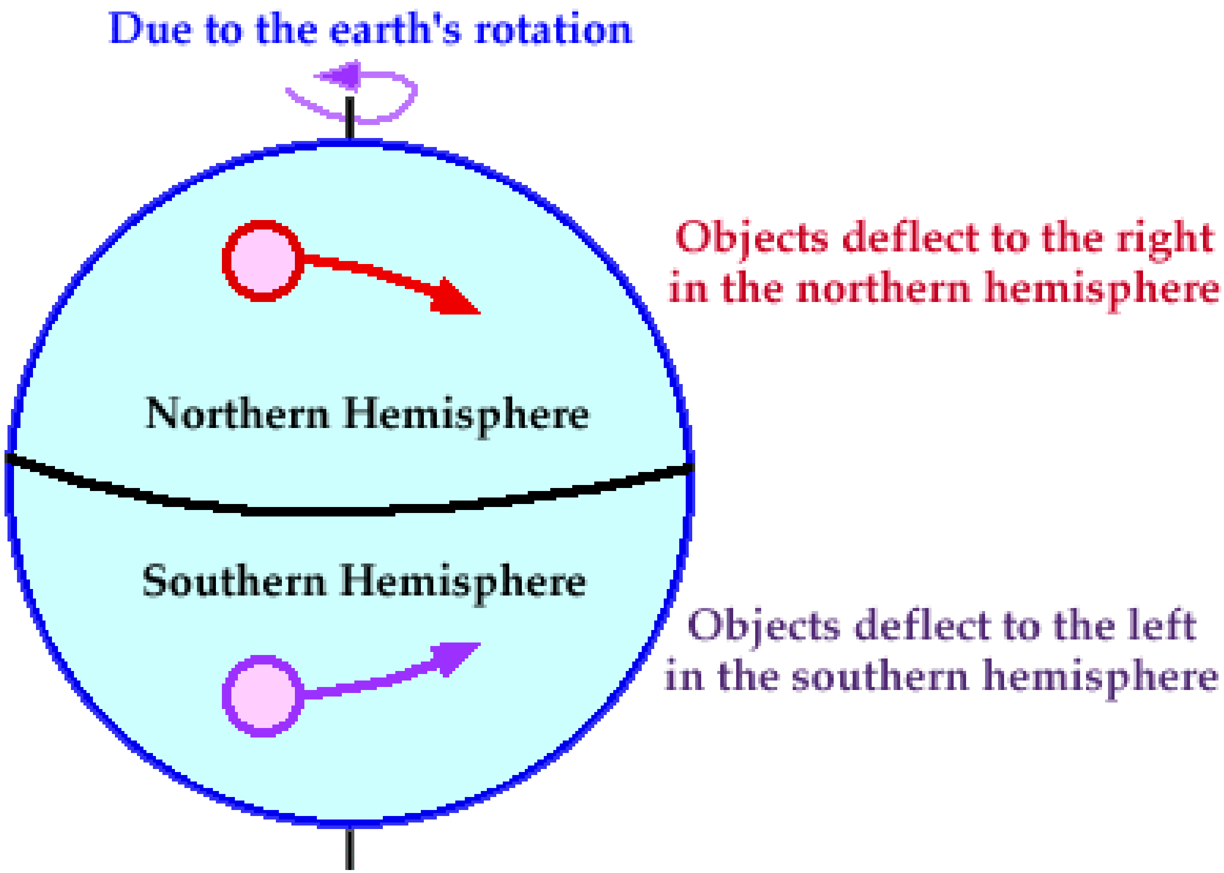



FIG. 6.4. (a) Schematic diagram (vertical section) of isobaric and isopycnal surfaces and corresponding steady-state, no friction, geostrophic flow direction (northern hemisphere) with pressure gradient force (*PGF*) and Coriolis force (*CF*) in balance, (b) plan view of the balanced forces and corresponding flow direction (*V*).

# Coriolis effect



# Geostrophic Equation

$$V\ 2\ \Omega\ sin\ \varphi = +\frac{1}{\rho}\frac{\partial p}{\partial x}$$

V = speed of flow

Ω = angular speed of rotation of the earth (7.29 x $10^{-3}$ $s^{-1}$)

Φ = geographic latitude

ρ = water density

∂p/∂x = Horizontal pressure gradient

# Geostrophic Equation

| Coriolis effect | Pressure gradient |
| --- | --- |

$$V\ 2\,\Omega\,\sin\varphi = +\frac{1}{\rho}\frac{\partial p}{\partial x}$$

V = speed of flow

Ω = angular speed of rotation of the earth (7.29 x $10^{-3}$ $s^{-1}$)

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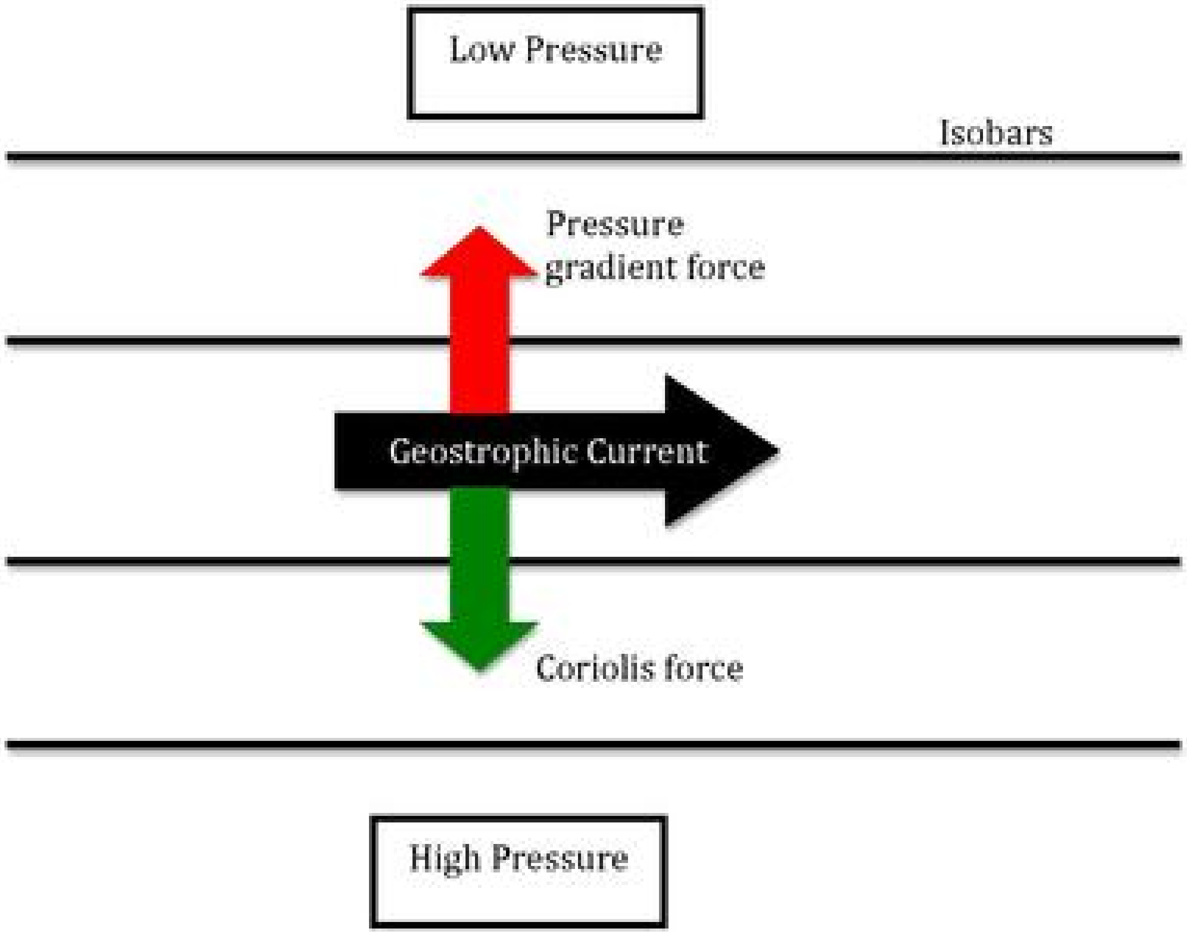
# Geostrophic Current



# MDT ?!?

MSS

And a dynamic part

Corresponding to the major currents …

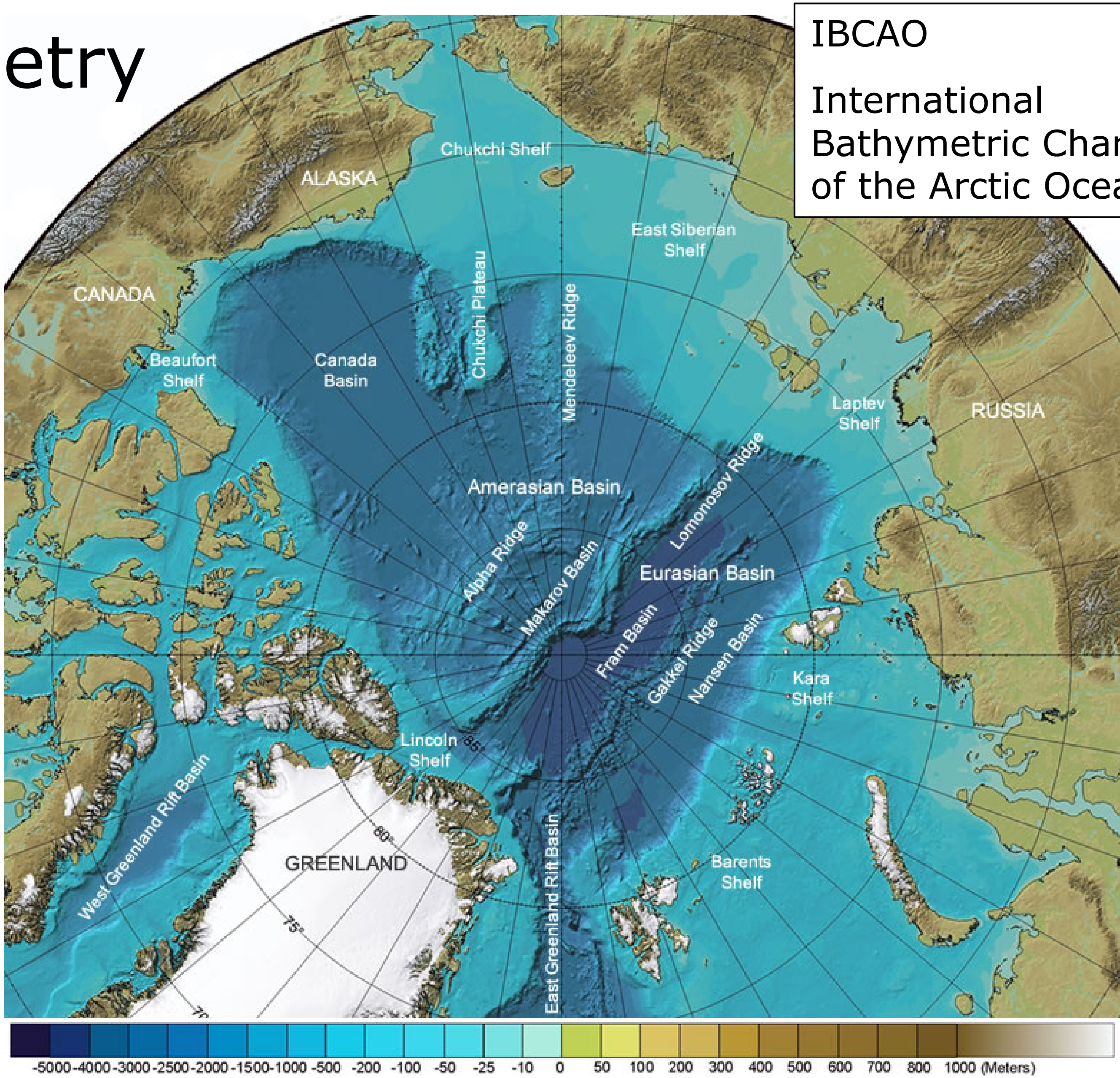
Armitage … geostrophic current …


TAKE
A
BREAK
Colourbox

# Bathymetry

IBCAO

International Bathymetric Chart of the Arctic Ocean



# Bathymetry - exercise

Take a look at the International Bathymetric Chart of the Arctic Ocean (IBCAO)

What are the 2 largest basins called, and how deep are they approximately ?

In what basin is the North Pole located ?

How shallow are the continental shelves ?

What are the three main ridges called ?

Identify the main Straits giving access to the Arctic and how deep are they at the deepest place:

Why is the bathymetry of interest ?

# Bathymetry - exercise

Take a look at the International Bathymetric Chart of the Arctic Ocean (IBCAO)

What are the 2 largest basins called, and how deep are they approximately ?

- The Canadian and Eurasian Basin up to 4.200m depth

In what basin is the North Pole located ?

- Eurasian Basin (Fram Basin)

How shallow are the continental shelves ?

- About 200 m deep

What are the three main ridges called ?

- Lomonosov Ridge, Gakkel Ridge and Alpha Ridge

Identify the main Straits giving access to the Arctic and how deep are they at the deepest place:

- Bering Strait (50m), Fram Strait (~2500m at the deepest), Canadian Islands and Svalbard/Franz Josef land (<200m)

Why is the bathymetry of interest ?

- Deep current circulation, Oil reservoirs, Right of land

# Arctic Ocean – Surface currents

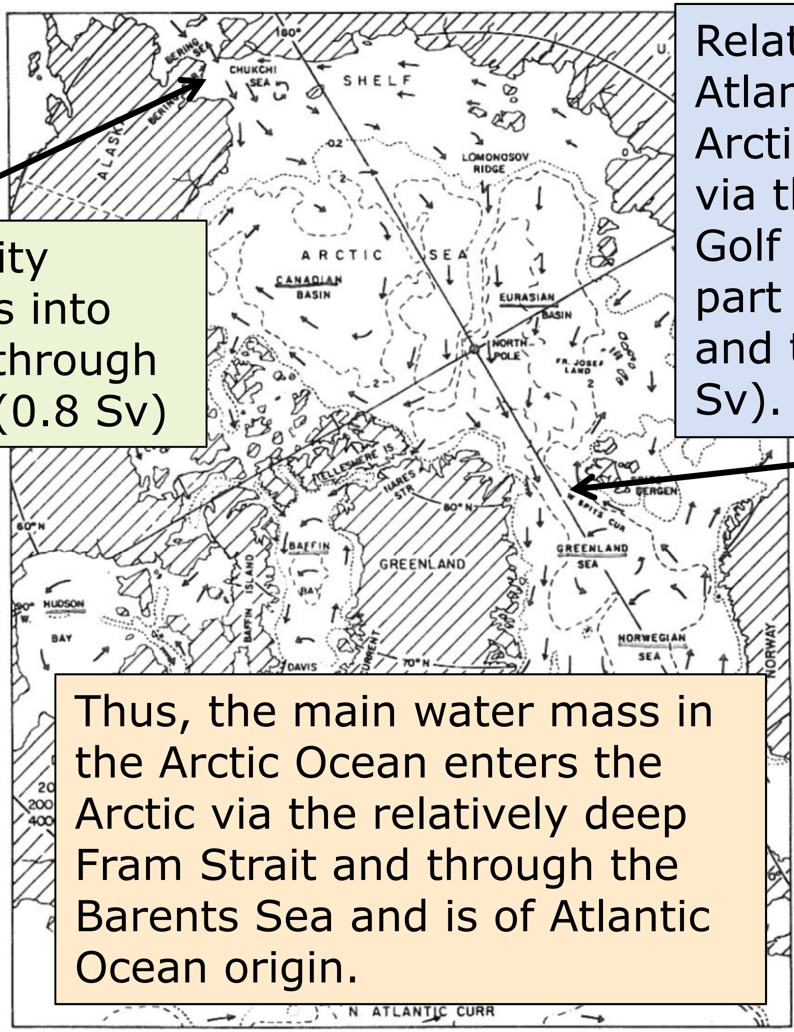


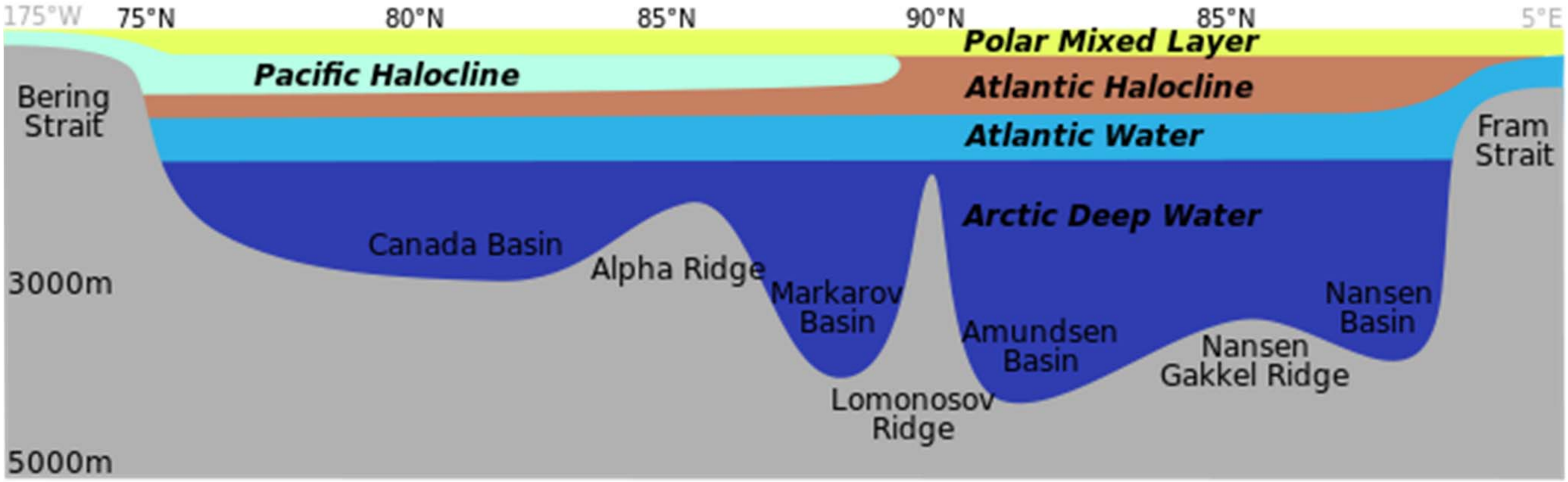

Fig. 7.26. Arctic Sea and North Atlantic adjacent seas: bathymetry and surface currents.

Relative low-salinity Pacific water flows into the Arctic Ocean through the Bering Strait (0.8 Sv)

Relative warm and saline Atlantic water flows into the Arctic Ocean from the Atlantic via the northern branch of the Golf Stream through Eastern part of Fram Strait (1-1.5 Sv) and through the Barents Sea (2 Sv).

Thus, the main water mass in the Arctic Ocean enters the Arctic via the relatively deep Fram Strait and through the Barents Sea and is of Atlantic Ocean origin.

# Arctic Ocean profile




*https://commons.wikimedia.org/w/index.php?curid=21104281*

# Arctic Ocean layers

The Polar mixed layer (PML) is a shallow (typically 50 m deep) cold and fresh (low salinity 27-33 psu) surface layer, which forms when the warm Atlantic and Pacific waters melt the sea ice from below.

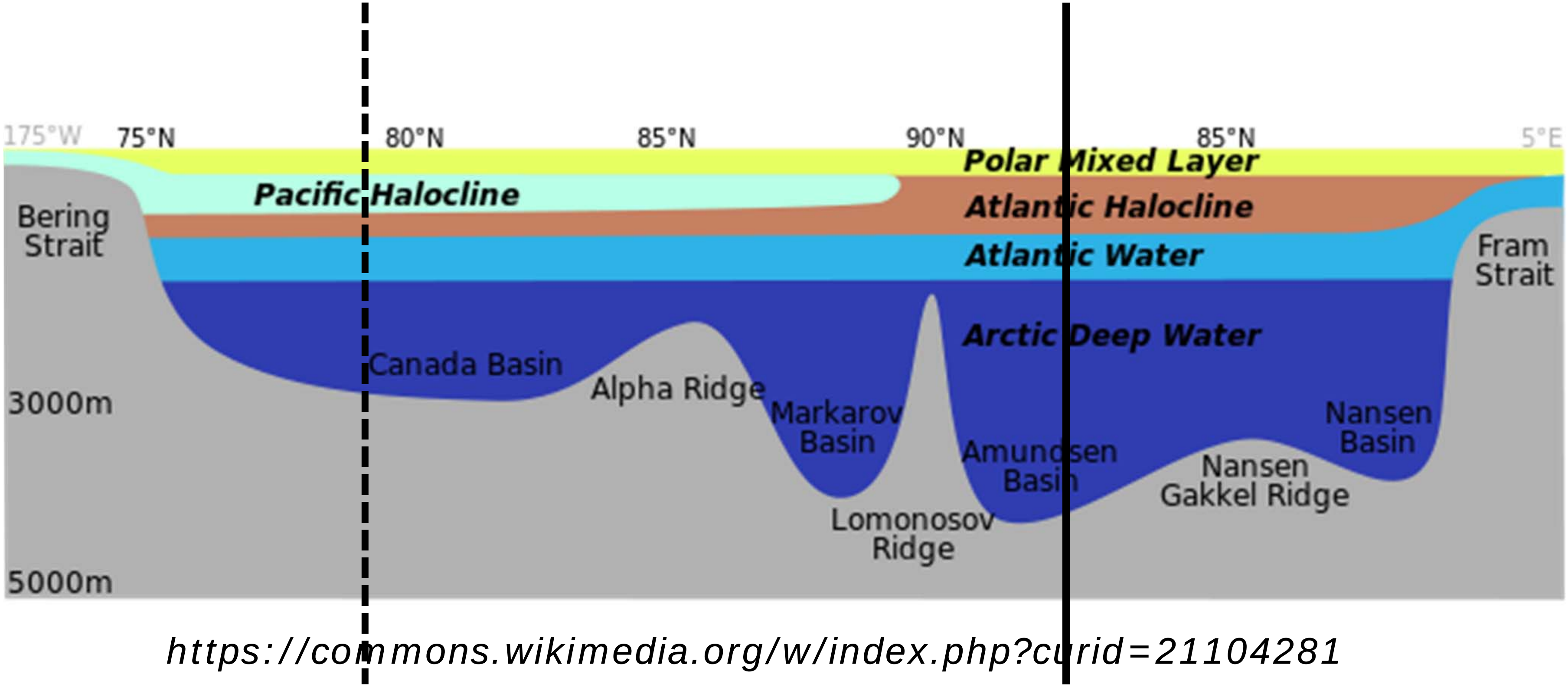
Atlantic Halocline: Is the intermediate layer between the cold fresh PML and warm saline Atlantic layer. In this intermediate layer about 100m thick the salinity changes abrupt.

Pacific Halocline: The Pacific is cold and salty compared to the PML, but less salty compared the Atlantic and forms a layer below PML and above the Atlantic Halocline

Atlantic Layer (200-500m): Relative warm and saline (34.5-34.8 psu) layer of Atlantic Ocean origin

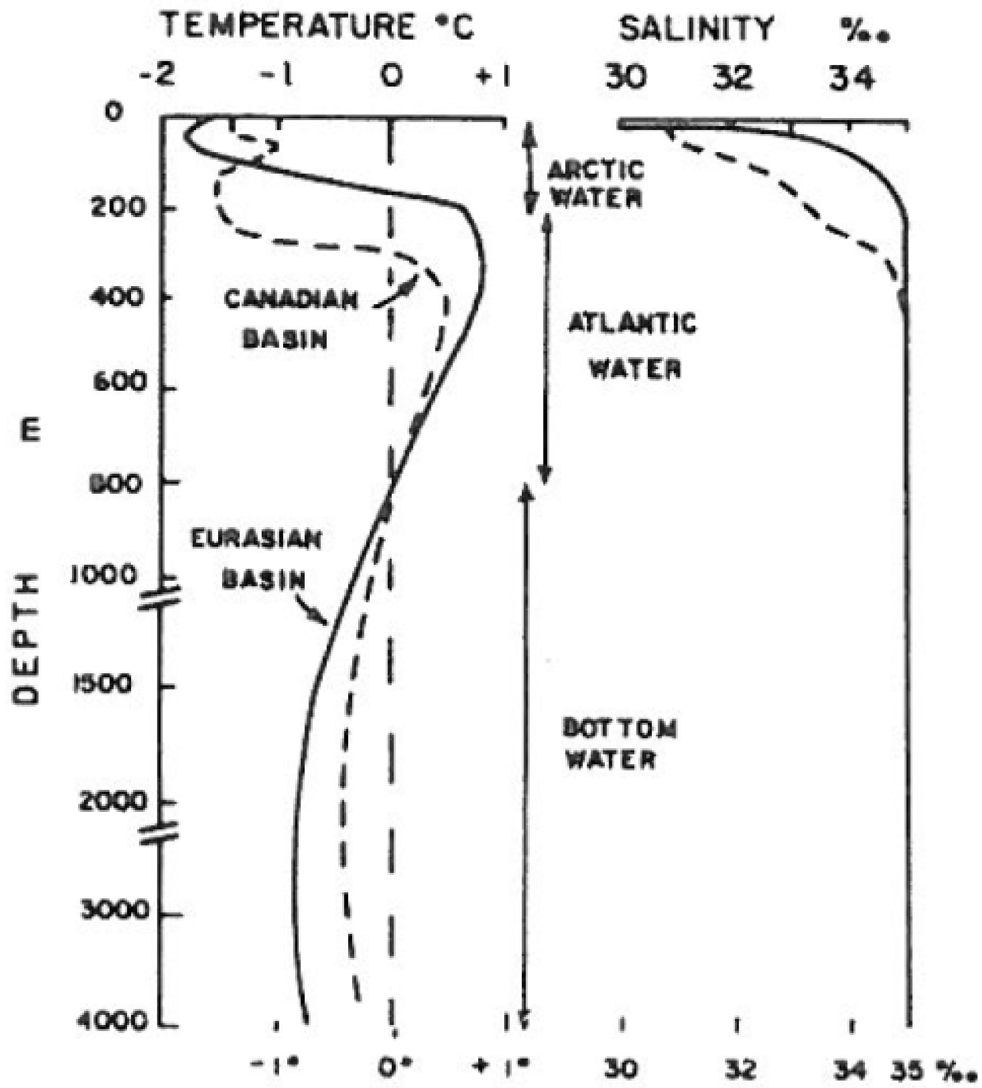
Arctic deep water: Of Atlantic origin (34.9 psu, -0.95C)

# Arctic Ocean profile

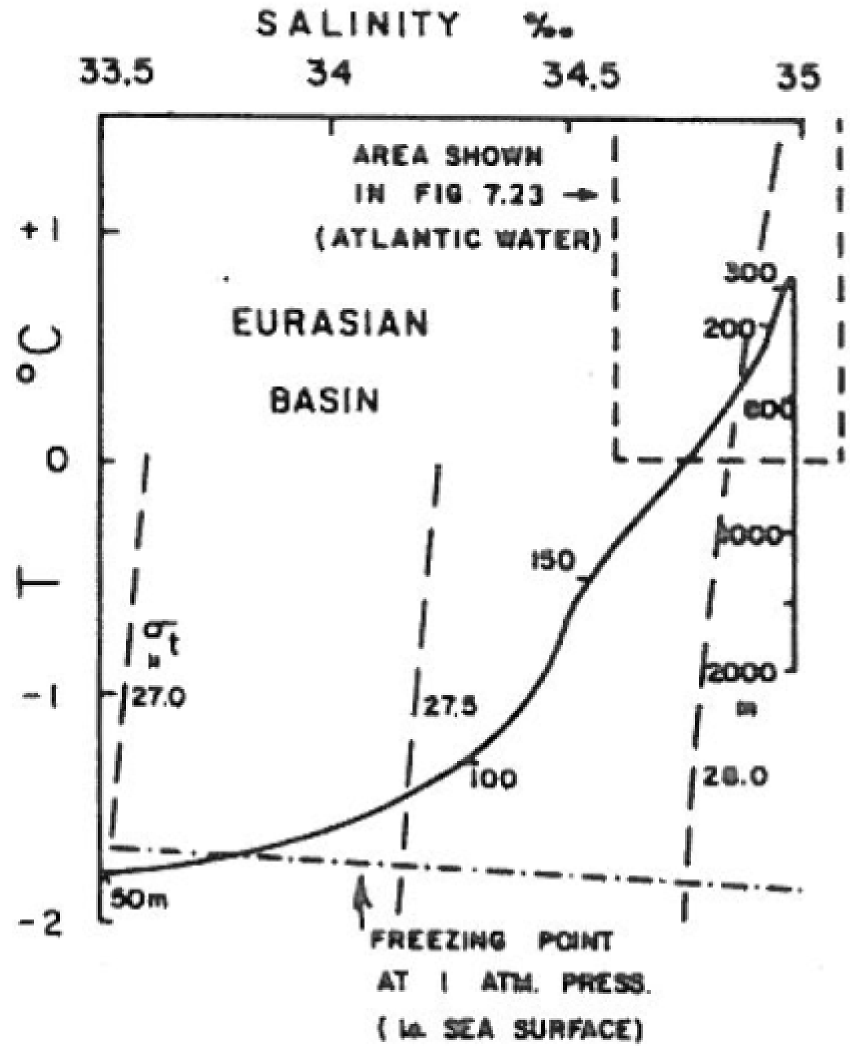



*https://commons.wikimedia.org/w/index.php?curid=21104281*

# Temperature and salinity profiles

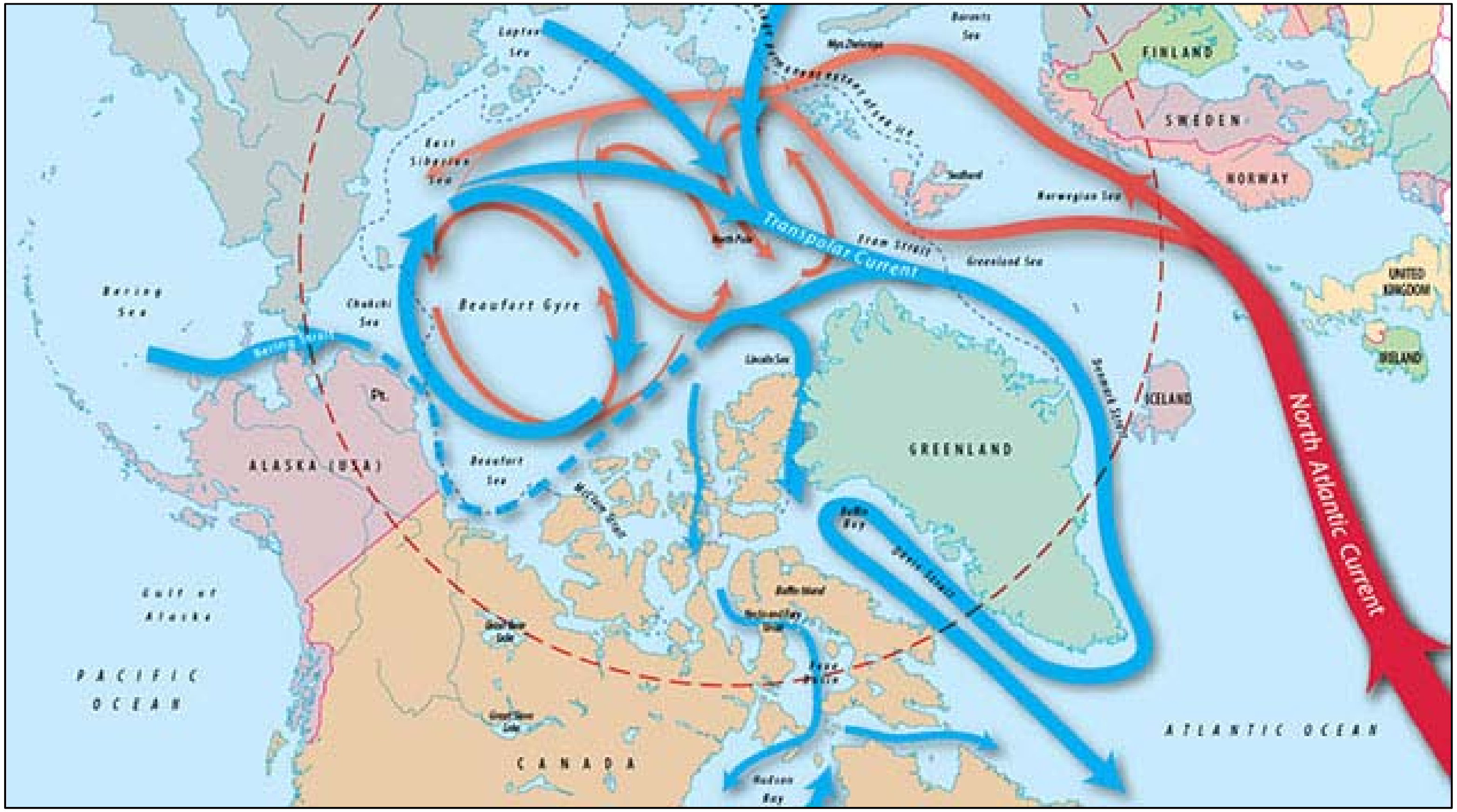


# T-S diagram



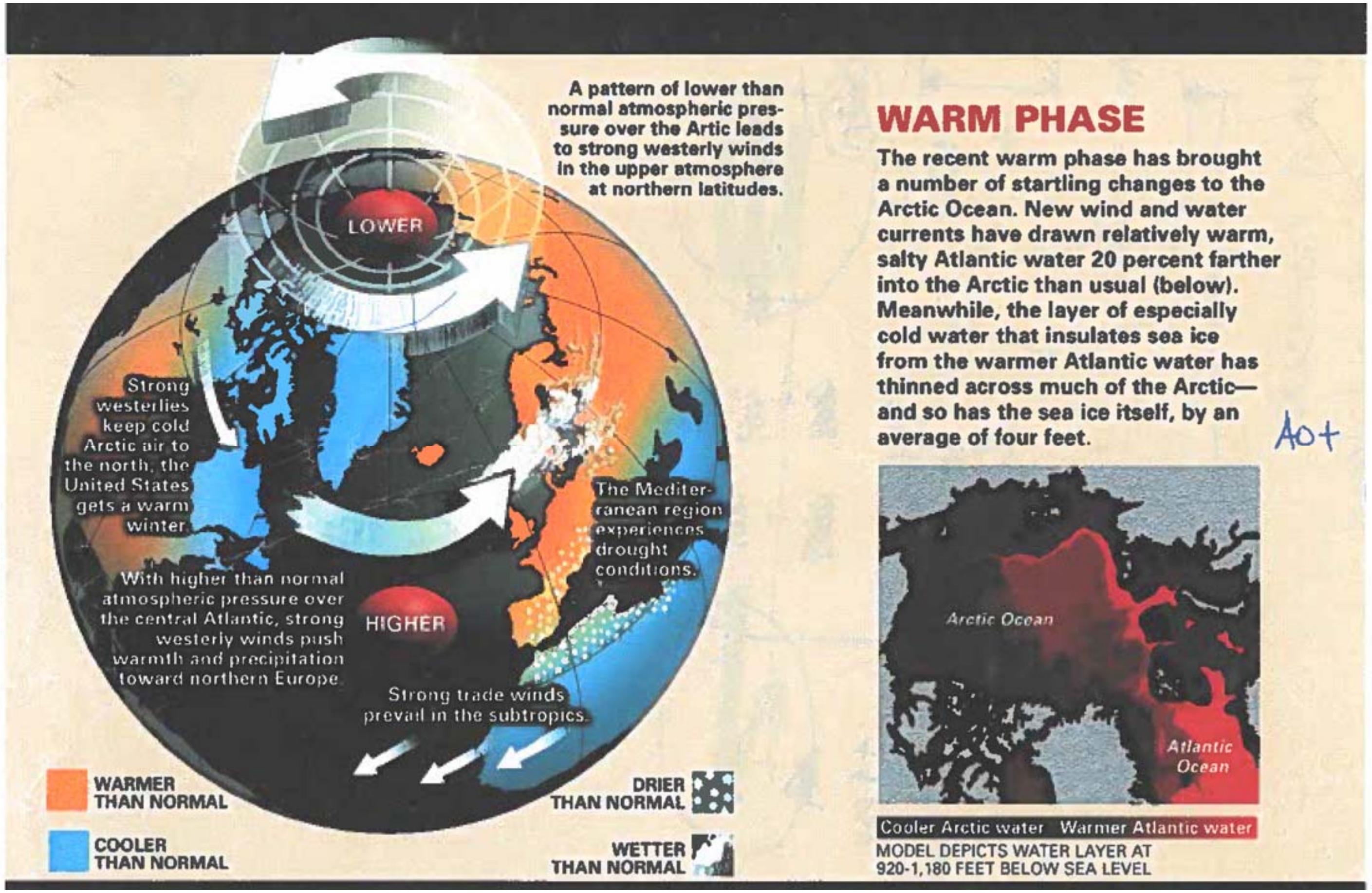
SALINITY ‰
33.5
34
34.5
35
AREA SHOWN IN FIG 7.23 → (ATLANTIC WATER)
EURASIAN BASIN
+1
0
-1
-2
T °C
σt
27.0
27.5
28.0
300
200
600
1000
2000 m
150
100
50m
FREEZING POINT AT 1 ATM. PRESS. (i.e. SEA SURFACE)

# Arctic Ocean Deep Water

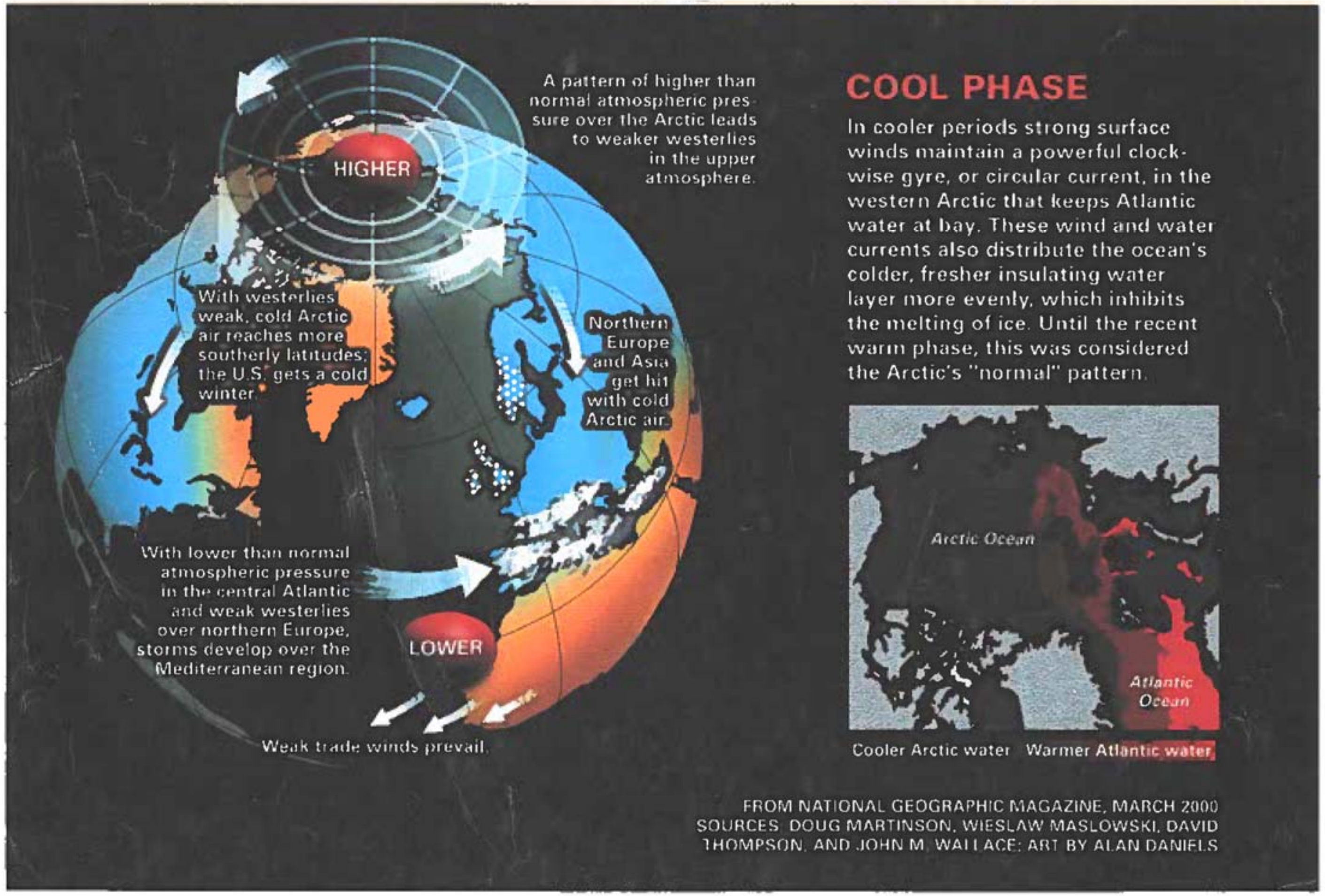



*https://www.whoi.edu/main/topic/arctic-ocean-circulation*

# AO+ Warm phase



# AO- Warm phase



# NAO ?!?

North Atlantic Oscillation Index ….

Driving surface water ….

The Arctic Oscillation often shares phase with the North Atlantic Oscillation (NAO), and its phases directly correlate with the phases of the NAO concerning implications on weather across the U.S.

# CTD measurements

- Conductivity (salinity)
- Temperature
- Depth (pressure)

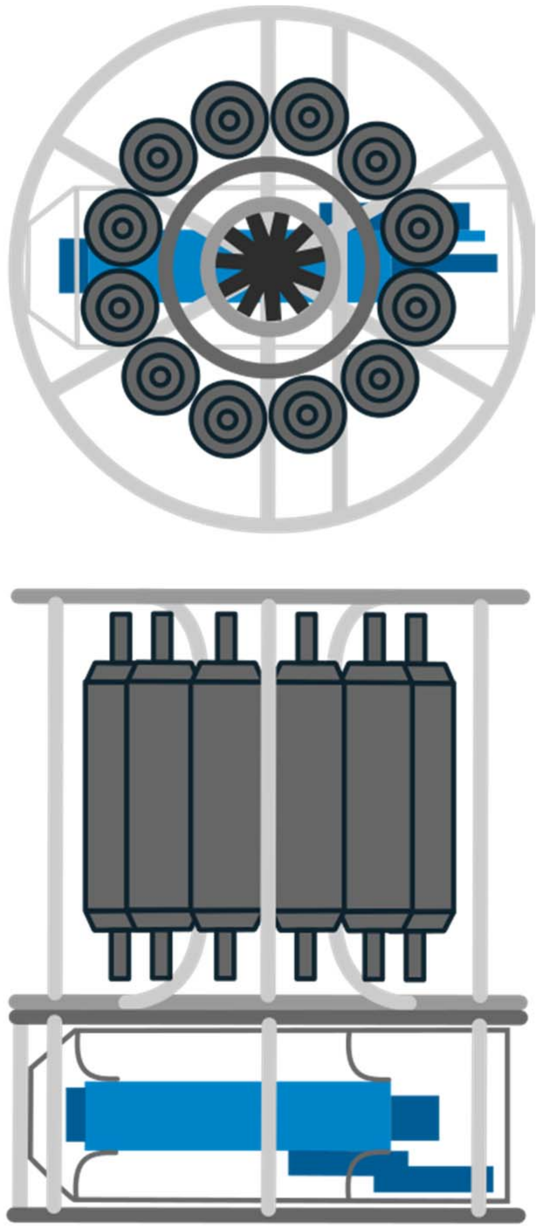
Some instruments also observe

- Content of oxygen ($O_2$)
- Water samples

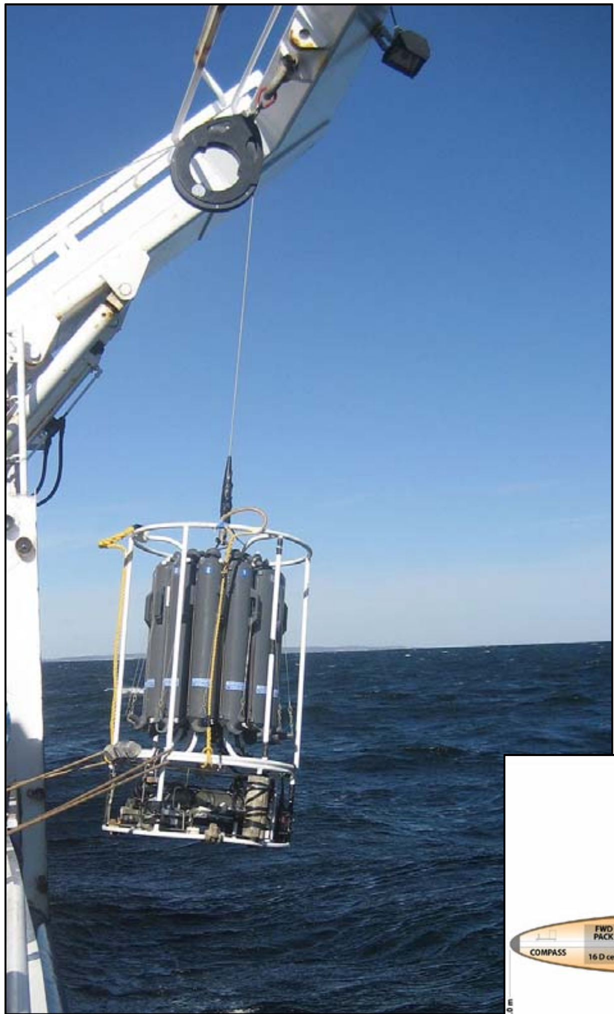
# CTD measurements

The CTD may be incorporated into an array of Niskin bottles referred to as a carousel or rosette. The sampling bottles close at predefined depths, triggered either manually or by a computer, and the water samples may subsequently be analyzed further for biological and chemical parameters.

Figure show side and top views with (grey) Niskin bottles and (blue) CTD-logger



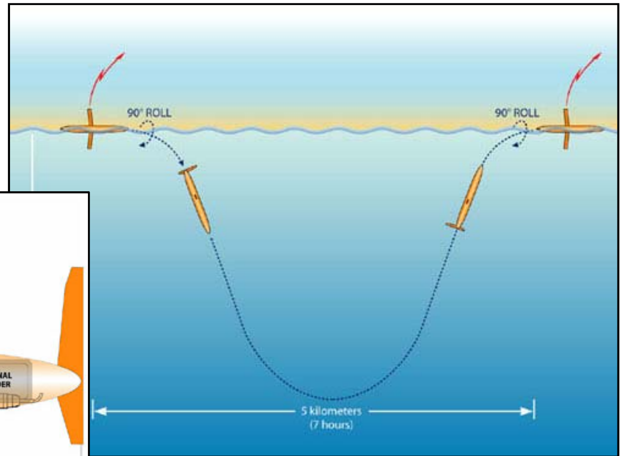
# CTD deployment open ocean

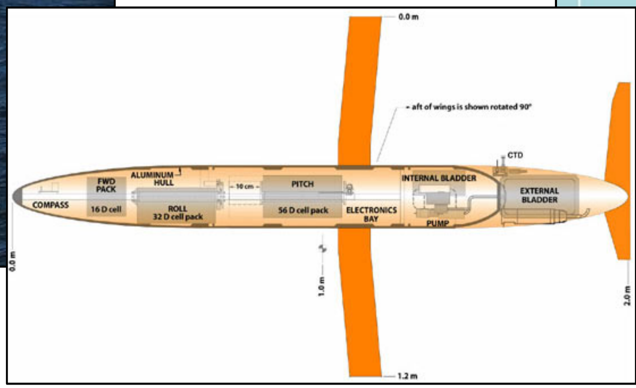


Obtained from ship:

A standard CTD cast, depending on water depth, requires two to five hours to collect a complete set of data

Small, low-powered CTD sensors are used on autonomous instruments like the moored profiler, gliders, profiling floats and AUVs



# CTD deployment in Arctic

Are hampered by sea ice, but can also be used as an platform itself:

- Obtained directly from icebreakers
- Temporary ice stations (aircraft landings, icebreakers)
- Buoys on the sea ice

# CTD deployment in Arctic

*http://polarforskningsportalen.se/en/arctic/expeditions/lomrog-ii/cruise-reports/oceanography-ctd-measurements*

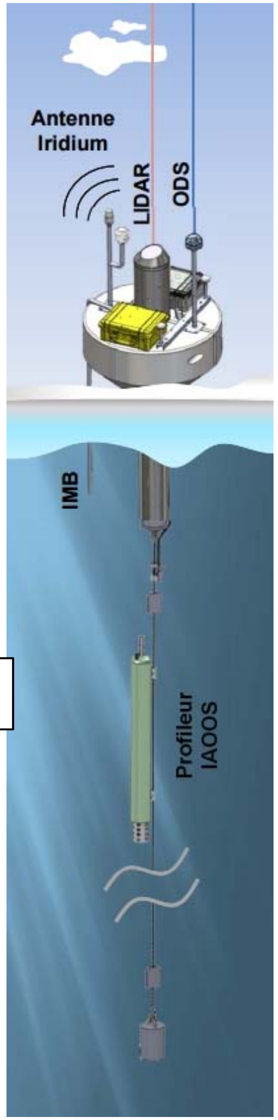
# CTD aircraft landings

https://www.youtube.com/watch?v=qL6A_RmfhI0

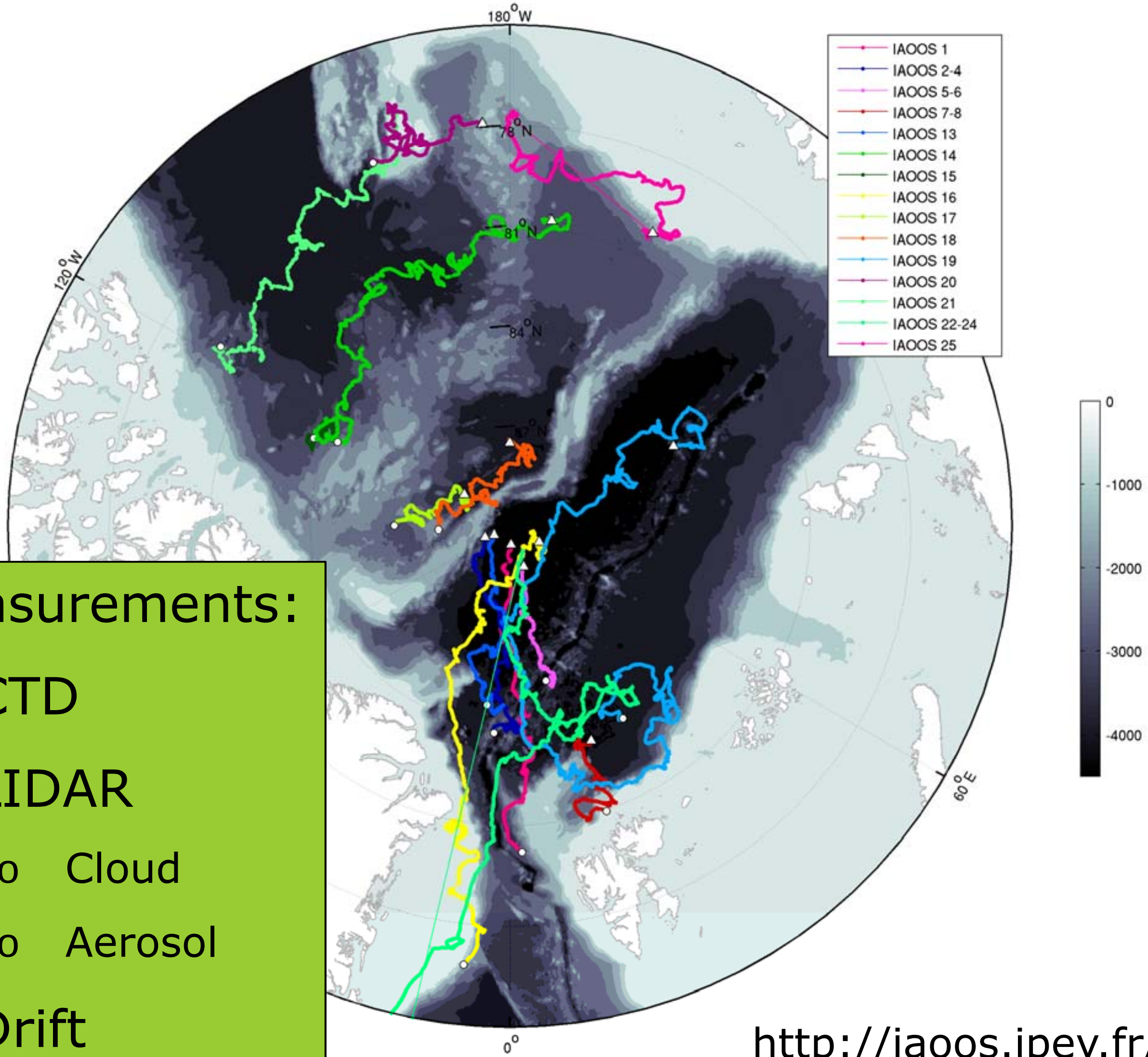
Switchyard and

North Pole Earth Observatory

# iAOOS buoys 2013-present




800m




Measurements:

- CTD
- LIDAR
  - Cloud
  - Aerosol
- Drift

http://iaoos.ipev.fr/

## Advantages and limitations?

### Advantages:

- Remote sensing
- Very accurate
- Light weight (CTD only)
- Can be used at depths up to several thousand meters

### Disadvantages:

The small, low-powered CTD sensors that are used on autonomous instruments like the MP, gliders, profiling floats and AUVs are more complex to operate, the chief limitation is the need to calibrate the individual sensors. This is particularly true for autonomous instruments deployed for long time periods. (Ship-deployed CTDs are referenced with the water sample data which are not generally available with autonomous instrument deployments.) Therefore, the sensors must be stable for the period of deployment, or assumptions about the ocean water properties must be made and referenced to the sensor data. (For example, deep water properties are usually very stable, so autonomous sensor data is adjusted to match the historical water properties at depth. The danger of course is that we miss real changes in the ocean - ship based measurements are still required!)

Sources: Encyclopedia of Ocean Sciences, vol. 1, p. 579-588

# Exercise: CTD measurements

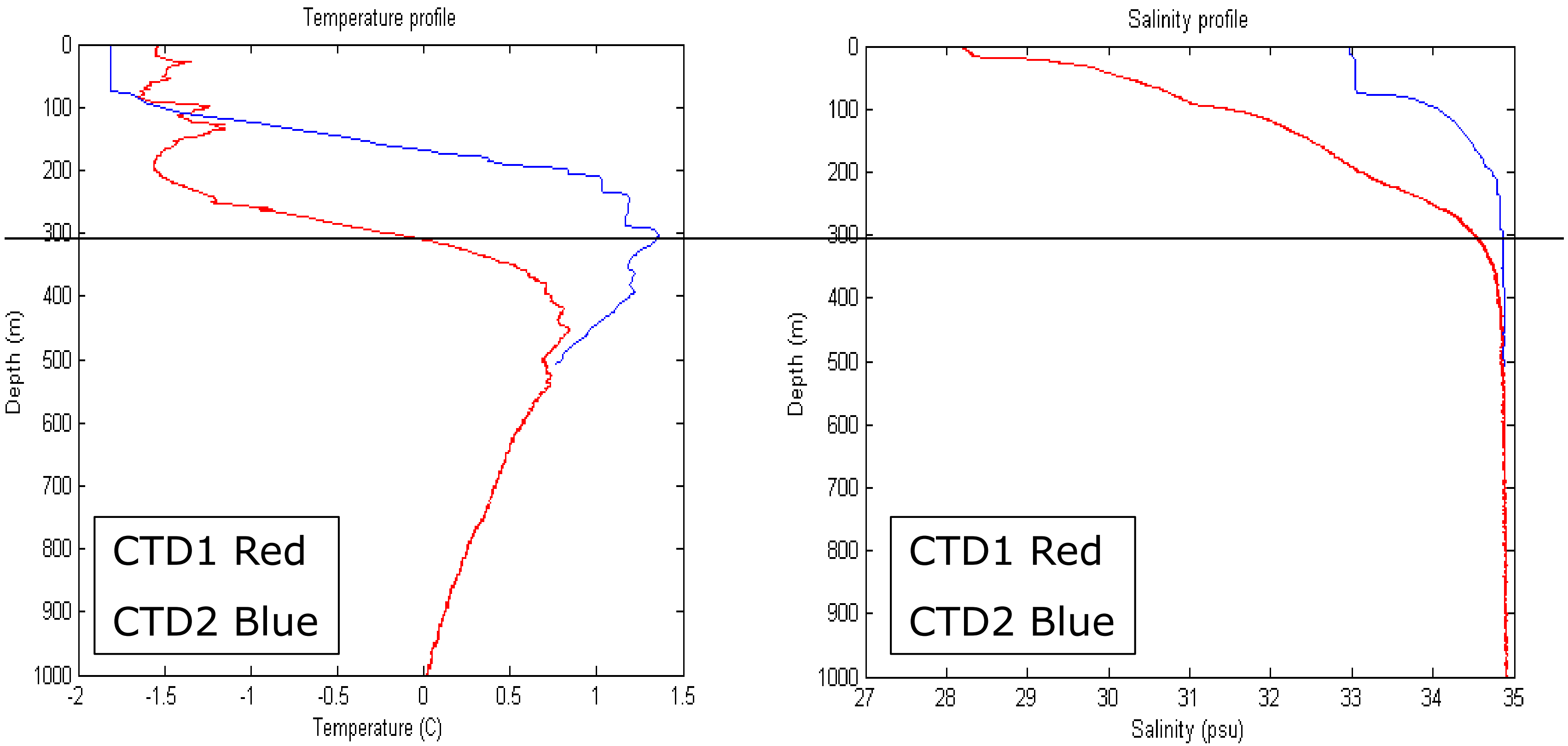
Based on two CTD casts (CTD1 and CTD2) obtained in 2008 during the North Pole Earth Observatory aircraft landings plot for both cases the:

- Temperature profiles
- Salinity profiles
- T-S diagram

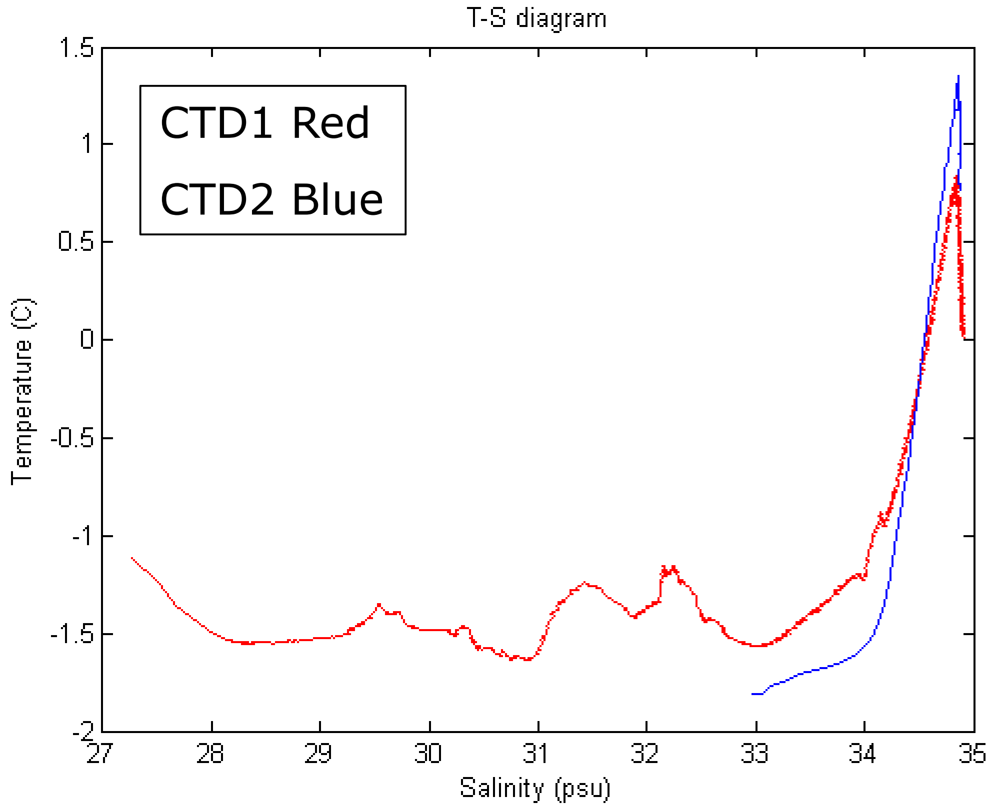
Based on the plots of the two casts:

- Which layers are represent in the casts ?
- What is the approx. depth of the halocline ?
- At what geographic location would you expect the measurements were obtained ?

# Exercise: CTD measurements



# Exercise: CTD measurements



# Exercise: CTD measurements

Based on the plots of the two casts:

- Which layers are represent in the casts ?
  - CTD1 (PML, Pacific+Atlantic Halocline, Atlantic Layer)
  - CTD2 (PML, Atlantic Halocline, Atlantic Layer)
- What is the approx. depth of the halocline ?
  - CTD1 25-350m
  - CTD2 75-200m
- At what geographic location would you expect the measurements were obtained ?
  - CTD1 Beafort Sea (75º 04.33’ N, 149º 32.31’ W), Canadian basin represented by
  - CTD2 North Pole (89º 00.78’ N 92º 51.53’ E), Amundsen Basin

The data was obtained at NOAA web-page
https://data.nodc.noaa.gov/cgi-bin/iso?id=gov.noaa.nodc:0057592

# Goals

- Sea ice mass balance
- Knowledge of sea ice definitions (new words ☺)
- Explain sea ice extent, type, and drift
- Observation methods
- Exercise in sea ice remote sensing of extent, type, and drift

- Feedback: What was good/not so good ?!? Did we reach our goals ?!?