Abyssal Circulation and Deep Water Formation

Lecture 21

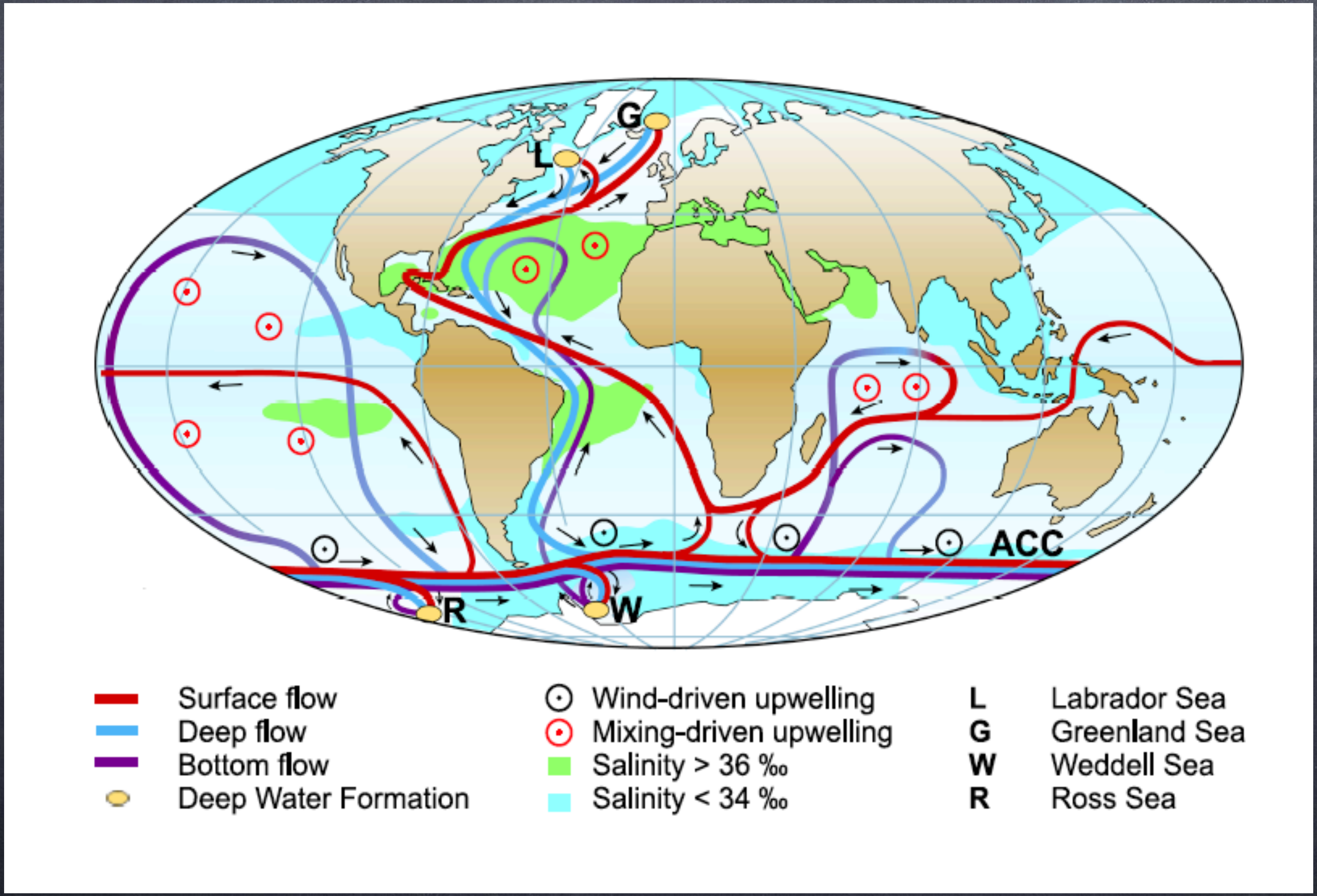
- DWF occurs where surface waters reach high density due to high salinity (from evaporation or brine-rejection) and/or strong seasonal cooling (reduced solar radiation and strong winds).

- As soon as surface waters become dense enough that the water column becomes unstable, there is convection.

- Hence, deep water formation occurs on fast time scales and small spatial scales.

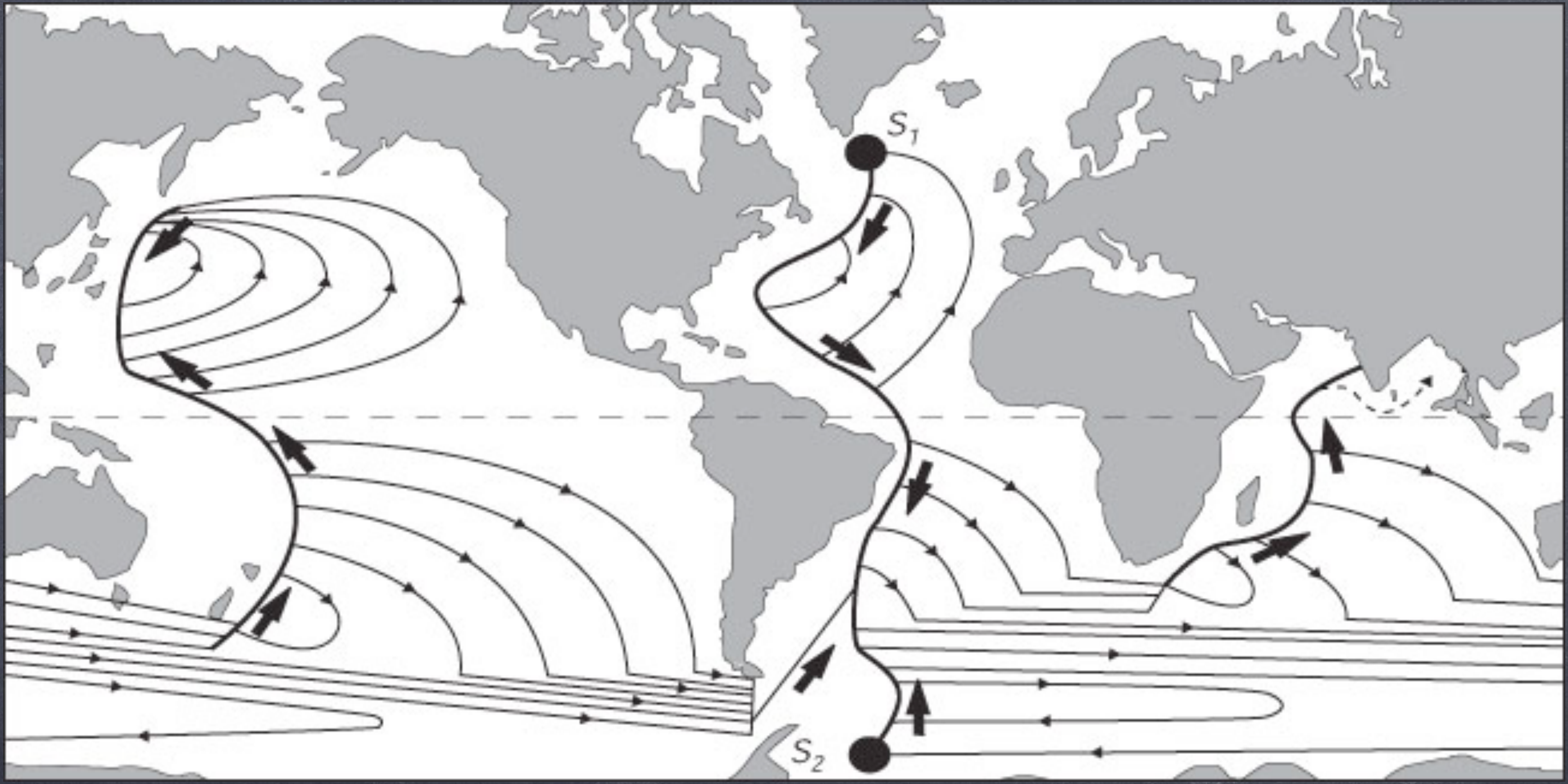
Four main sites for deep and bottom water formation:

Greenland Sea and Labrador Sea in the North Atlantic,
Weddell and Ross Seas in the Southern Ocean.



Kuhlbrodt et al. 2005

Stommel-Arons theoretical abyssal circulation (1958-1960)

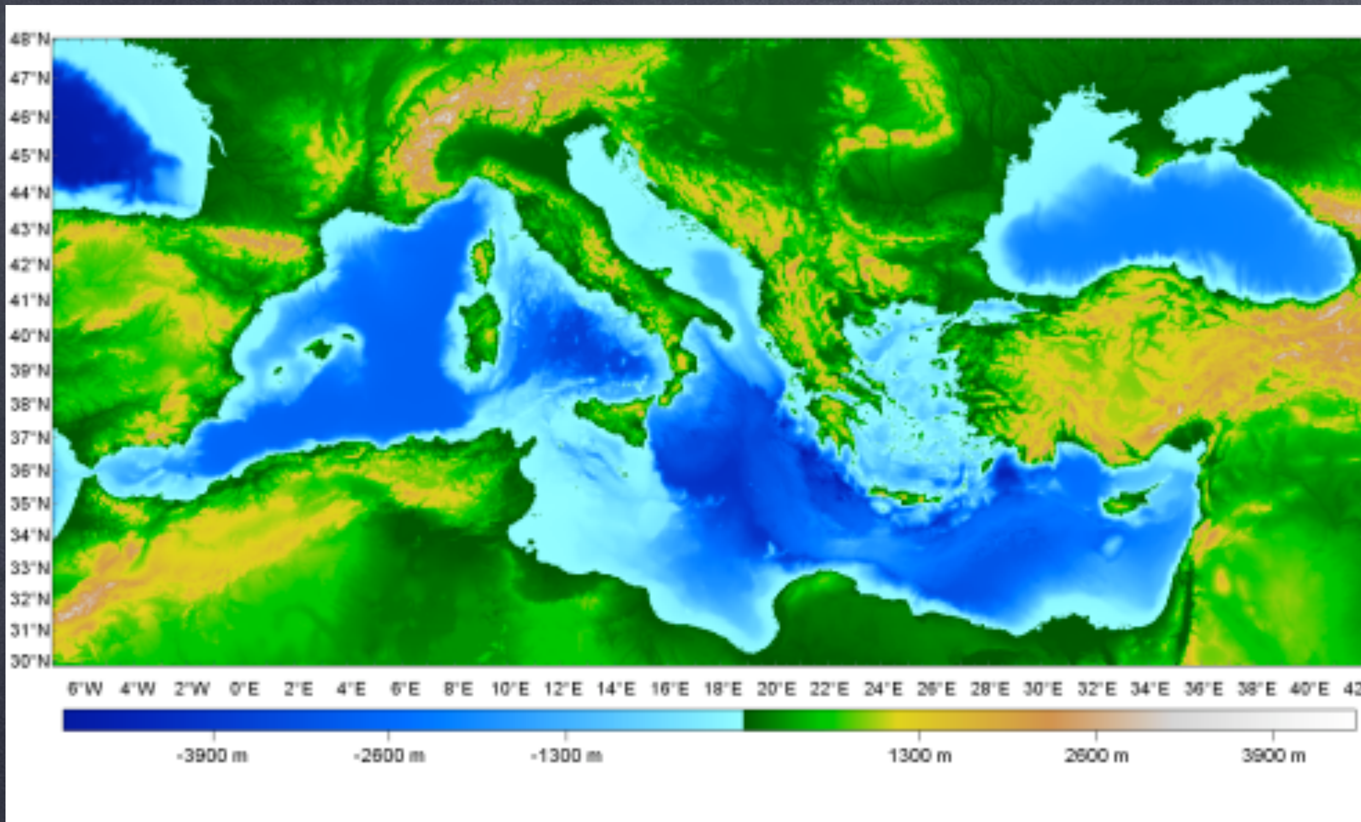


Sources in the North Atlantic and Southern Ocean.

Notice southward DWBC everywhere in Atlantic.

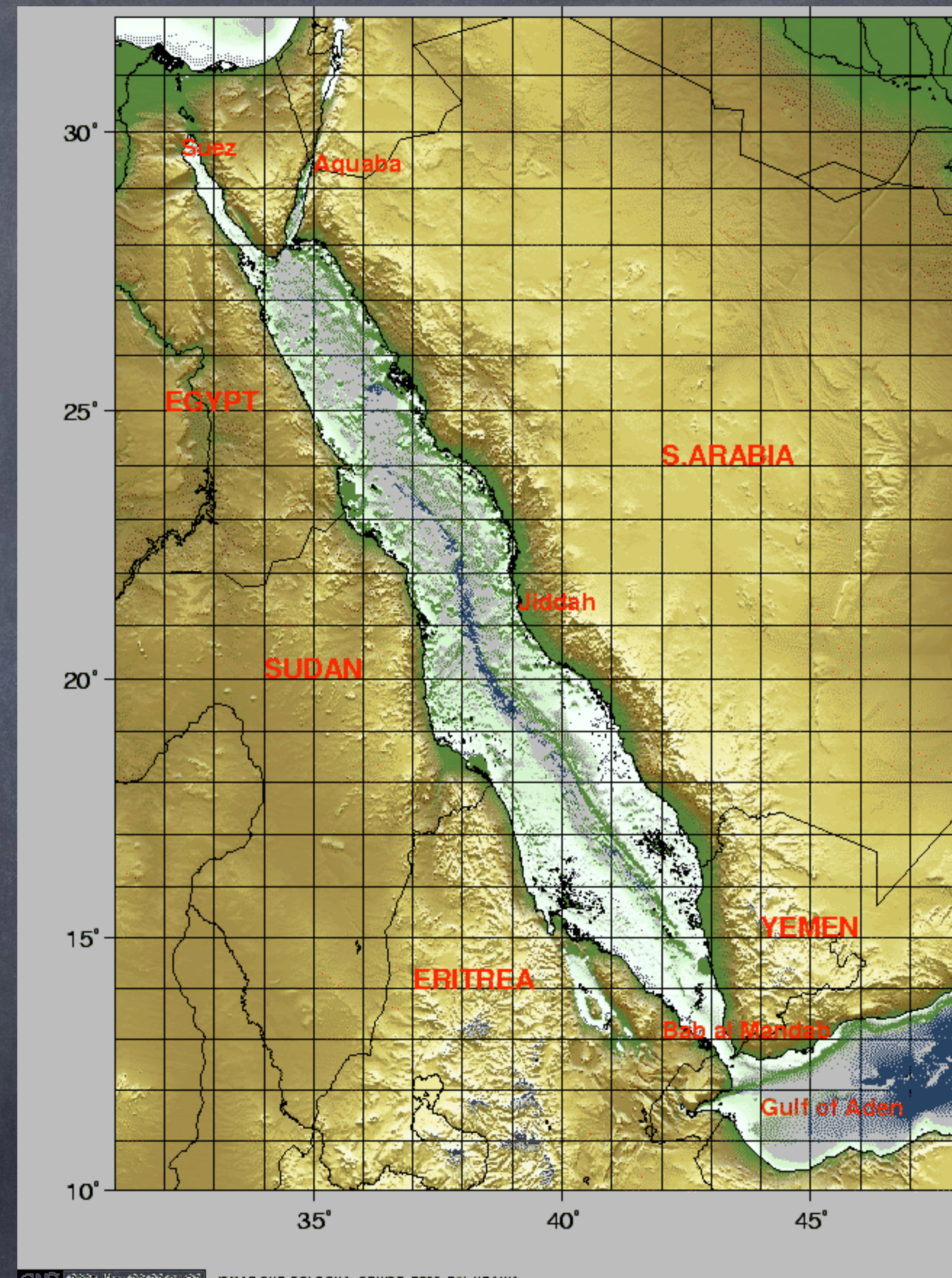
John Swallow invented the neutrally buoyant float and observed the DWBC, proving Stommel's theory. Swallow floats also first revealed that eddies dominate in the open ocean, during the MODE experiment of the 1970s.

Evaporative Basins also produce deep water



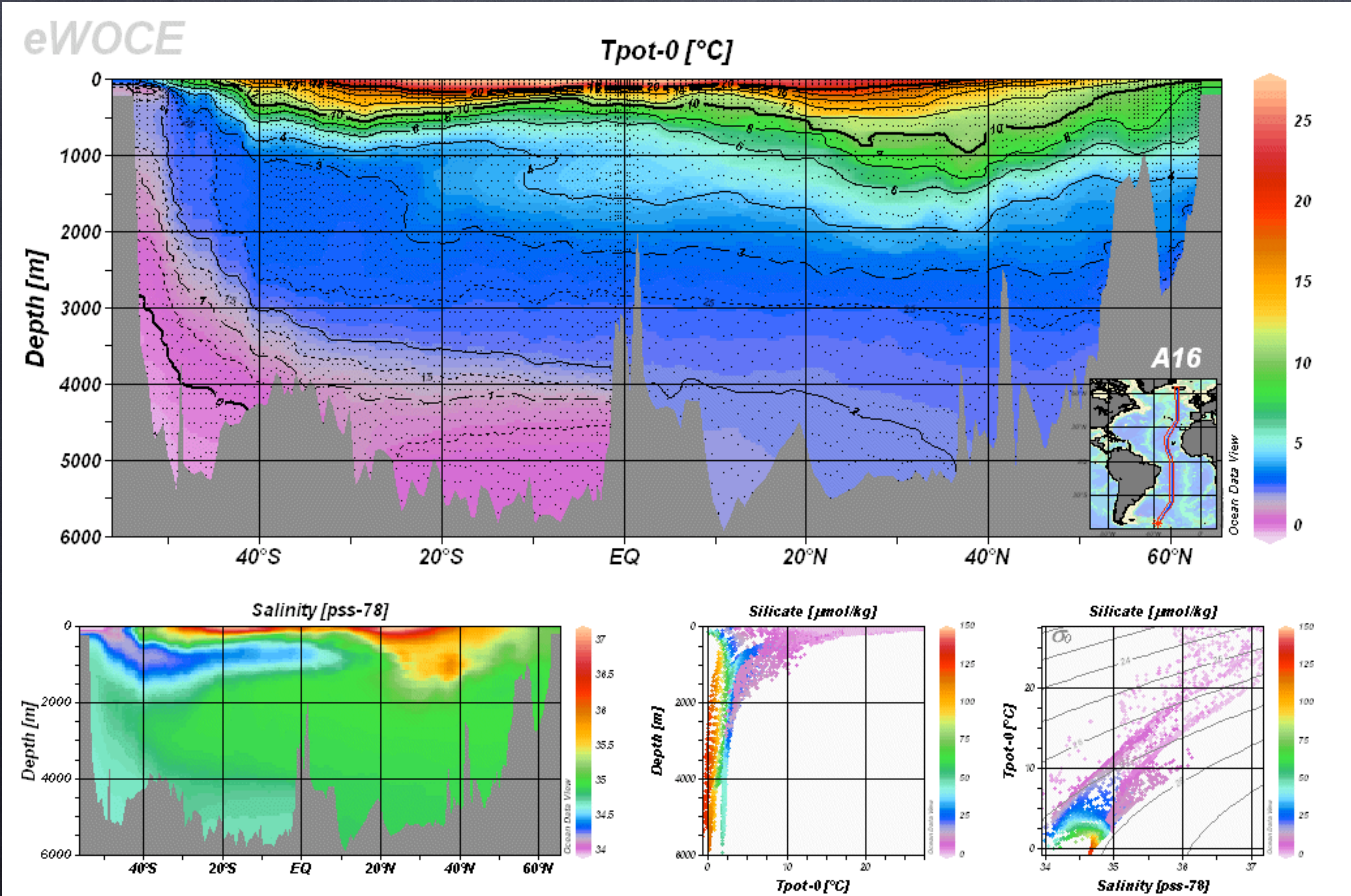
Med Sea Water, 39 psu

Although these waters are dense enough to sink to the bottom, rigorous mixing occurs as they overflow shallow sills into the open ocean. Both these waters end up spreading at about 600 - 1000 m depth with salinities 3-4 psu less than at their source.



Red Sea Water, 40 psu

Atlantic Ocean (A16)



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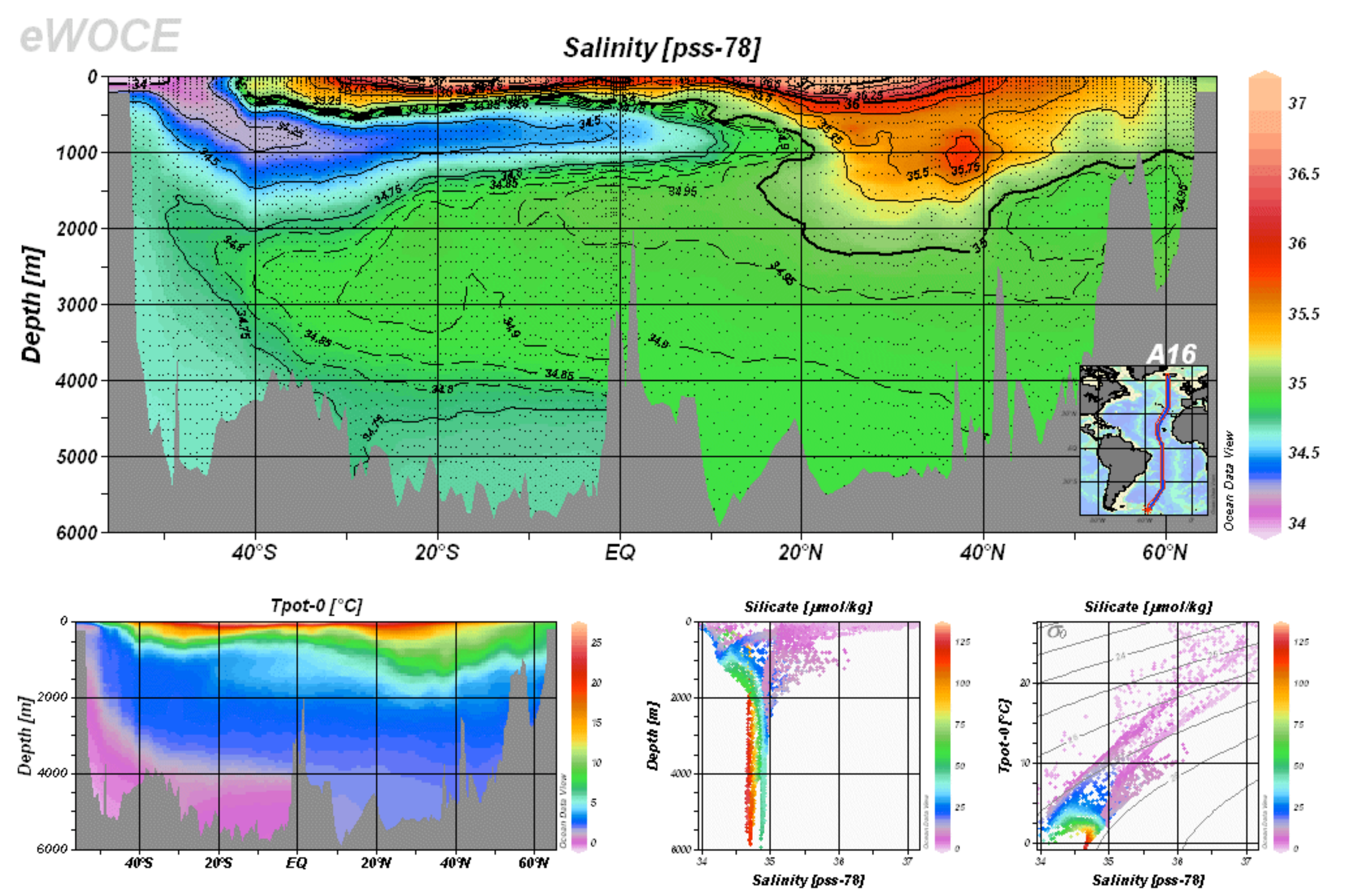

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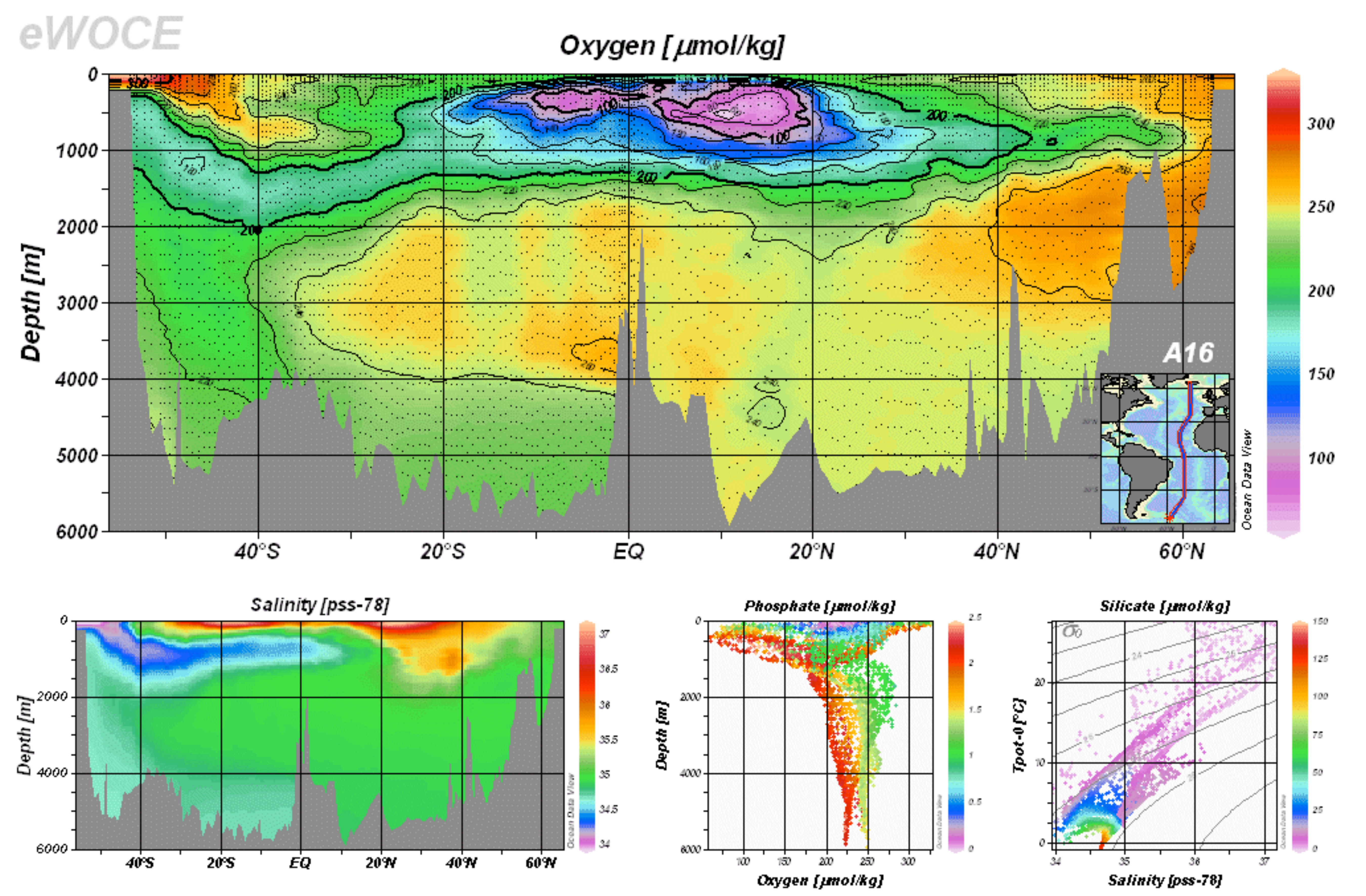
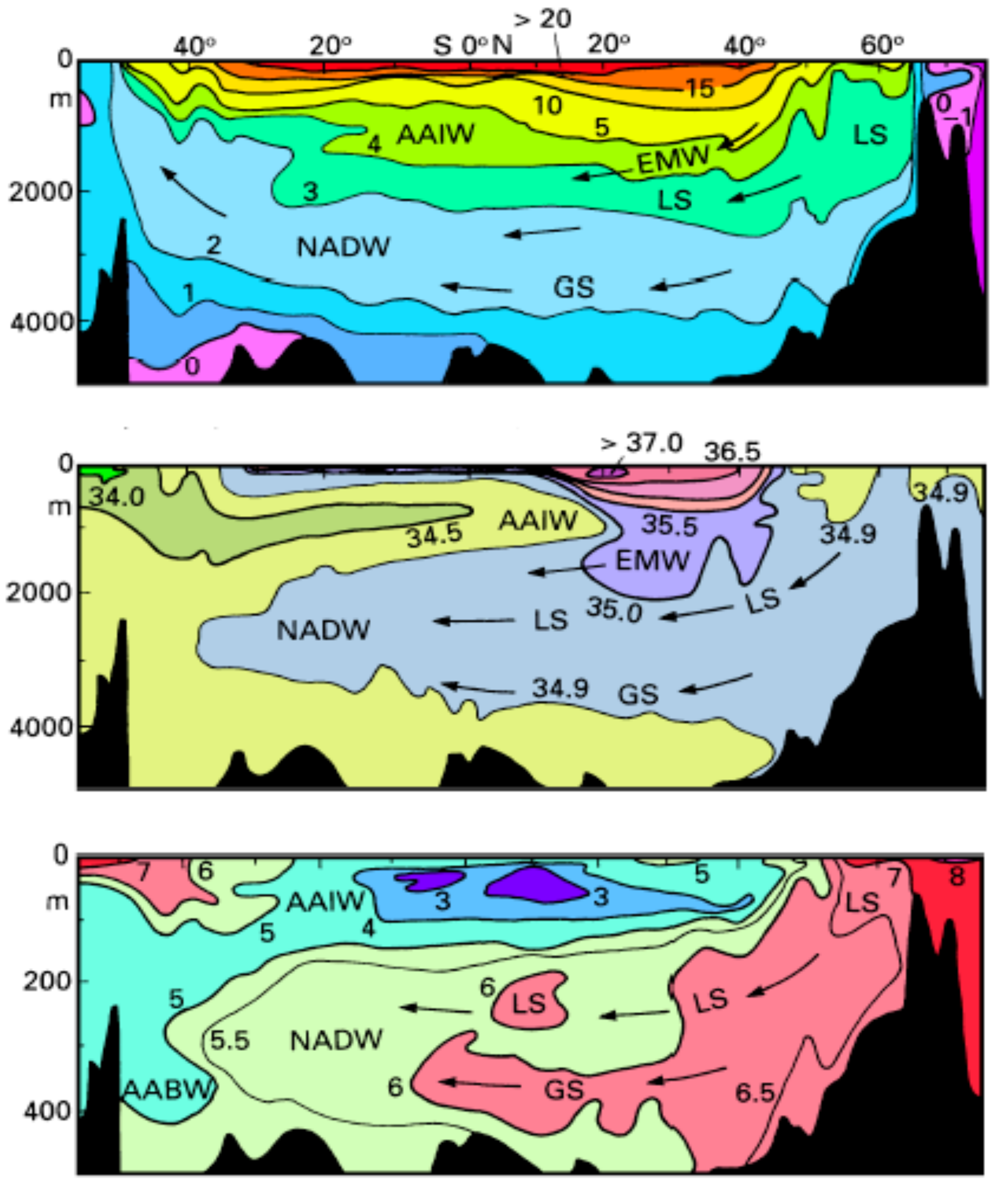




A section through the western basins of the Atlantic Ocean. (a) Potential
salinity, (c) oxygen (ml/l). See Fig. 15.7 for position of section. AABW
Water, AAIW: Antarctic Intermediate Water, NADW: North Atlantic
g from the Labrador Sea (LS) or the Greenland Sea (GS) or containing a con
Mediterranean Water (EMW). Adapted from Bainbridge (1980).

From water properties we can determine the origin of the water masses:

Labrador Sea, Greenland Sea, and to some extent Mediterranean overflow waters all contribute to NADW.

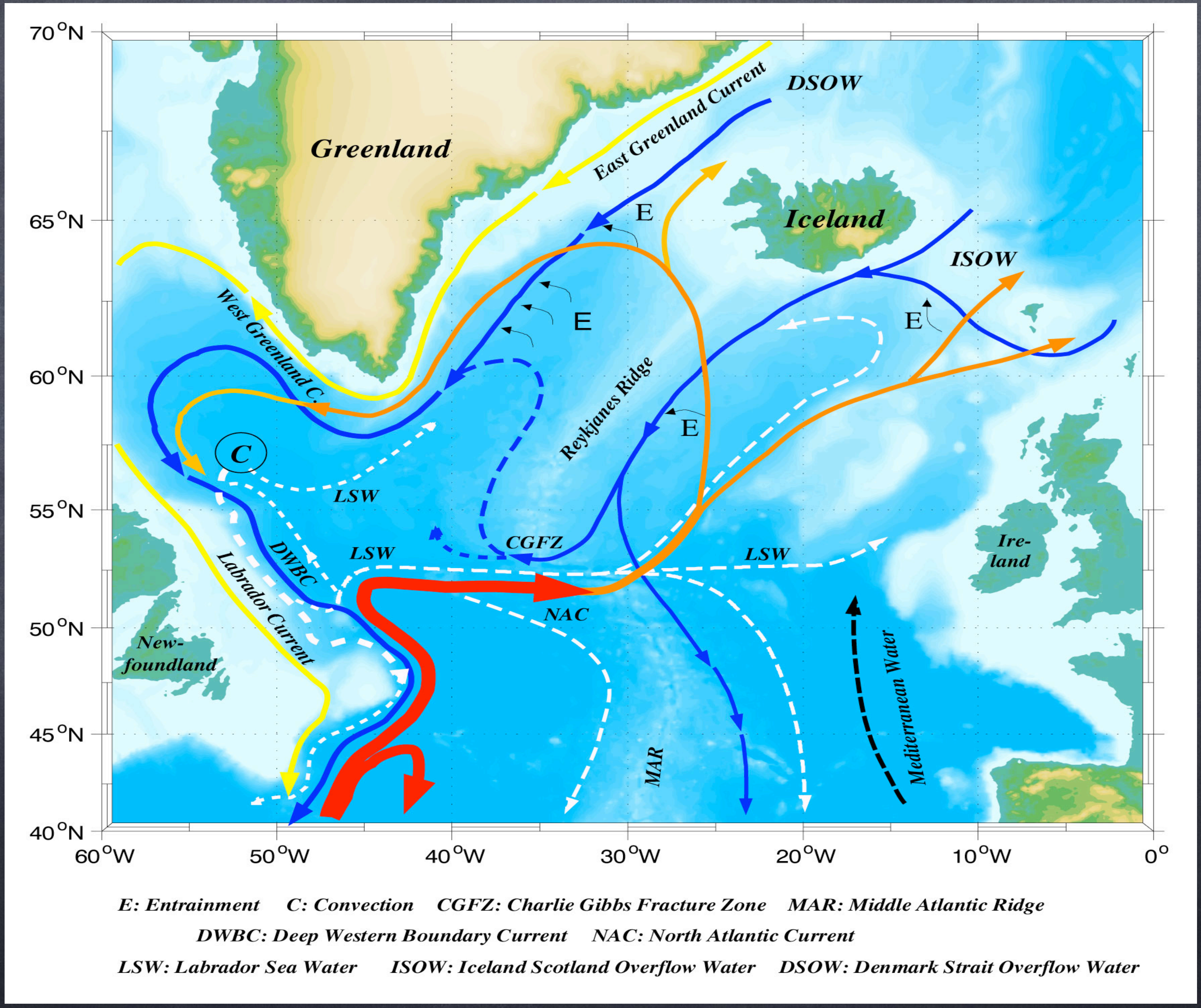
The region of deep water formation that is the best studied is the Labrador Sea, owing to its relative accessibility.

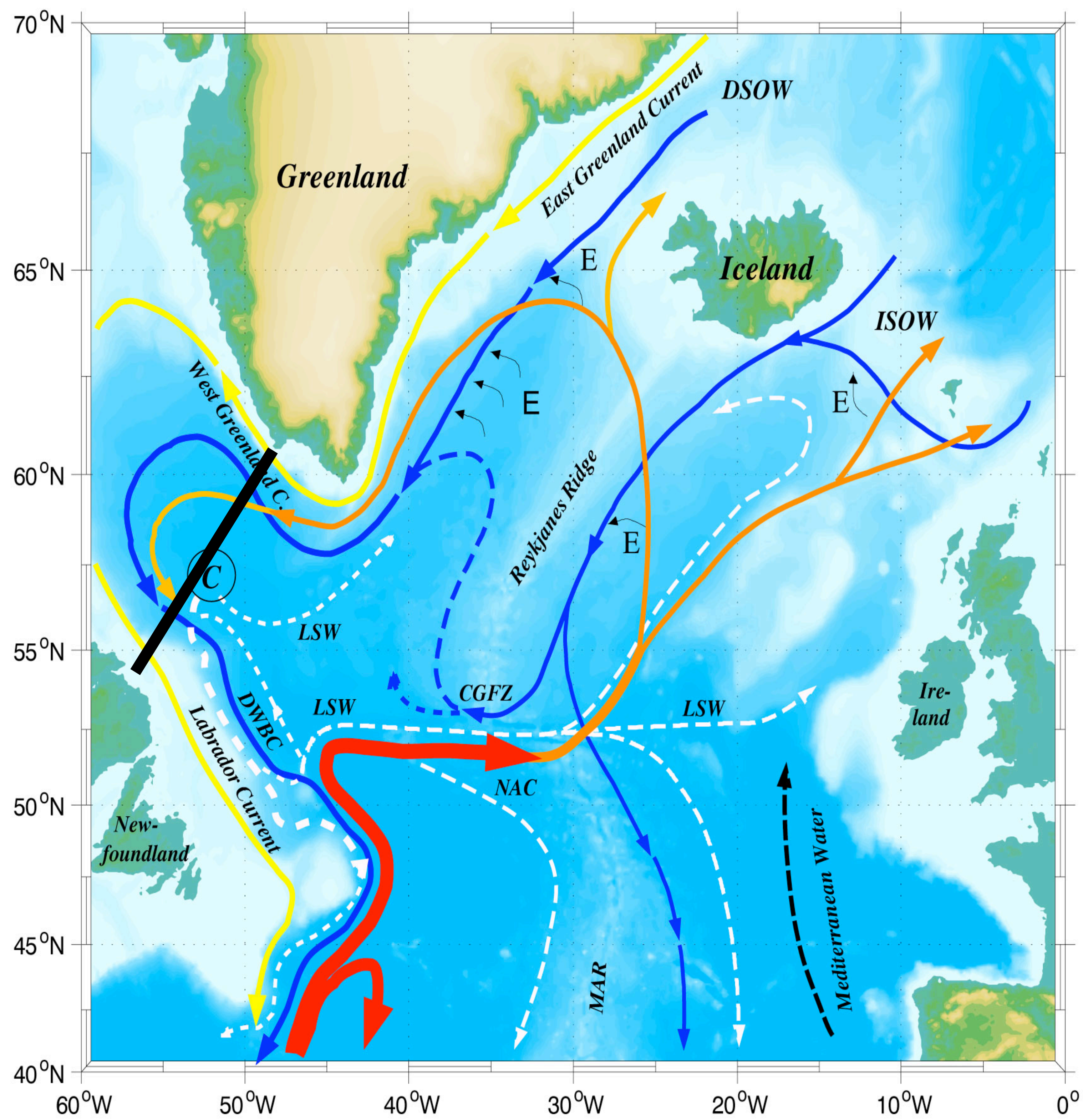
Subpolar gyre circulation

fresh Arctic water

salty subpolar gyre water

deep overflow water

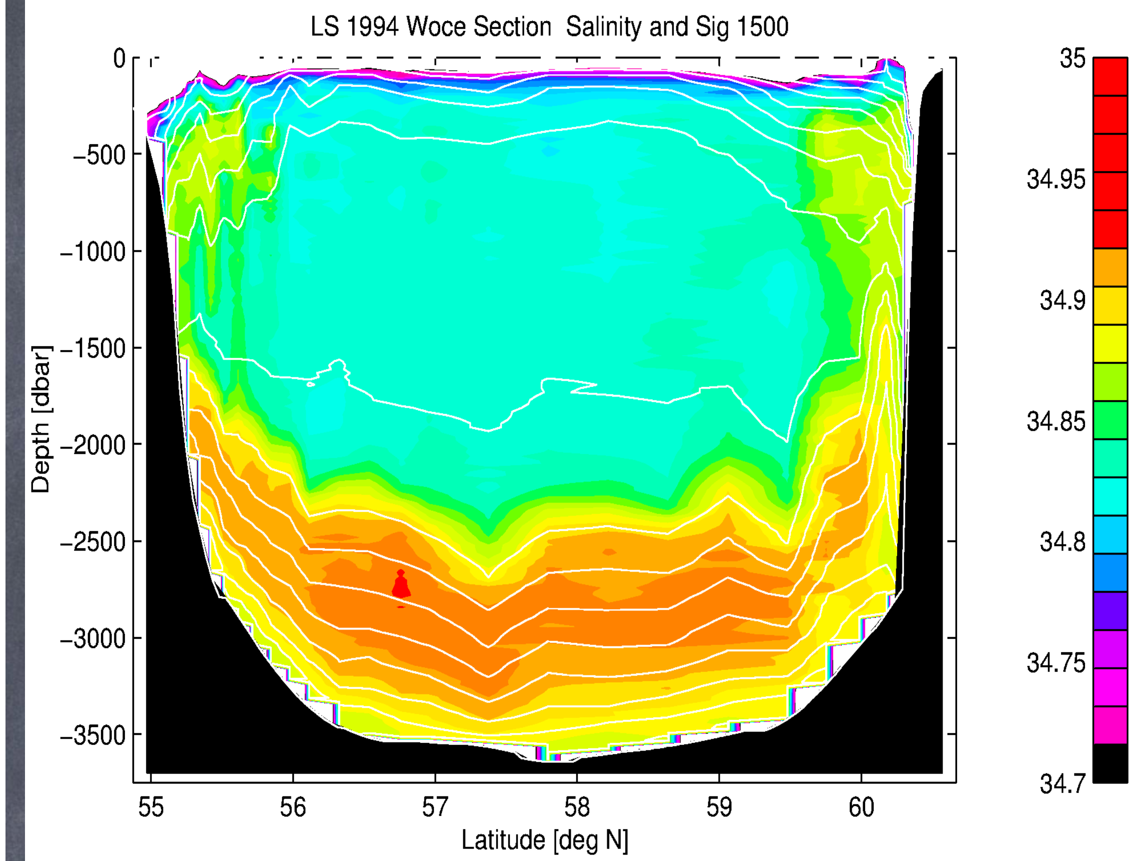


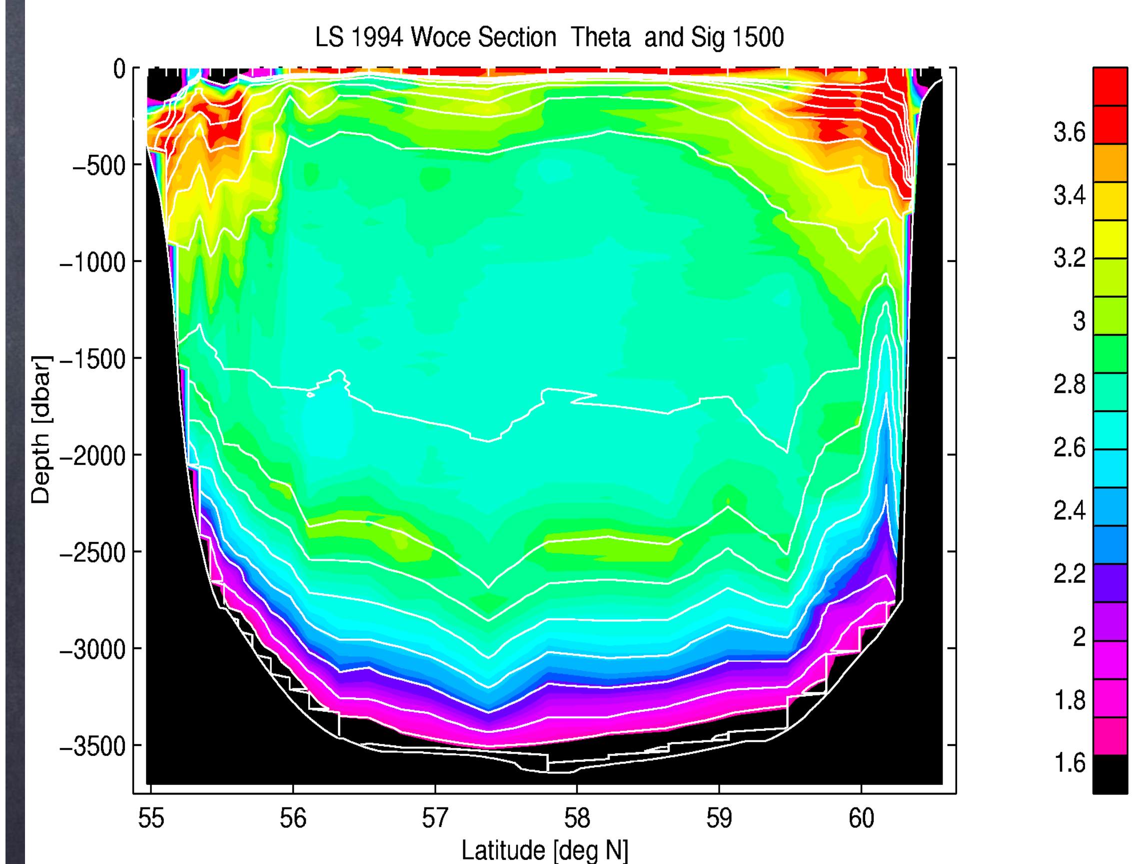


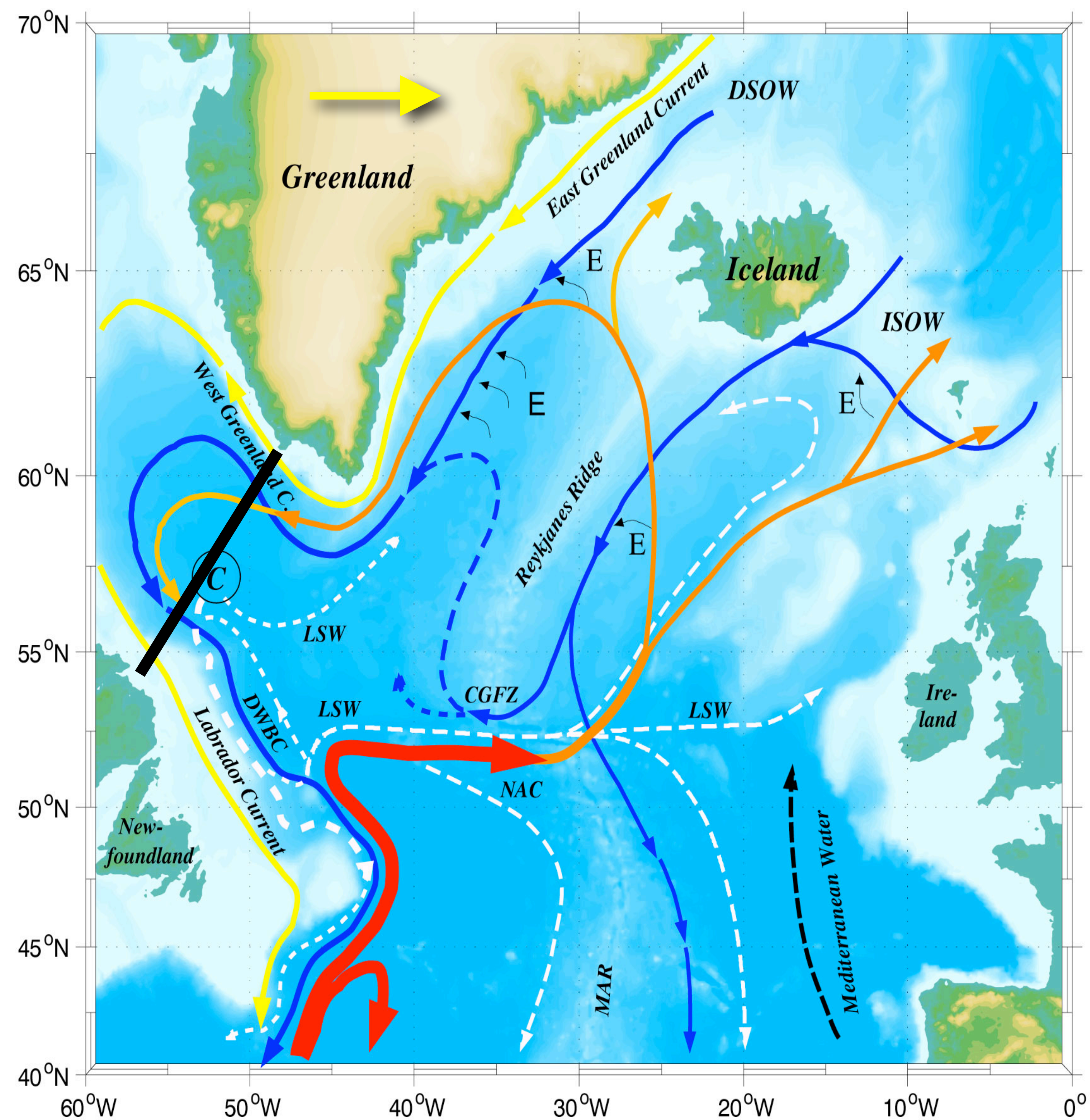
E: Entrainment C: Convection CGFZ: Charlie Gibbs Fracture Zone MAR: Middle Atlantic Ridge

DWBC: Deep Western Boundary Current NAC: North Atlantic Current

LSW: Labrador Sea Water ISOW: Iceland Scotland Overflow Water DSOW: Denmark Strait Overflow Water







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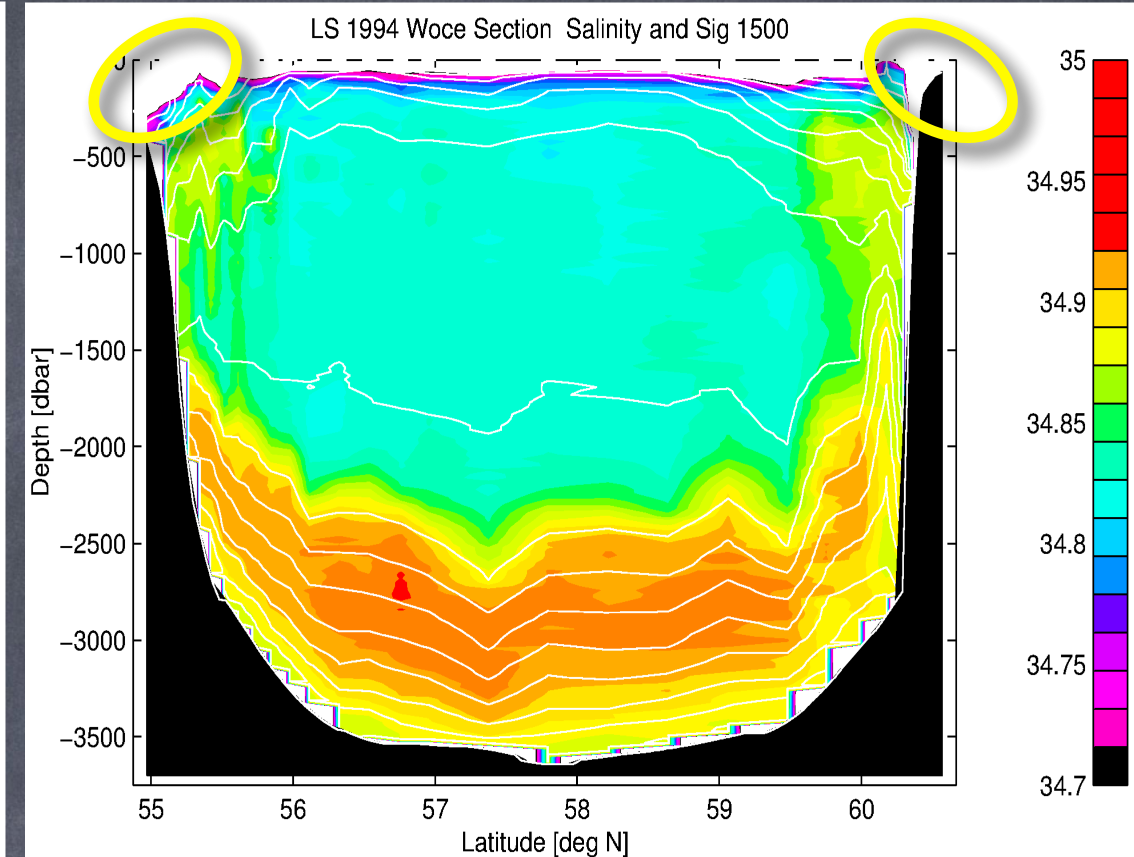

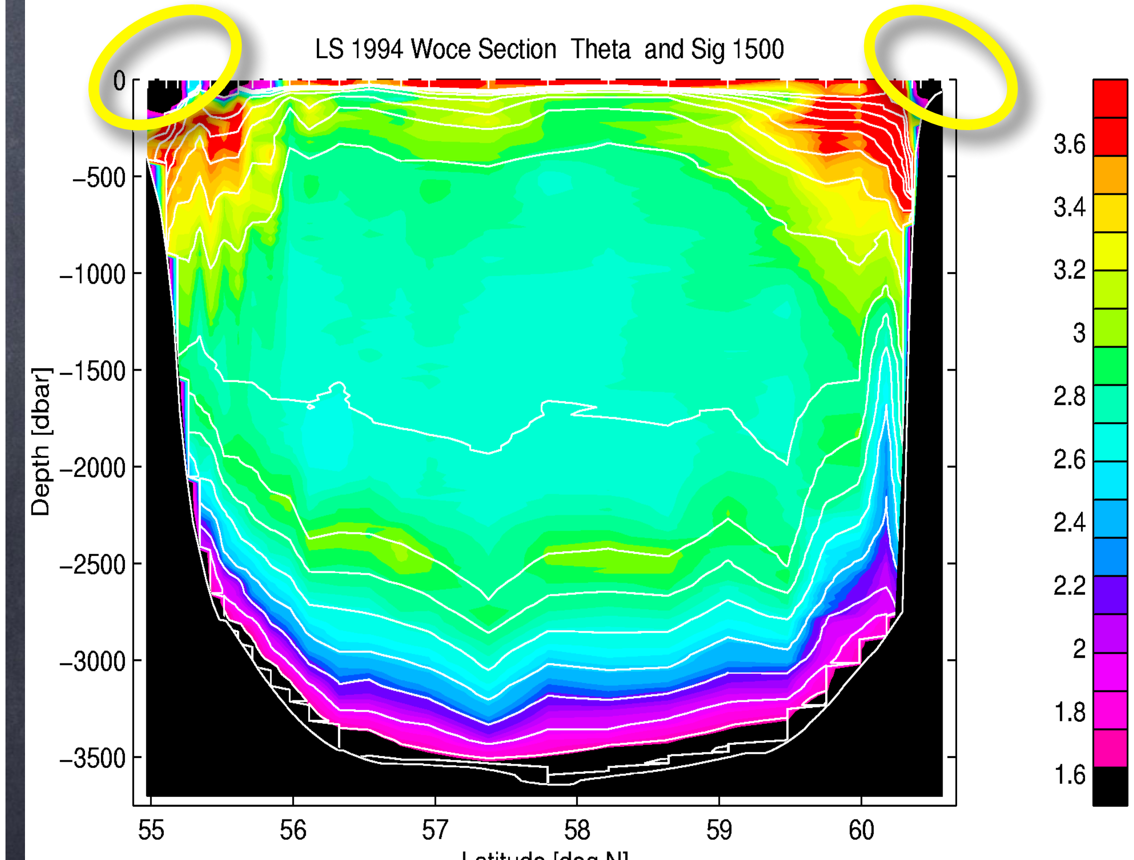

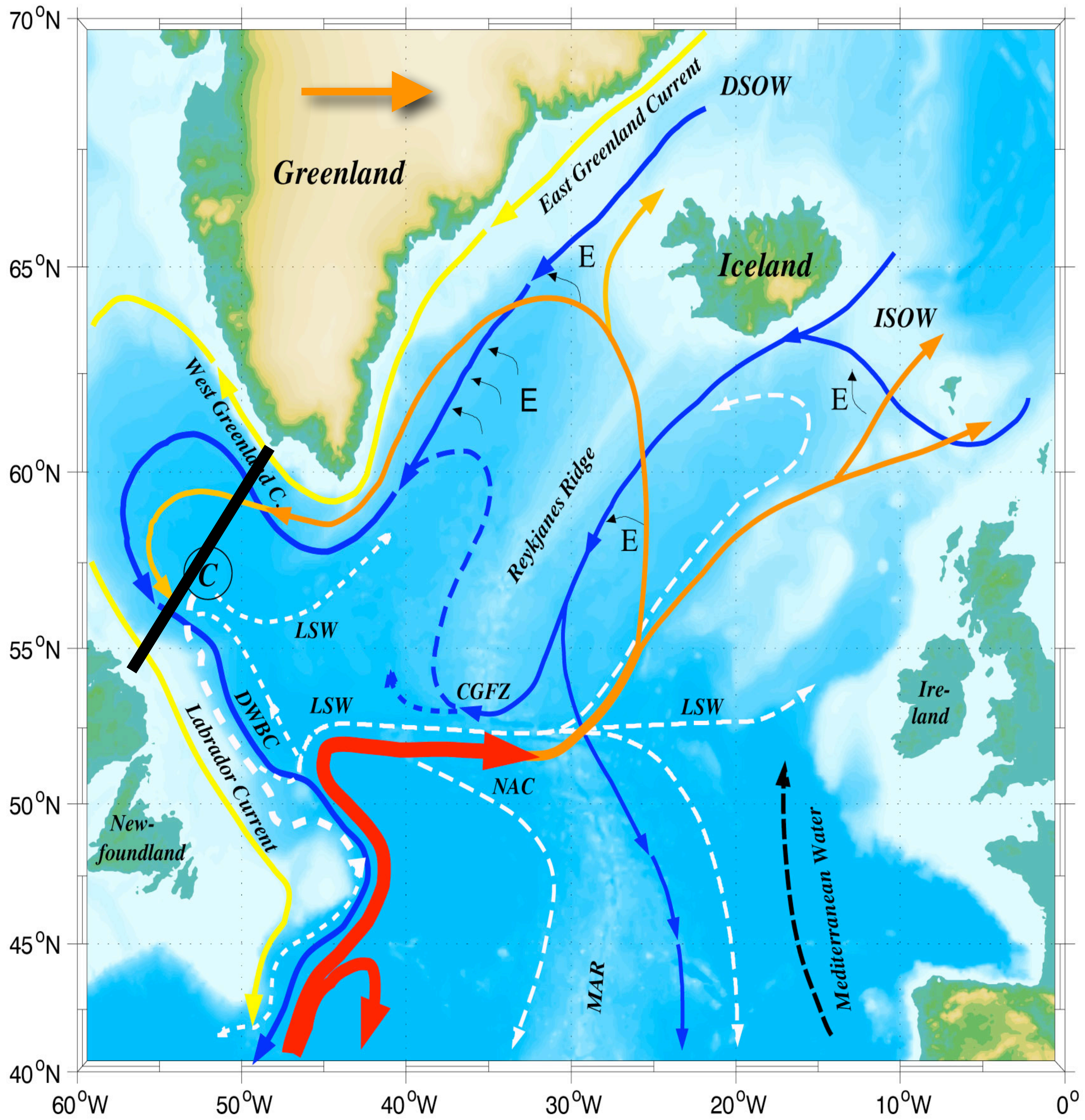

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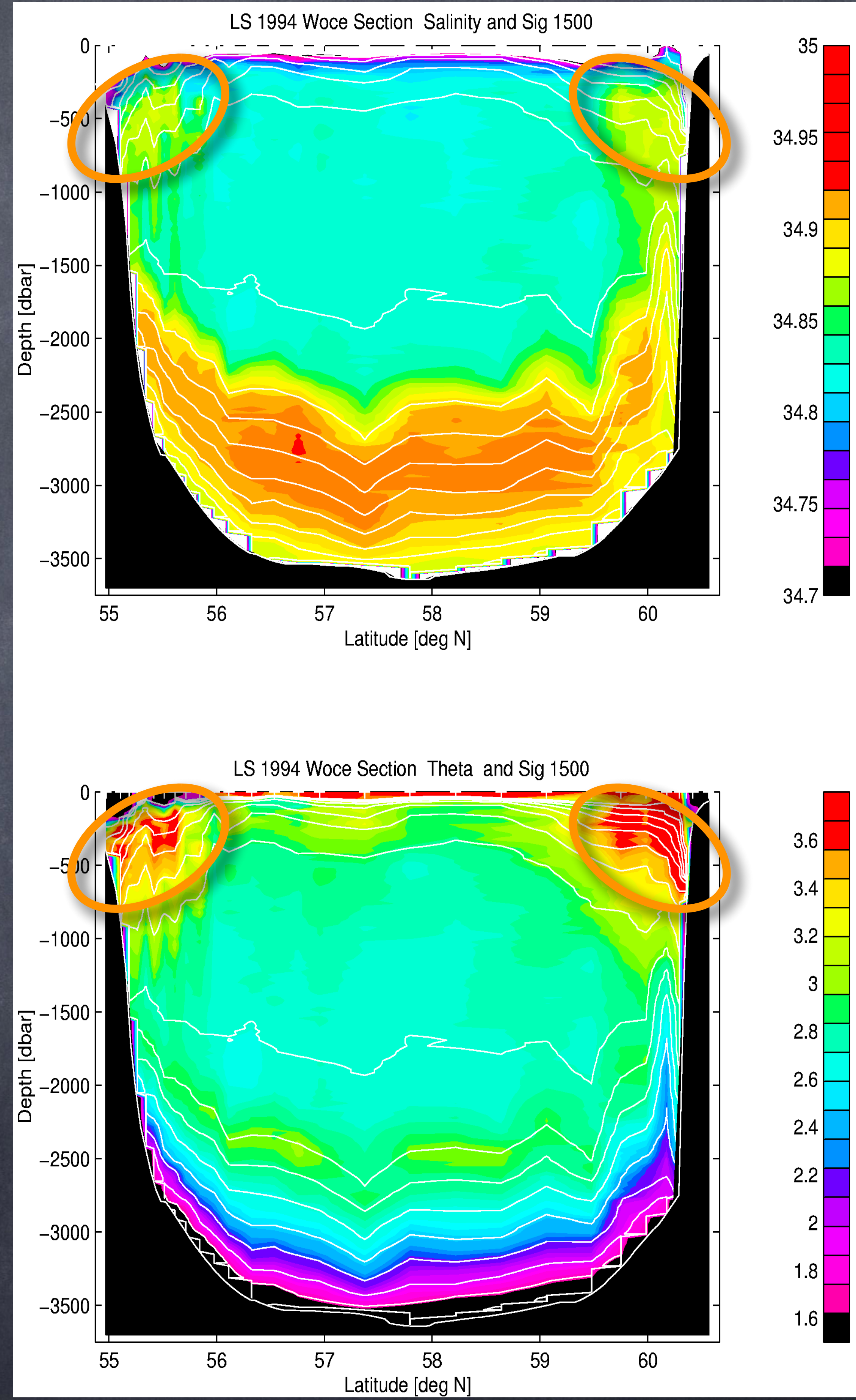

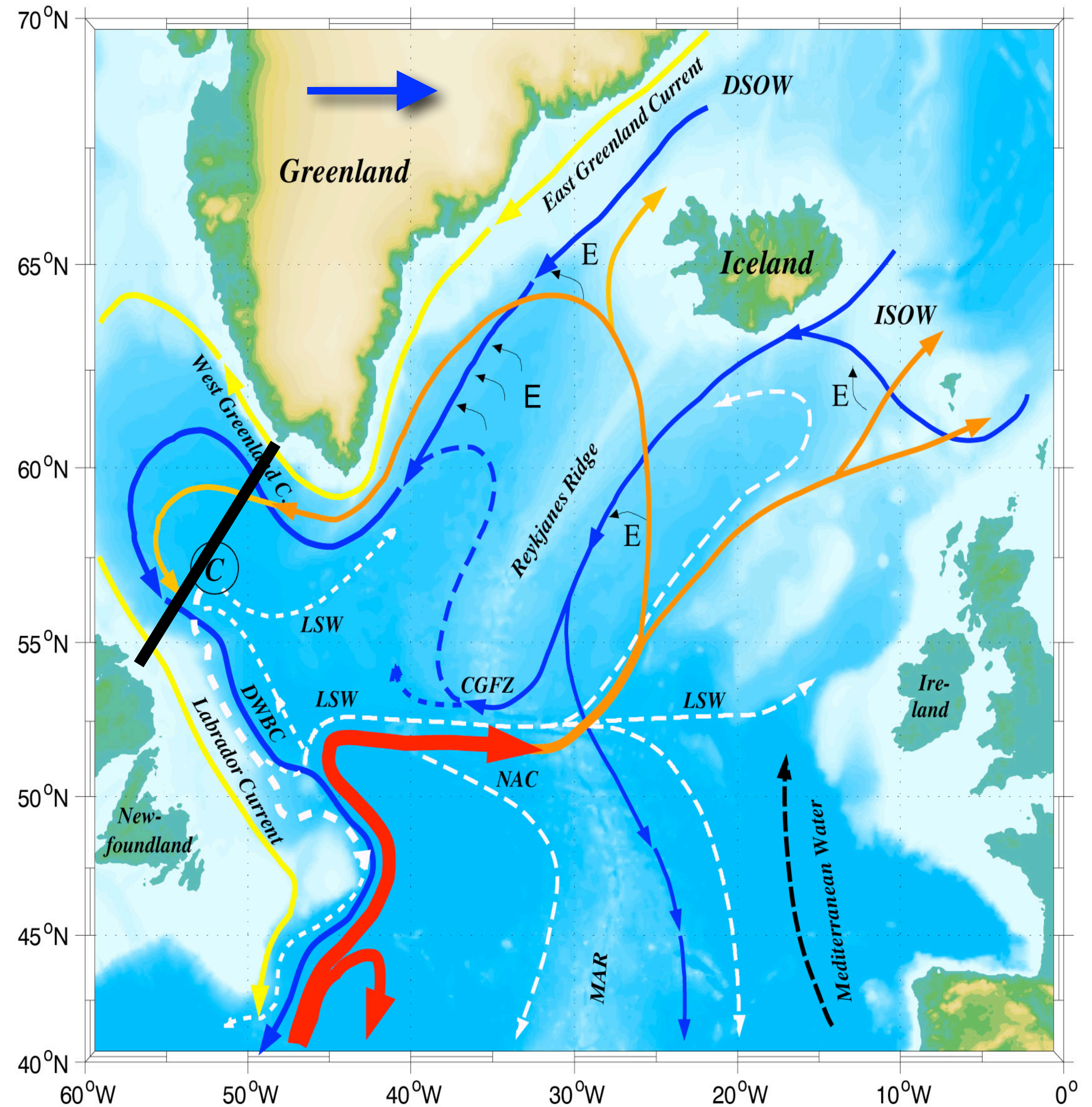

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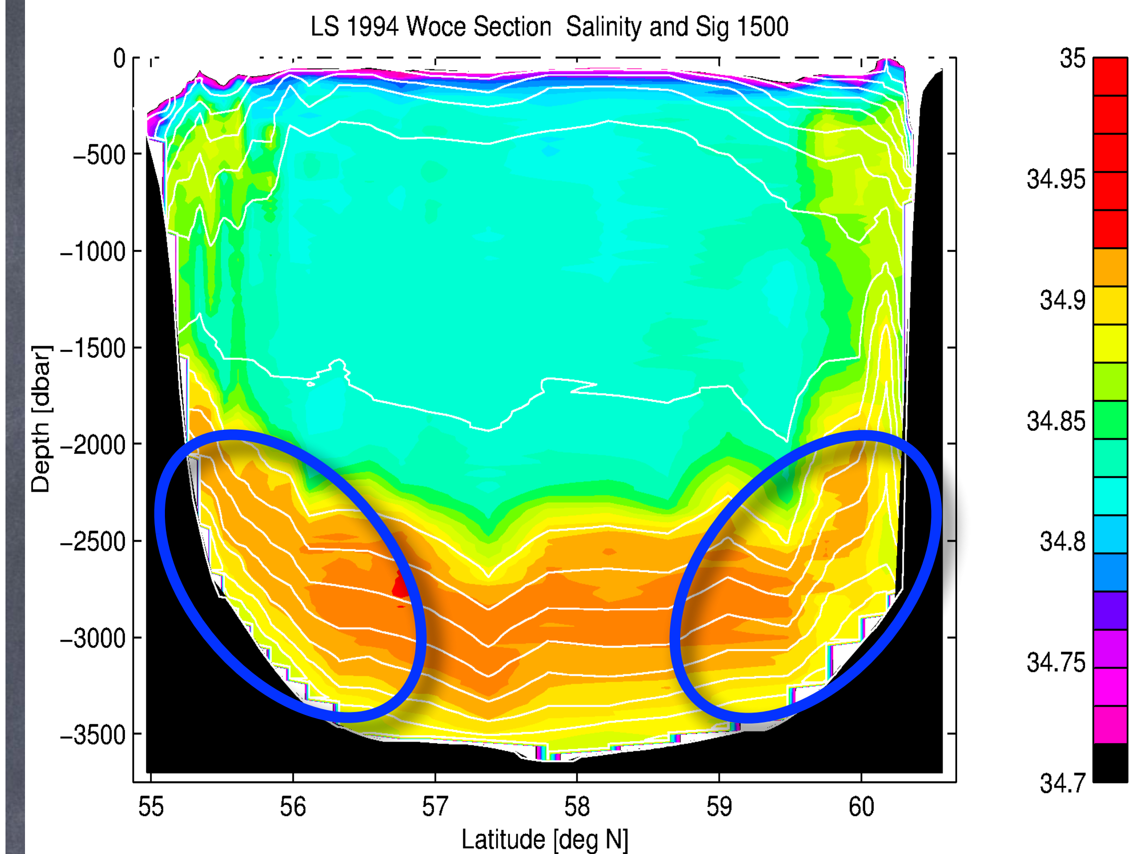

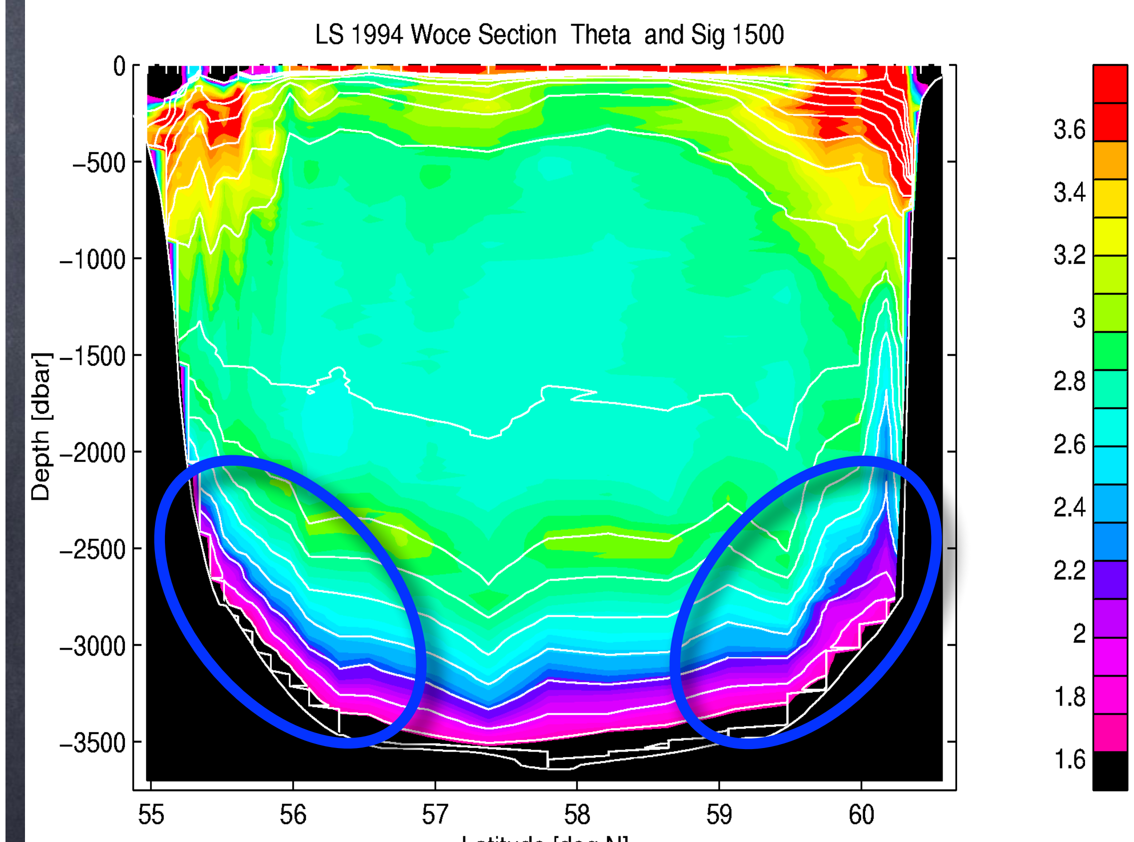

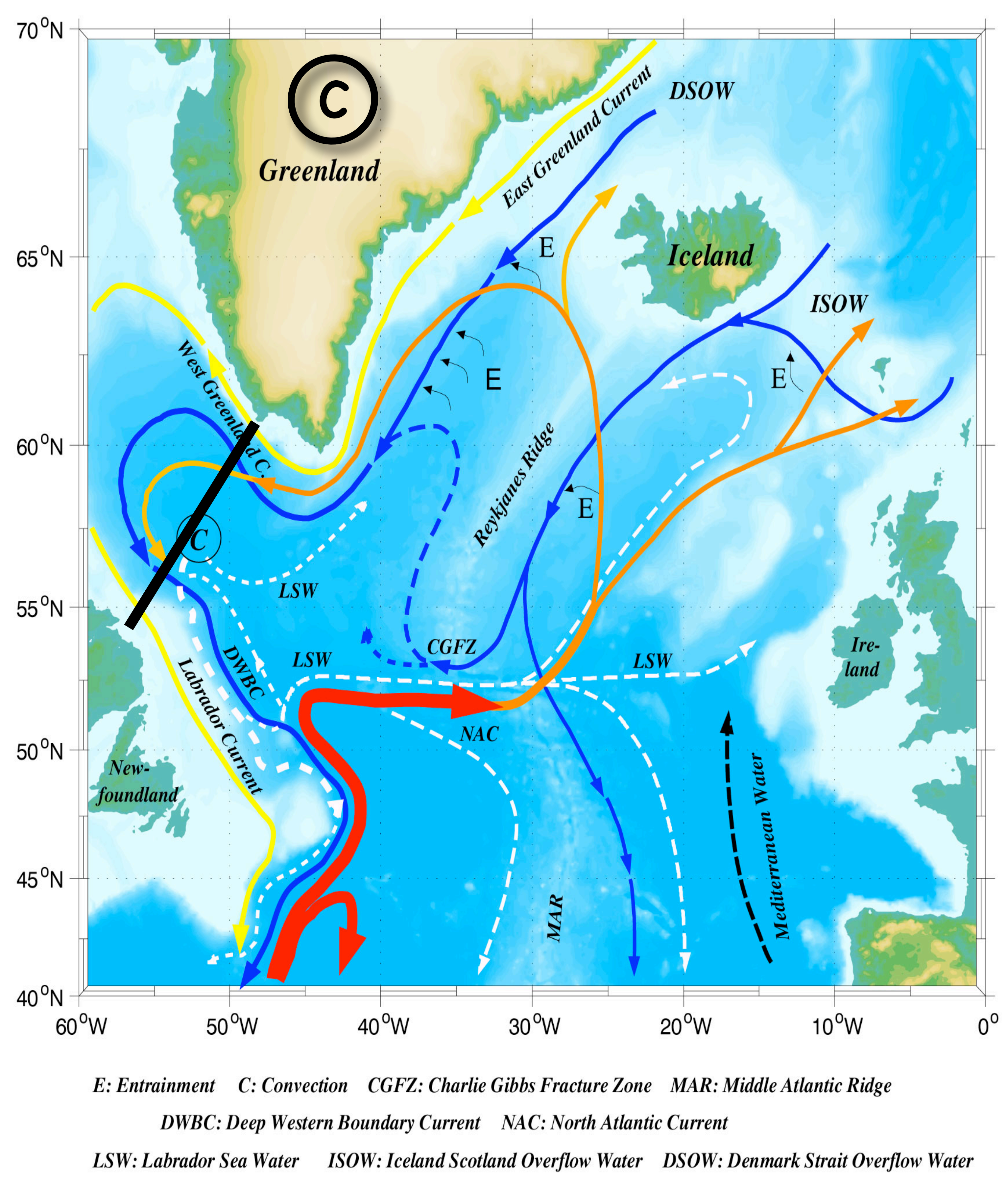
Greenland
Iceland
East Greenland Current
West Greenland C.
Labrador Current
DSOW
ISOW
E
C
LSW
DWBC
CGFZ
NAC
MAR
Reykjanes Ridge
Mediterranean Water
Ire-land
New-foundland
70°N
65°N
60°N
55°N
50°N
45°N
40°N
60°W
50°W
40°W
30°W
20°W
10°W
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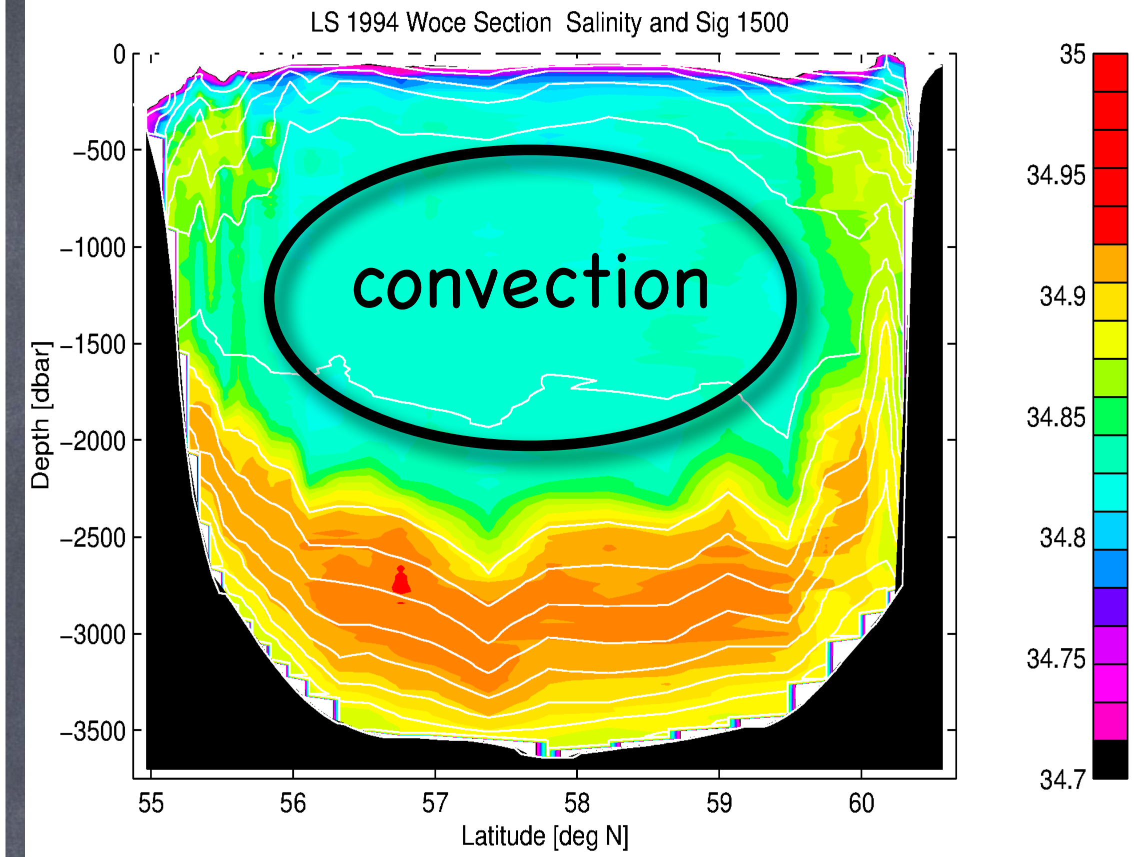
LS 1994 Woce Section Salinity and Sig 1500
convection
Depth [dbar]
Latitude [deg N]
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−1500
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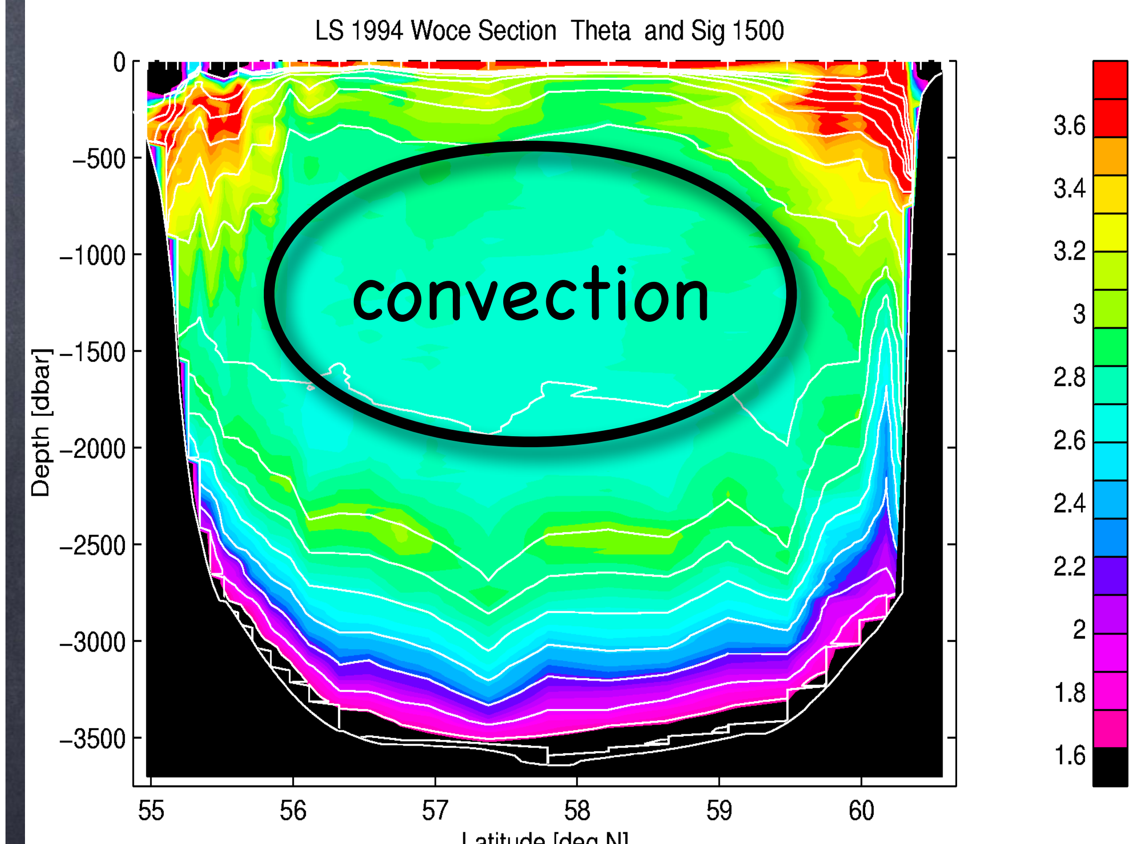
34.8
34.75
34.7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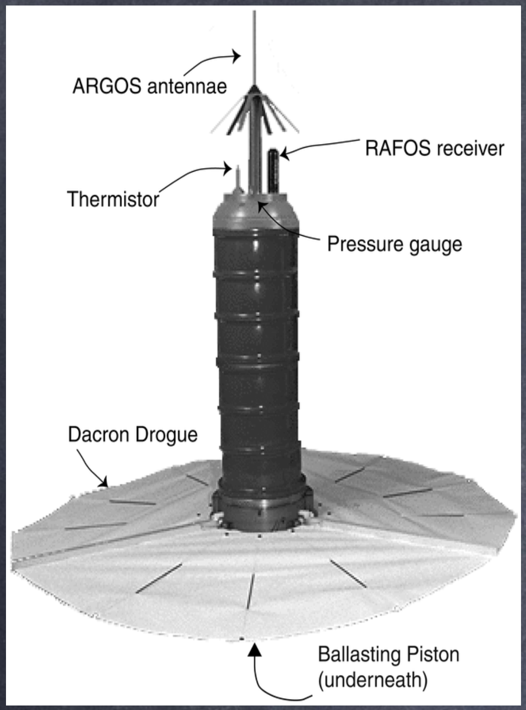
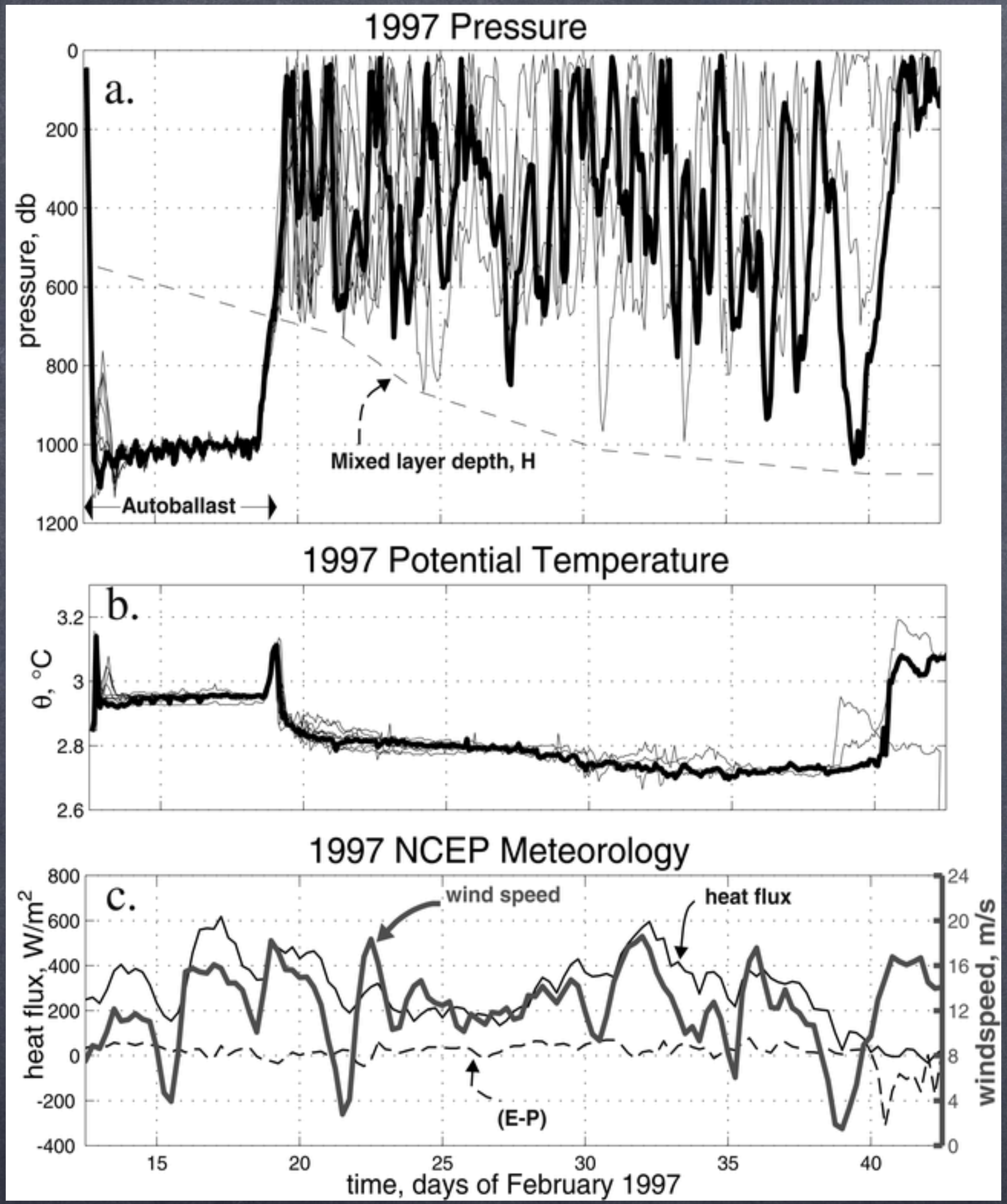
55
56
57
58
59
60
3.6
3.4
3.2
3
2.8
2.6
2.4
2.2
2
1.8
1.6

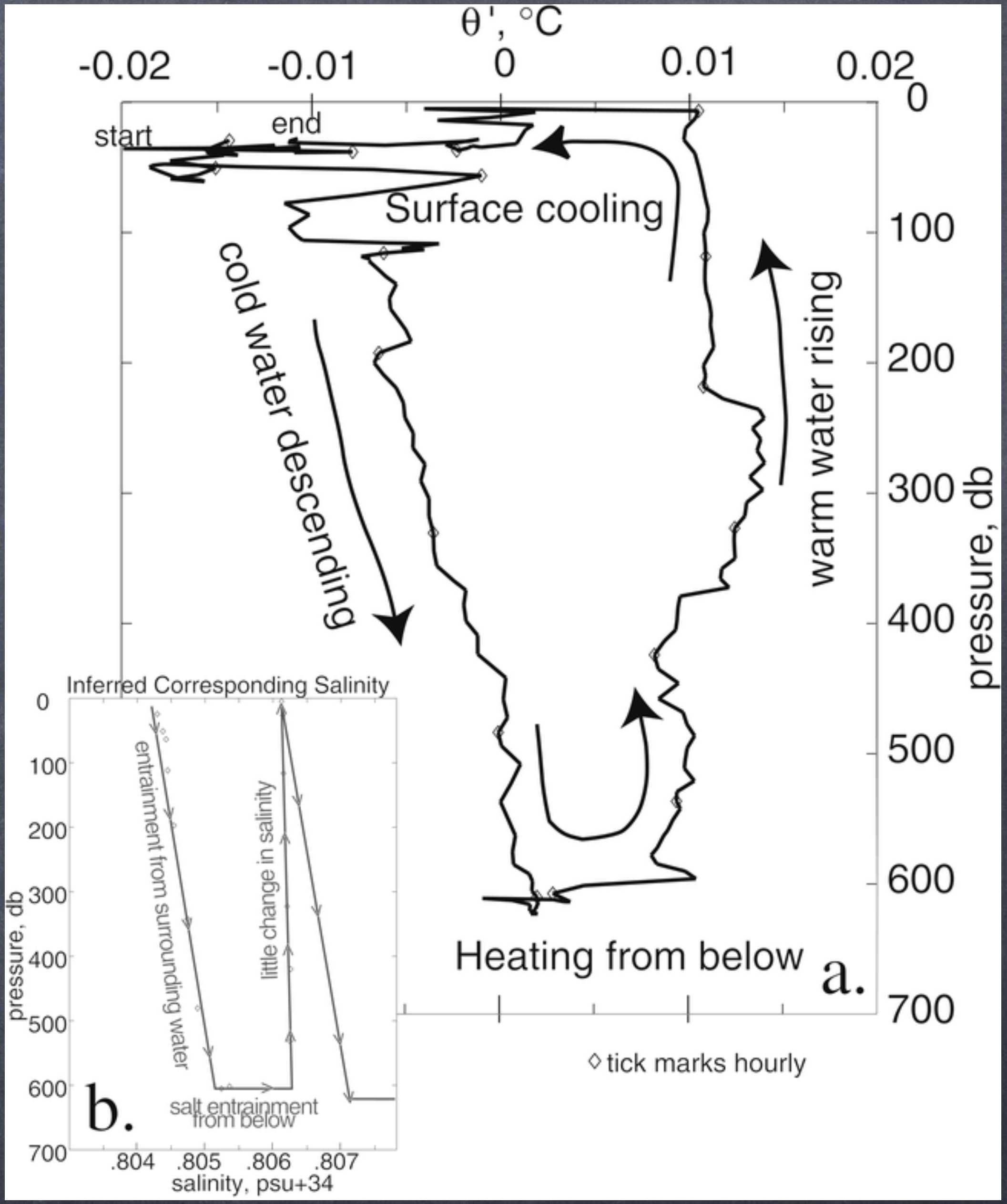
Deep Convection in the Labrador Sea

- Heat loss to atmosphere increases density of mixed layer, which gradually deepens.
- Deepest mixed layers occur near the ice edge - perhaps due to albedo effects? and/or brine rejection?
- Interior weakly stratified.
- Mixed layers up to 1500 m!

Deep Convection in the Labrador Sea



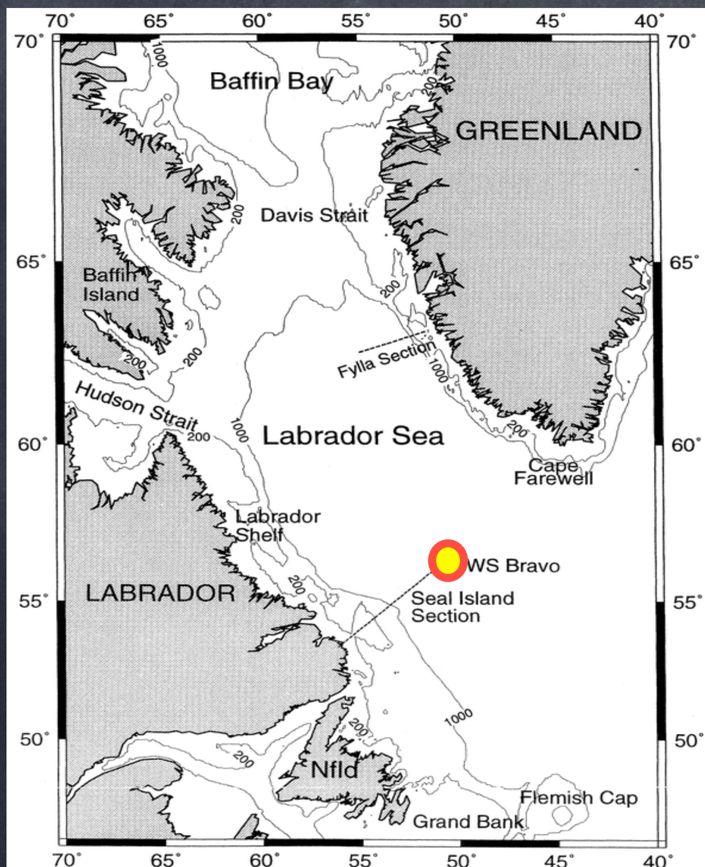


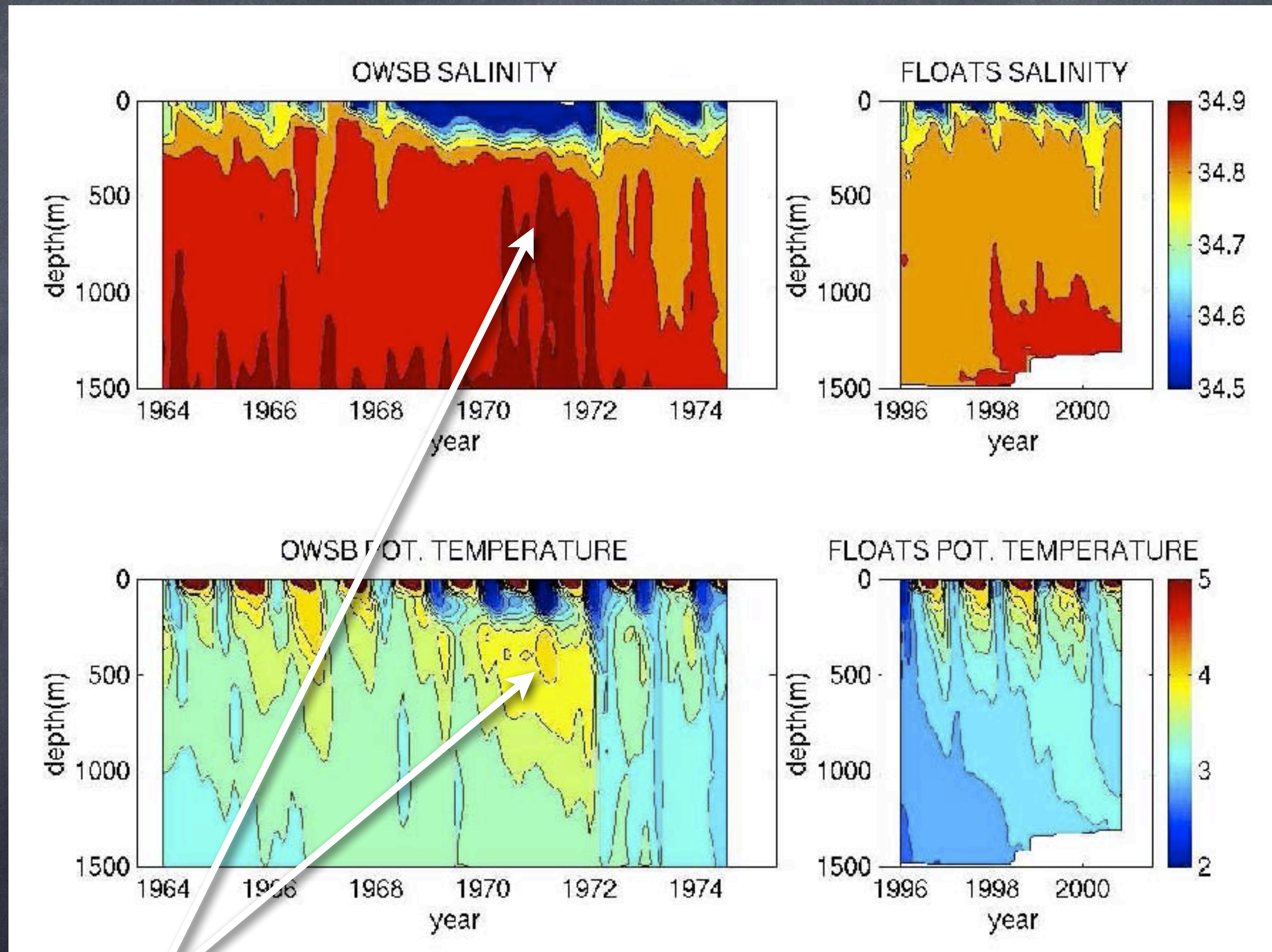


Lagrangian view of deep convection.
Note: water parcels move UP and DOWN - there is no mean vertical flow - is there sinking!?

Steffen and D'Asaro

Deep Convection in the Labrador Sea





Deep convection does not occur every year

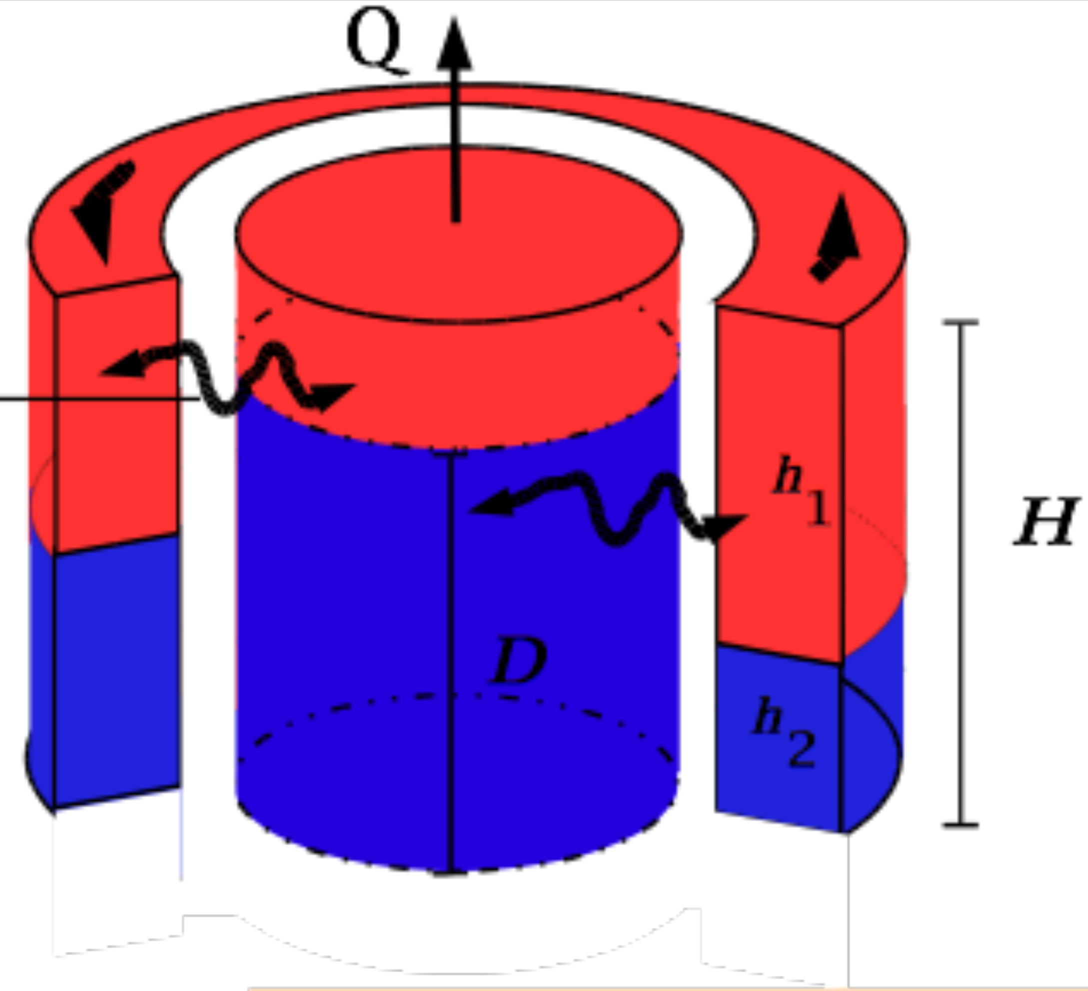
No convection for three years: warming and salinity increase, but still an export of deep waters.

A Two Layer Model for the Labrador Sea

Interior
- no mean flow, no sinking
- buoyancy loss converts light fluid into dense fluid

Eddy fluxes
- proportional to the isopycnal gradient between interior and boundary current

$$u'\rho' = c\,\Delta\rho\,V_{bd} = \frac{2cg'}{fL^2}(D-h_2)$$



Boundary Current
- wind and buoyancy driven
- geostrophic
- no convection
- mass conservation
- buoyancy conservation

While about 2 Sv of LSW may be formed in a season, it is the amount exported from the basin by eddies (about 1 Sv) that contributes to DBWC.

Straneo (2006)

- in the Southern Ocean the most well-studied region of deep water formation is the Weddell Sea (e.g. Gordon, Muench)
- convection is common in polynyas - small areas of ice-free ocean (50-200 km) - where rapid cooling quickly destabilises the water column.