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COURSE ON CLIMATE VARIABILITY STUDIES IN THE OCEAN
"Tracing & Modelling the Ocean Variability"
16 - 27 June 2003

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Oceanic Deep Convection and its role in Climate
Lecture I - Climatological Seasonal Cycle

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Please note: These are preliminary notes intended for internal distribution only.

Oceanic Deep Convection and its role in Climate

Lecture I − Climatological Seasonal Cycle

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Climate Variability Studies in the Ocean:
Tracing and Modeling the Ocean Variability
ICTP − June 2003

Outline Lecture I − The Climatological Cycle

I. Why is deep convection important within our climate system?

II. Climatological Seasonal Cycle at a Deep Convective Location

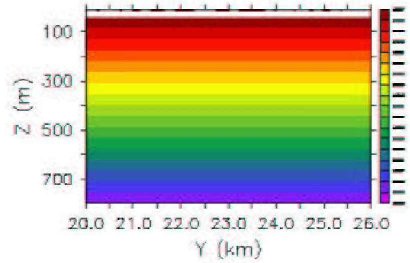
Outline Lecture II: Variability of Deep Convection

Part III. Variability of Deep Convection Observations and Theories

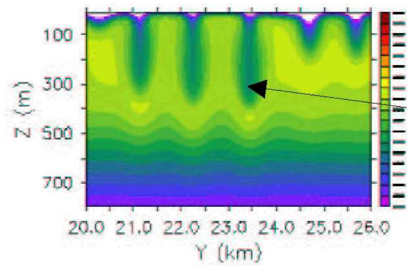
Part IV. An idealized model as a tool to study variability

What is Deep Convection ?

Stratified ocean

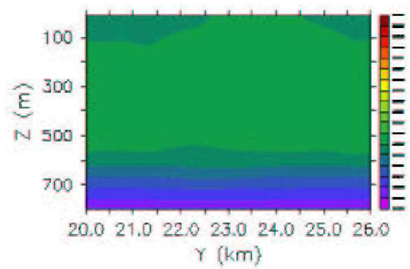


Ocean strongly cooled at the surface



Plumes: convective mixing agents diameter O(1km)

Unstratified cold mixed layer overlying stratified ocean



(model simulations − Straneo et al., 2002)

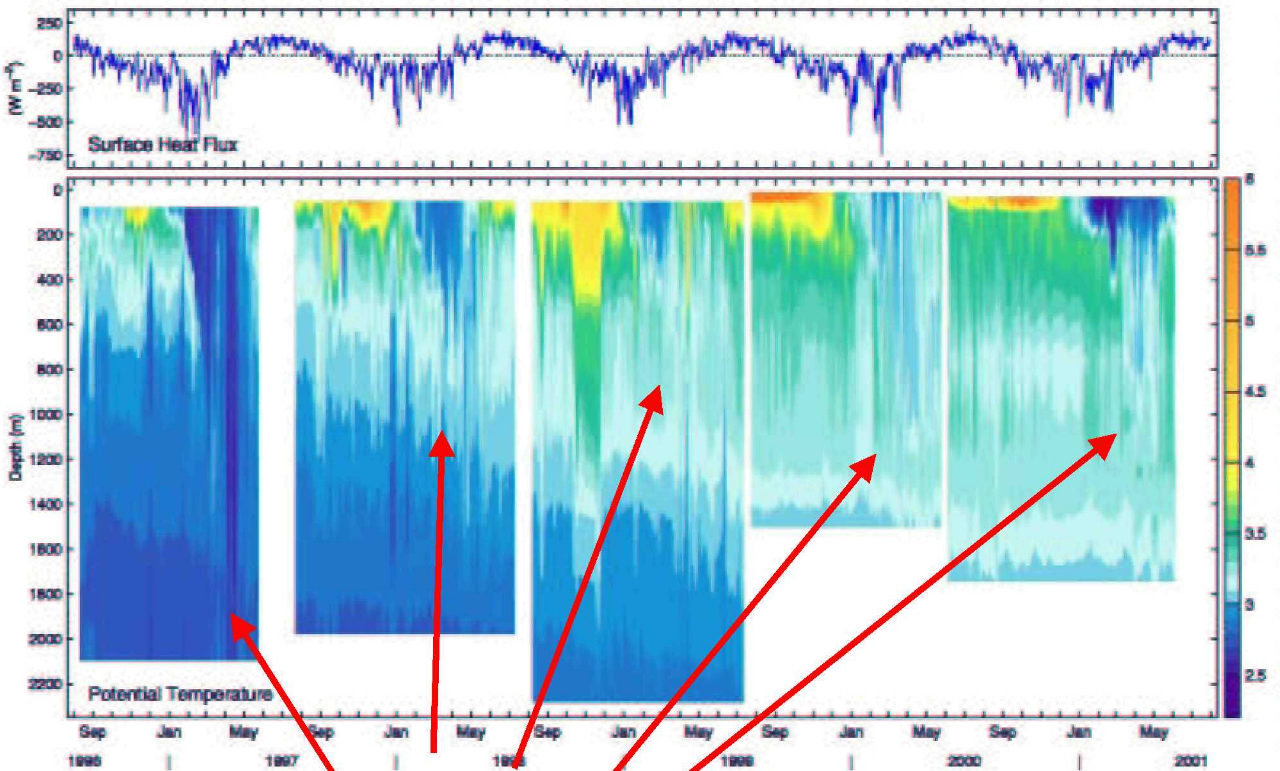
Deep Convection: vertical overturning driven by a large surface heat loss

Mooring Location

Observations from mooring at a convective location: the Central Labrador Sea

Surface Heat Loss

Temperature of the water column



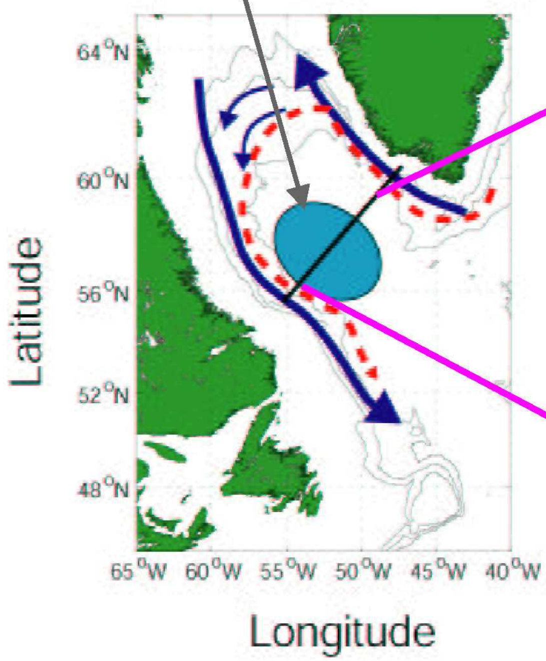
convection events

(Schott et al., Univ. of Kiel)

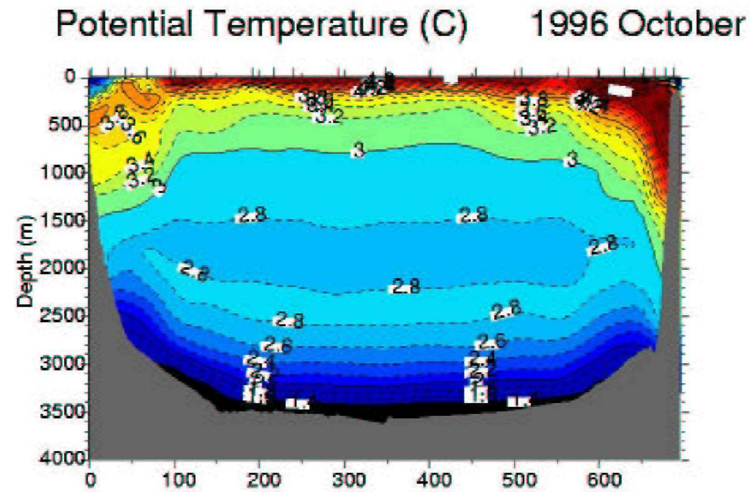
Large Scale Aspects of Deep Convection

Deep convection location

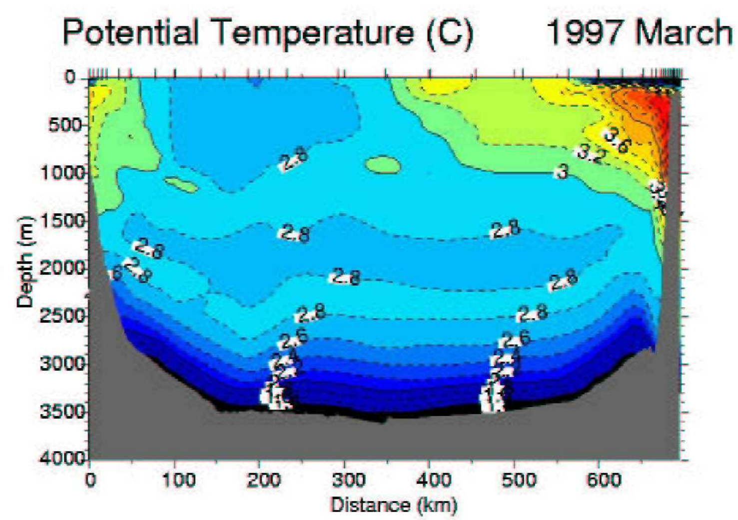
Section location



Section Across the Labrador Sea



Stratified end of summer



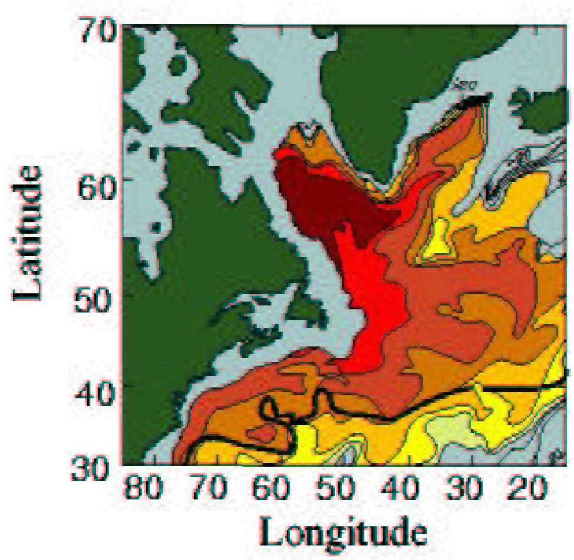
Unstratified end of winter

Pickart et al. 2002

300km

Spreading of a convectively formed water mass

<u>Labrador Sea Water Spreading in the North Atlantic</u>

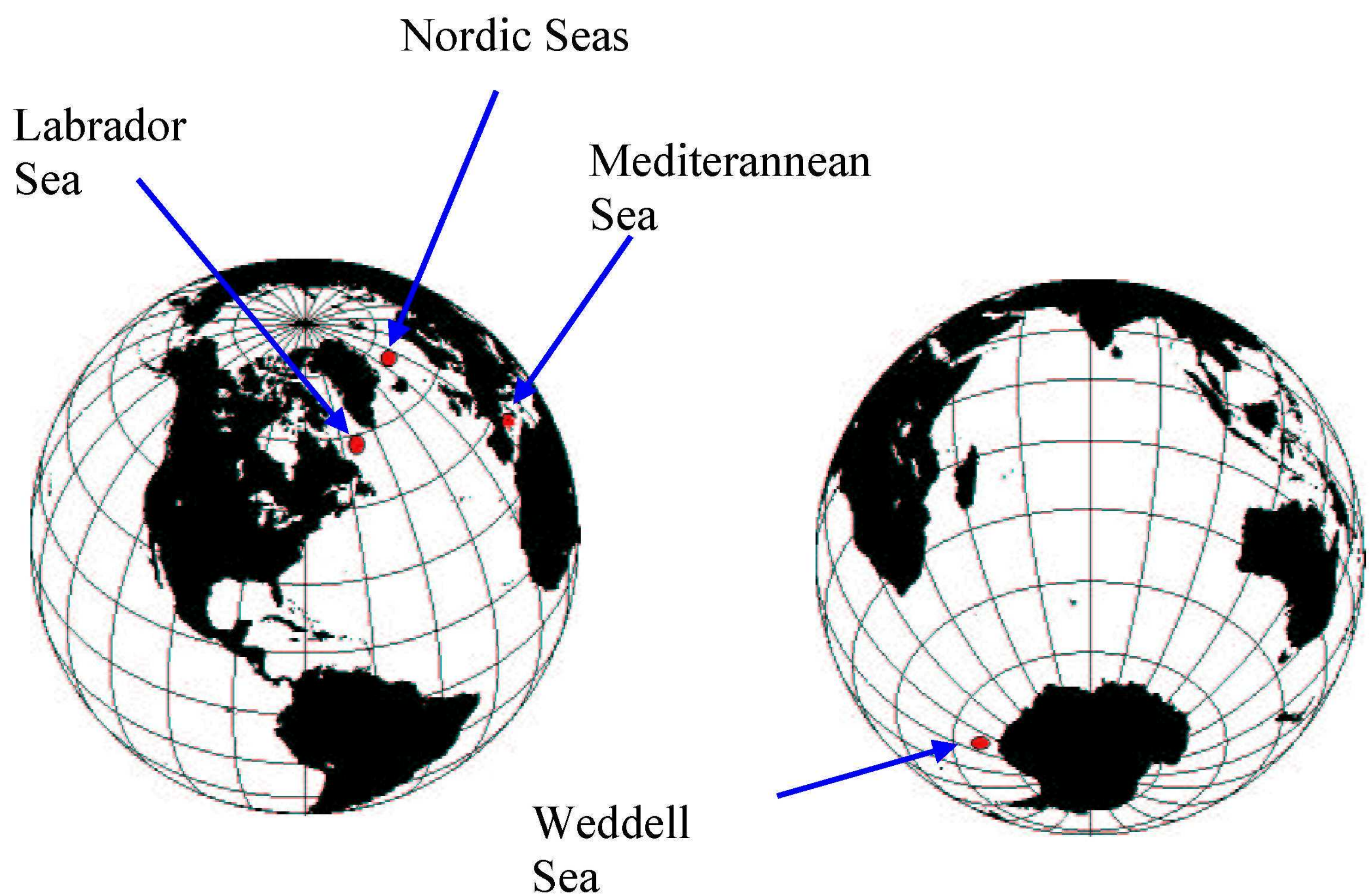


Southward movement of a cold (fresh) water mass at mid−depth as part of the oceanic poleward heat transport.

Watermass tracked via potential vorticity minimum.

(Talley and McCartney, 1982)

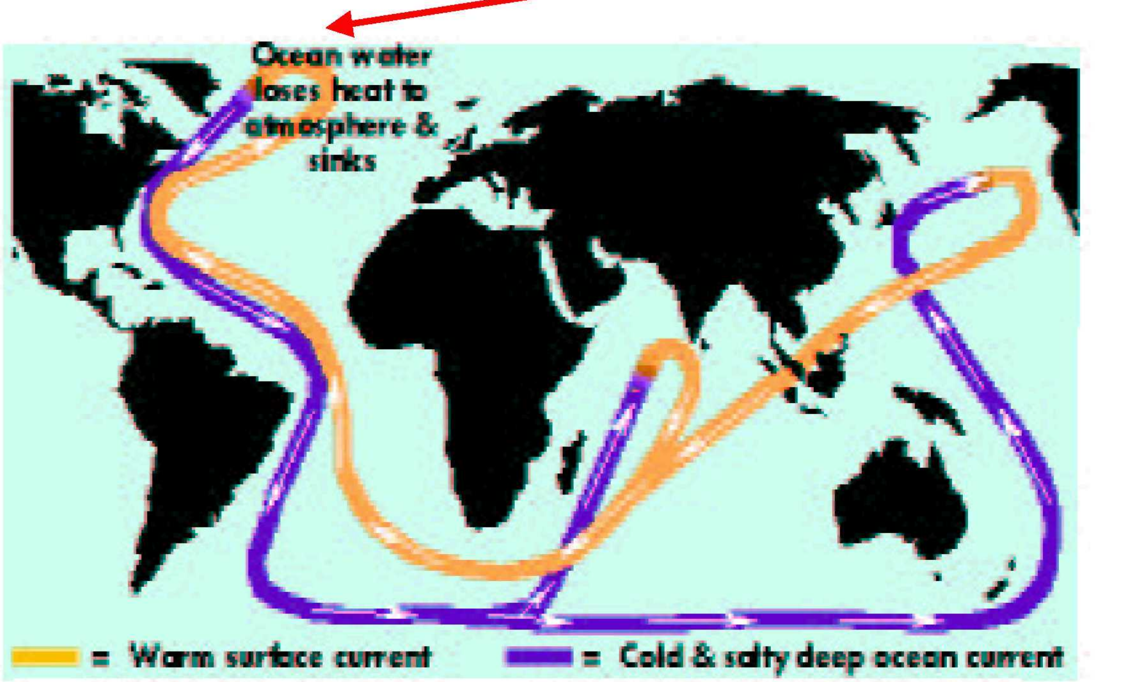
Deep Convection at a Limited Number of Locations



The dense water formed via convection is an integral part of local (Mediterranean) or global overturning circulations.

Deep Convection Regions As a Key Component of the Ocean's Poleward Heat Transport and Meridional Overturning Circulation

Schematic of the Thermohaline Circulation

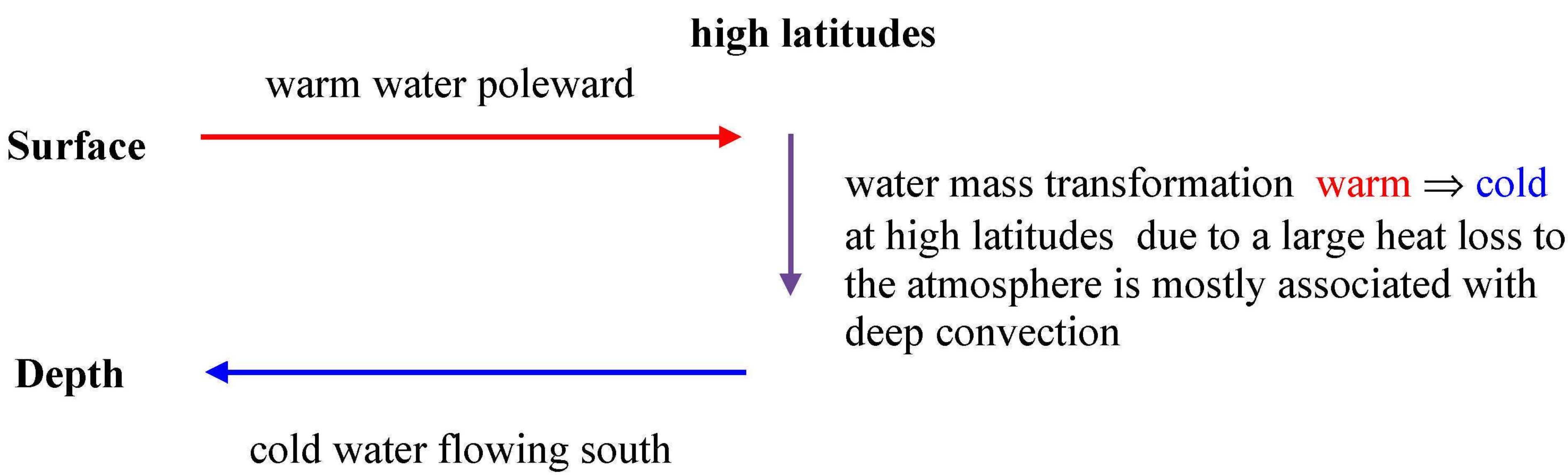


Water Mass Transformation in the North Atlantic due to deep convection is associated with the sinking limb of the global overturning circulation.

Convection in the North Atlantic results in the formation of North Atlantic Deep Water (NADW).

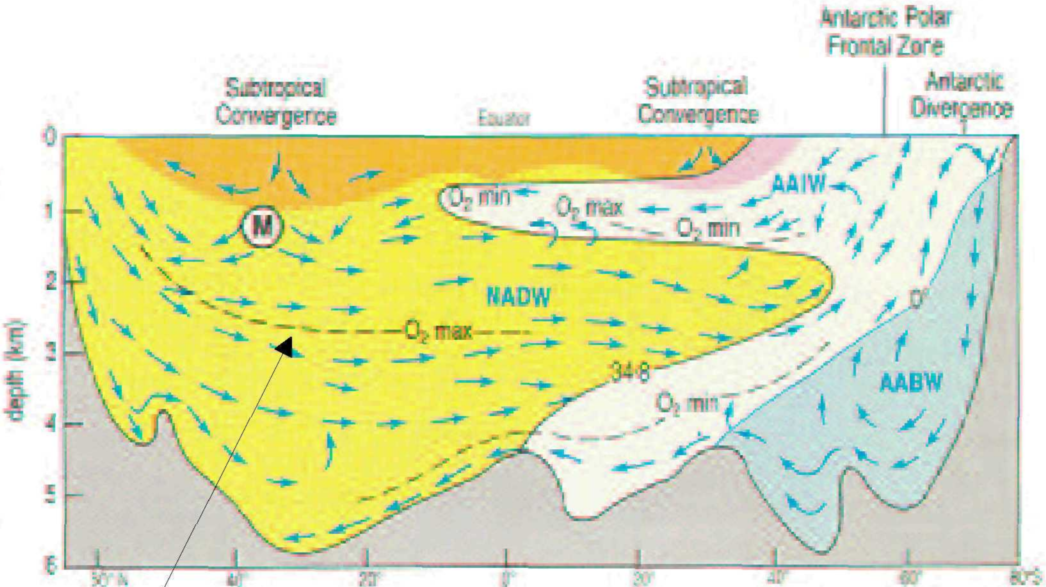
Meridional Overturning Streamfunction of the North Atlantic

North Atlantic Ocean transports $O(10^{15}\ W)$ northward
mostly via NADW formation and the vertical overturning cell



OVERTURNING CIRCULATION OF THE NORTH ATLANTIC

Figure 6.15 Meridional cross-section of the Atlantic Ocean, showing movement of the major water masses; NADW = North Atlantic Deep Water; AAIW = Antarctic Intermediate Water; AABW = Antarctic Bottom Water. Water with salinity greater than 34.8 is shown yellow; note how the low salinity tongue of AAIW extends northwards from the Antarctic Polar Frontal Zone, to overlie the more saline NADW. The M at about 35°N indicates the inflow of water from the Mediterranean. Water warmer than 10 °C is shown pink/orange, and the cooler than 0 °C (corresponding approximately to the distribution of AABW) is shown blue. The oxygen maxima and minima will be explained in Section 6.5.



Dense waters formed via deep convection are ‘young’: rich in O_2, CFCs due to recent contact with the atmosphere.

Summary

Part I. Why is deep convection important within our climate system?

- principal mechanism for dense water formation
- poleward heat transport and meridional overturning circulation (especially in the North Atlantic)
- mixing of properties between the deep and surface ocean

Part II. Climatological Seasonal Cycle at a Convective Location

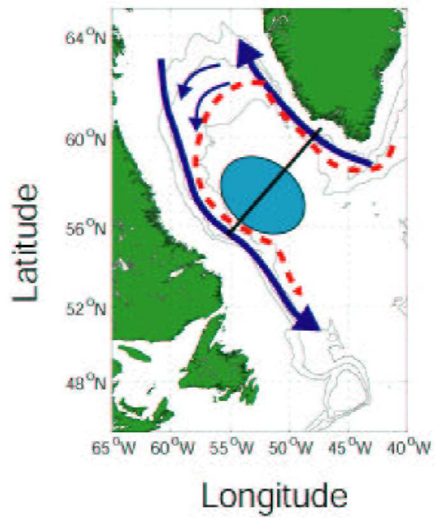
To understand the variability of a system, we first need to:

- describe its mean behaviour
- identify the physically significant variables
- understand the basic physical mechanisms

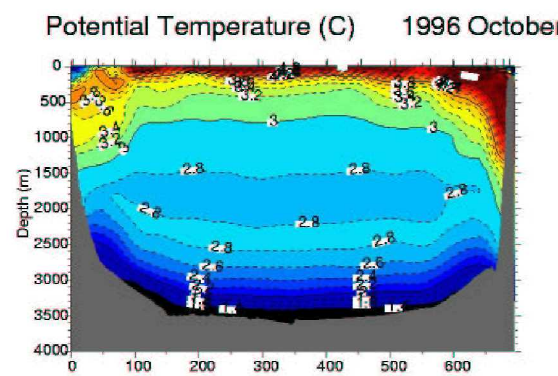
How Deep Convection Works: the Labrador Sea Case Study

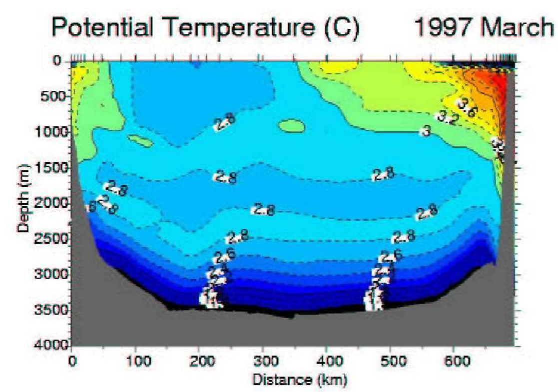
North Atlantic's Subpolar gyre:
the warm water pathway

Semi−enclosed basin
encircled by warm water
in boundary currents

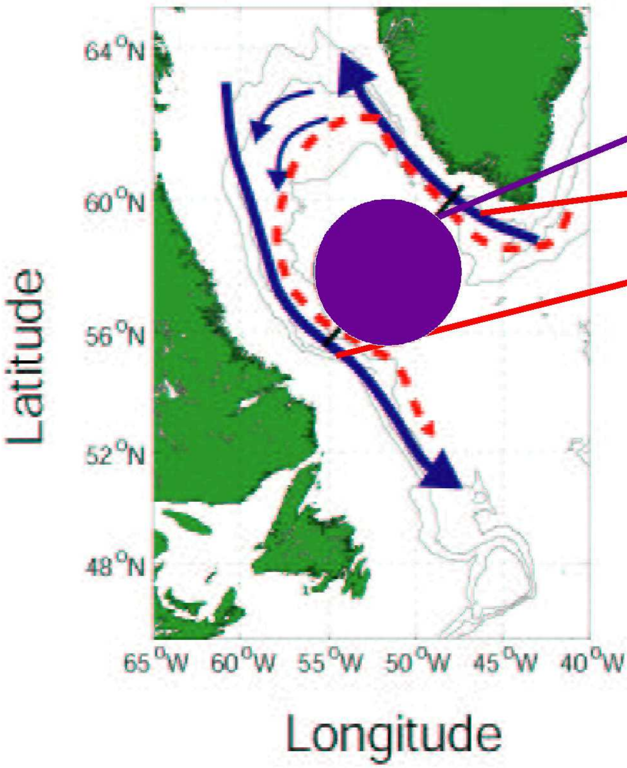


Convection occurs in
the western portion of
the basin.





ELEMENTS OF A CONVECTIVE SYSTEM

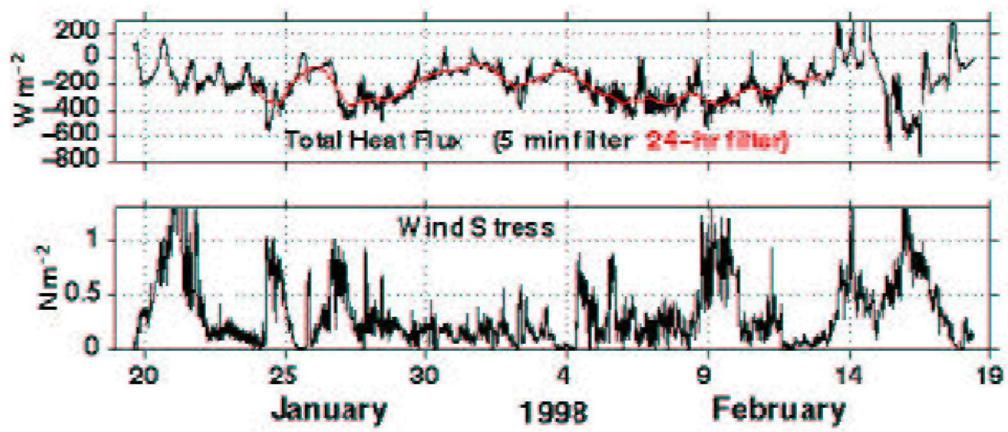


1. interior convective region

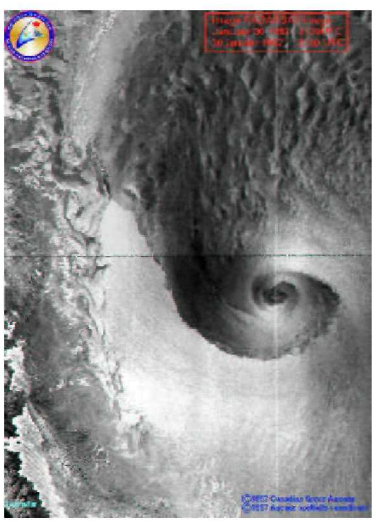
2. lateral forcing:
   exchange with the surrounding boundary currents

3. surface forcing:
   exchange with the atmosphere

Ship measured heat loss and wind



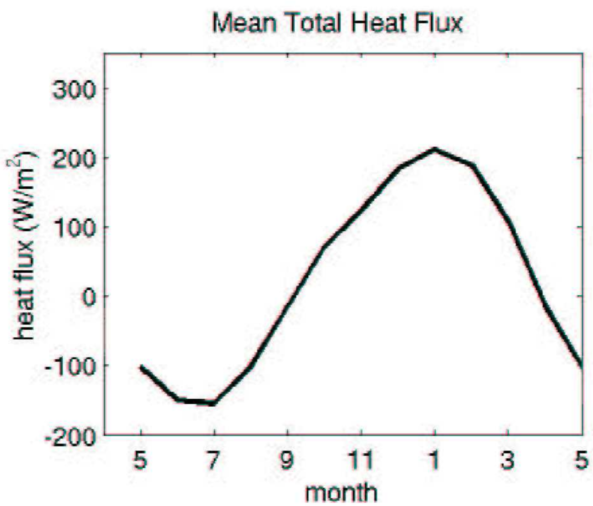
(P. Guest)

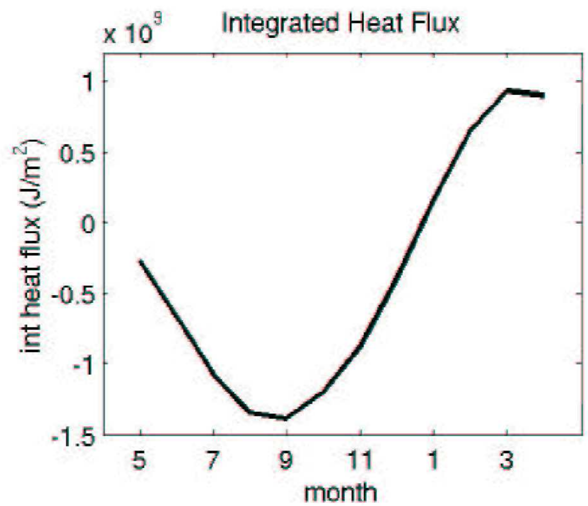


Winter storm over the Labrador Sea (Moore and Renfrew, 2002)

The Driving Force: the Atmospheric Heat Loss

Climatological Mean Heat Forcing over the Labrador Sea





Net annual heat loss of 10^9 J/m^2

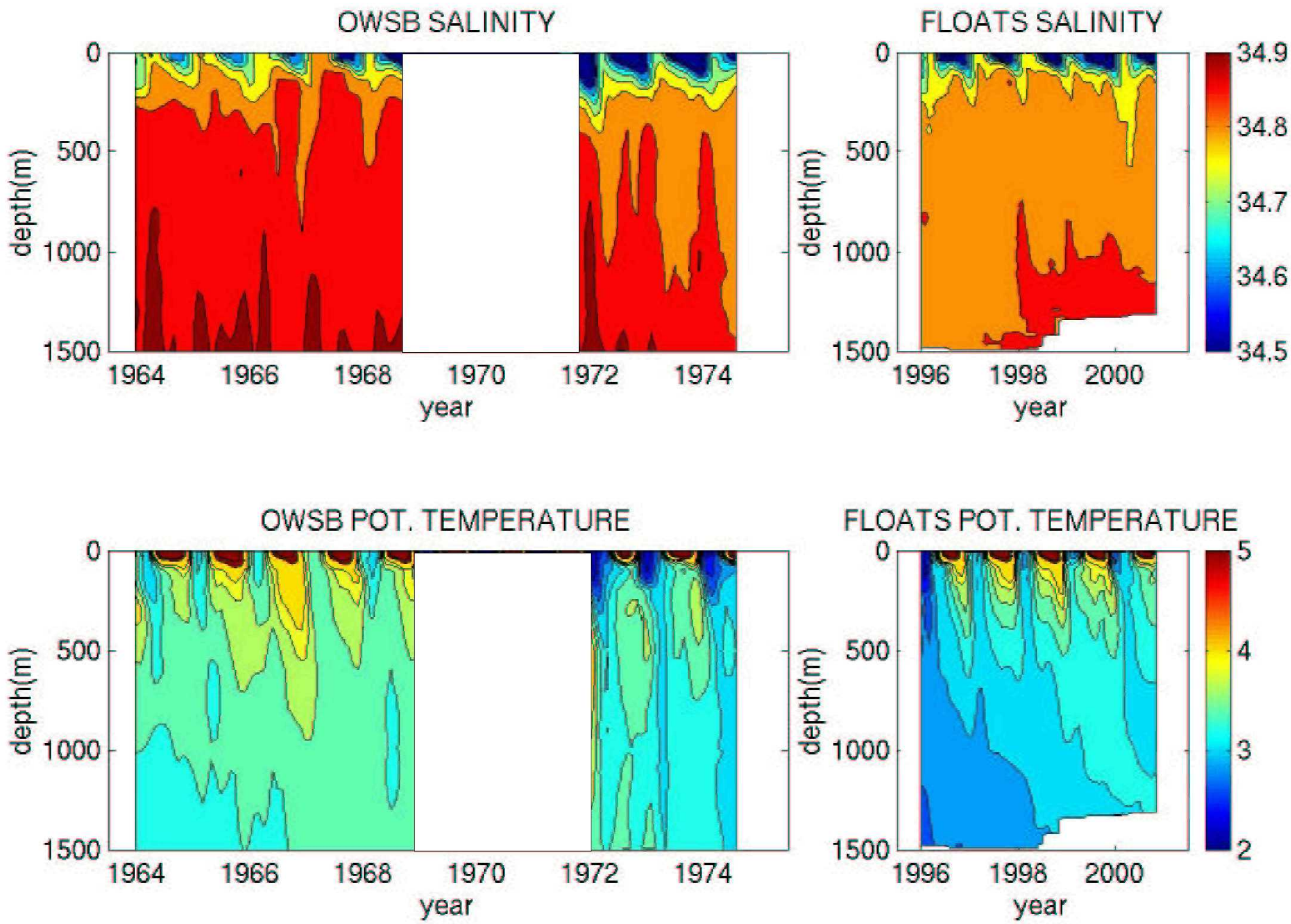
(NCEP data 1948:2000, K. Moore and I. Renfrew)

How to reconstruct the Labrador Sea's Mean Seasonal Cycle from data:

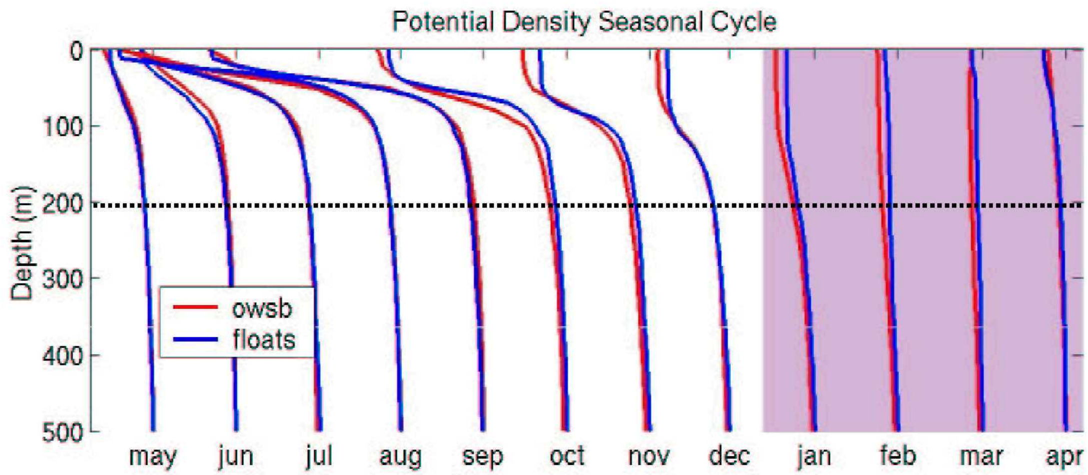
Two data timeseries:

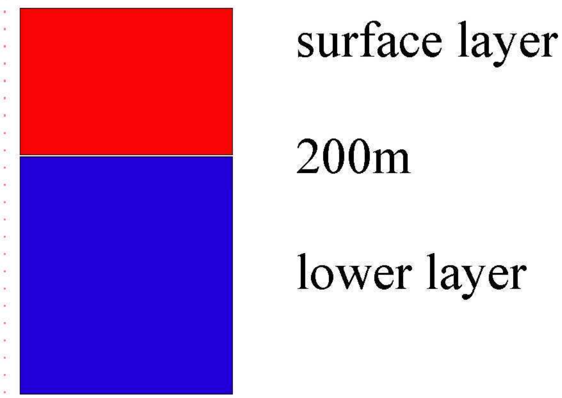
i. Ocean Weather Station Bravo (OWSB) 1964−1974

ii. P−ALACE float data (1996−2000)



Mean Evolution of Density in the Central Labrador Sea





Restratification (may to dec.)
mixed layer is shallower than 200m

Convection
(jan to april)
deep mixed layer

Density evolution suggests the following breakdown for a simplified description:

i. layer breakdown − surface and lower layer

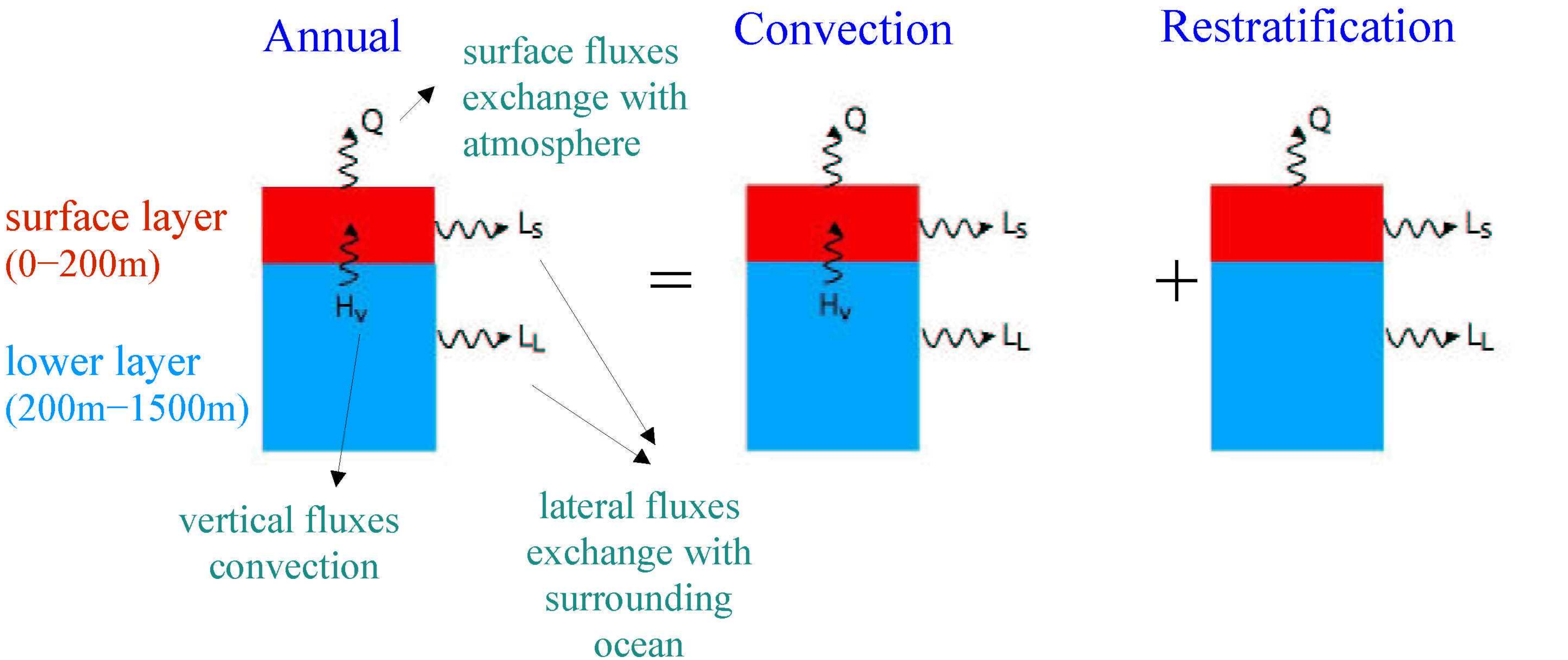
ii. temporal breakdown − restratification and convection

The Heat Budget of a Convective Region

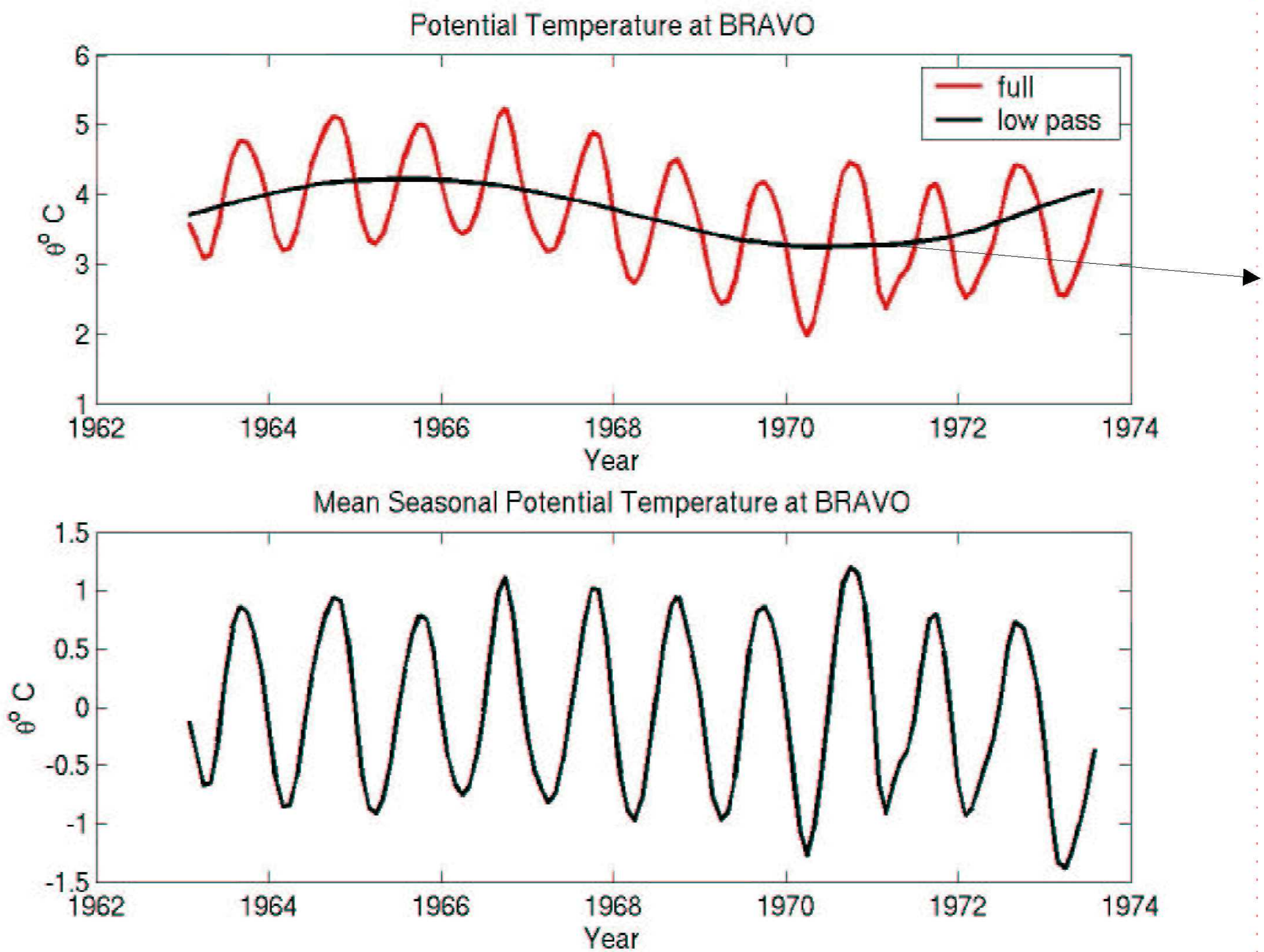
Given the temporal and layer breakdown chosen, how does heat flow through the system ?

i. The annual net heat loss to the atmosphere must be balanced by a net inflow of heat from the surrounding ocean.

ii. Vertical exchange between the two layers is limited to the convection phase.

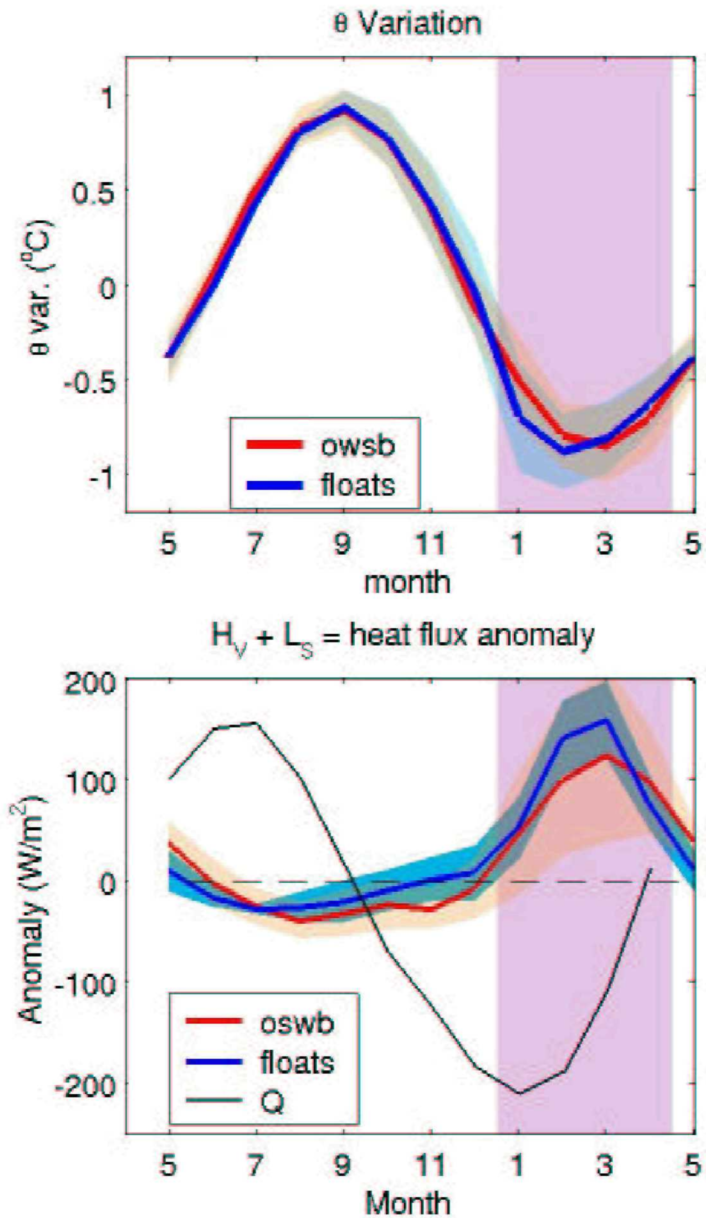


Extracting the Mean Seasonal Cycle



Long−term variability removed

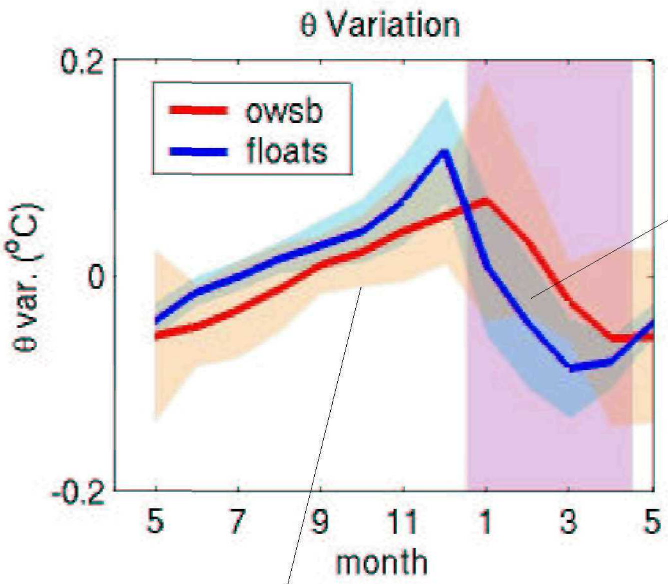
Climatological Variation in the Surface Layer Temperature



Surface layer temperature closely follows the atmospheric heat flux

Lateral exchange with the surrounding ocean contributes to cooling the surface layer during restratification

Climatological Variation in the Lower Layer Temperature

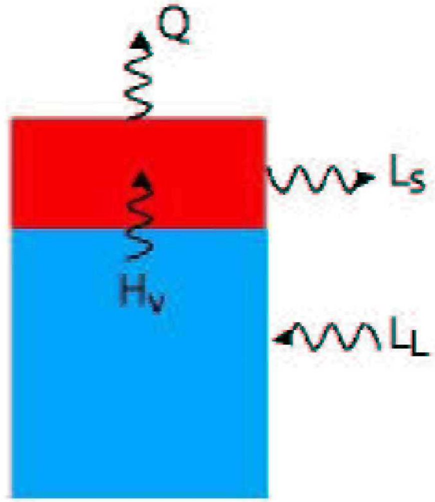


Rapid cooling during convection

Warming of the lower layer persists until january

ANNUAL BUDGET FOR THE CENTRAL LABRADOR SEA

−0.77 −0.83 Net surface heat loss to the atmosphere



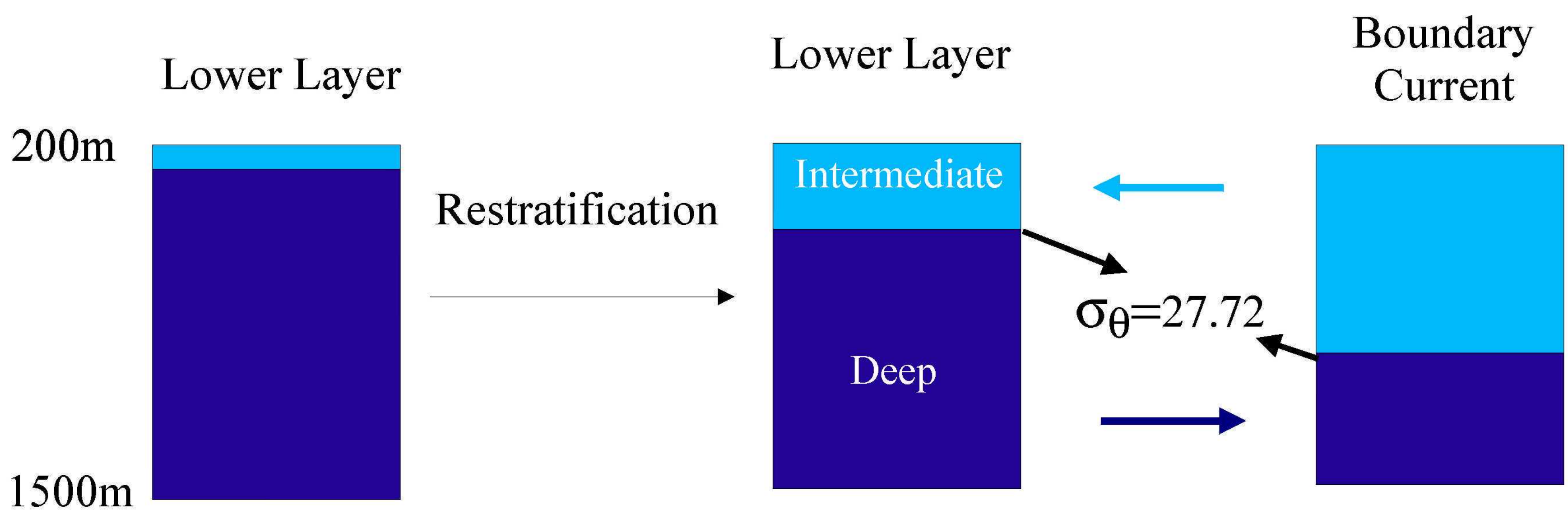
−0.19 −0.16 Cooling due to surface lateral exchange

0.96 0.99 Heating due to subsurface lateral exchange

red 1964−1974
blue 1996−2000

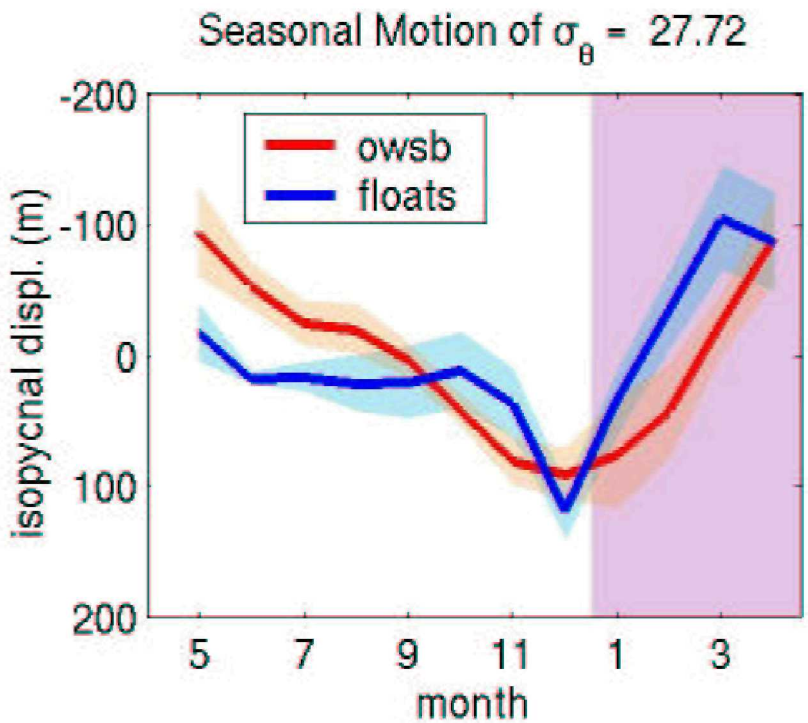
Inflow of heat into the lower layer: how does it occur ?

Proposed Mechanism = Baroclinic Exchange with the boundary currents



Climatological Motion of the 27.72 Isopycnal

Baroclinic Exchange = reduction of the gradient between the interior and the boundary current

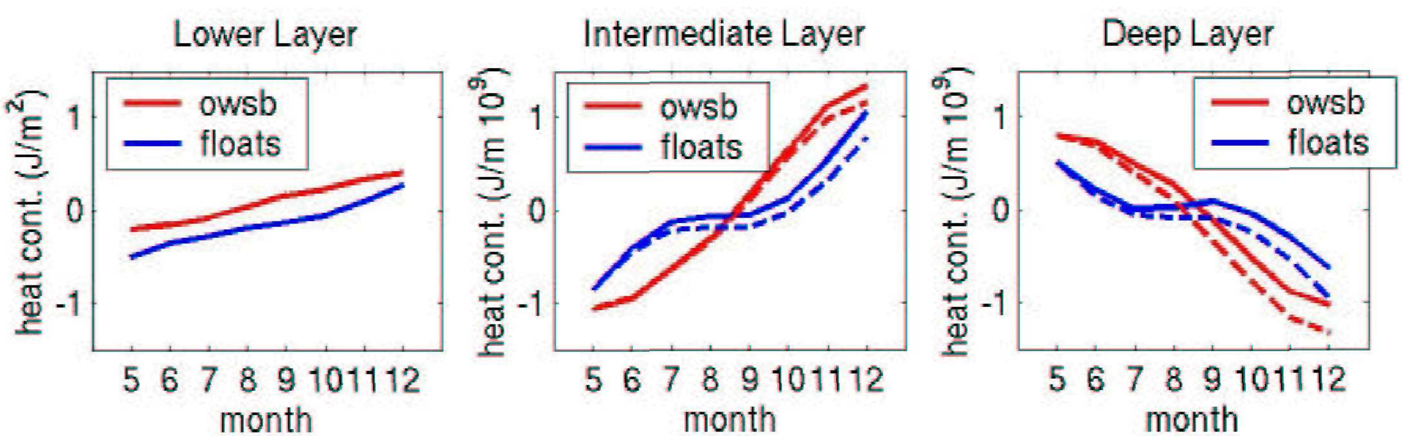


Restratification:
net sinking of the 27.72
by ≃200m

Convection:
net uplifting of the 27.72
by ≃200m

Heat Content Change in the Lower Layer during Restratification

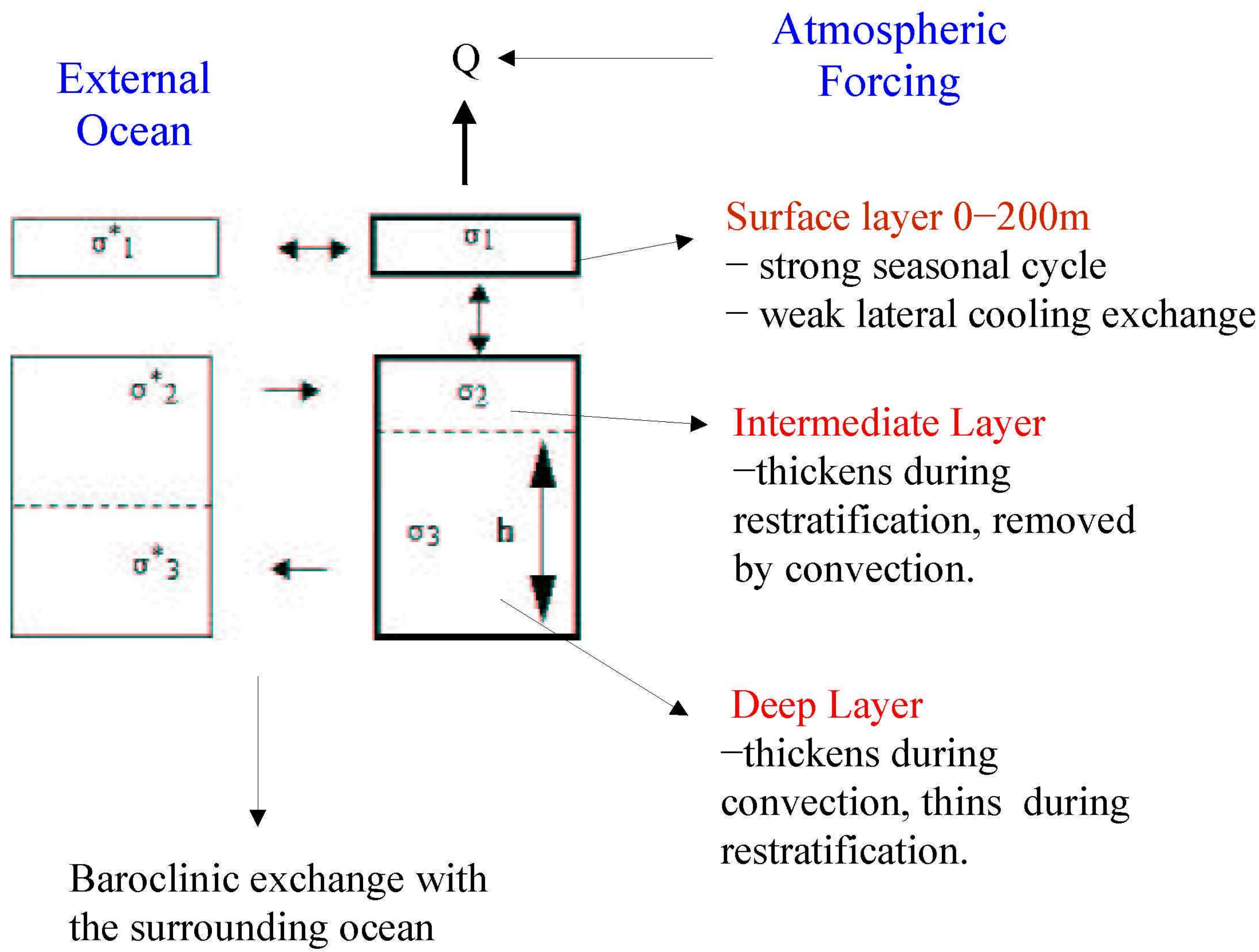
$$\mathbf{Hc(200-1500m) = Hc(200-\sigma_{27.72}) + Hc(\sigma_{27.72}-1500m)}$$



--- heat content change keeping the temperature within the layer constant

Warming of the lower layer (200−1500m) is primarily due to:
− thickening of the intermediate layer
− thinning of the deep layer

Simplified representation of convection:



The seasonal cycle for the two periods appears to be stable if described in these terms.

Summary

Why is deep convection important within our climate system?

- principal mechanism for dense water formation
- poleward heat transport and meridional overturning circulation
- mixing of properties between the deep and surface ocean

Part II. Climatological Seasonal Cycle at a Convective Location

- Simplified representation of the system includes:
    - atmospheric forcing
    - exchange with the surrounding ocean
    - mean heat budget
- physics of a convective system:
    - 3 layer representation
    - convection: heat flux from the lower into the surface layer
    - restratification: influx of heat at subsurface level via baroclinic exchange with the boundary current