Why are the densest waters in the North Atlantic formed in the Nordic Seas?

Fiamma Straneo

Acknowledgements/Collaborators

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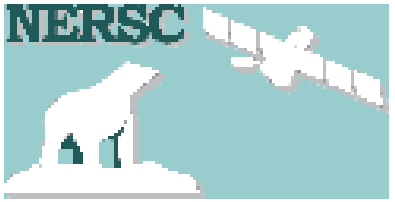
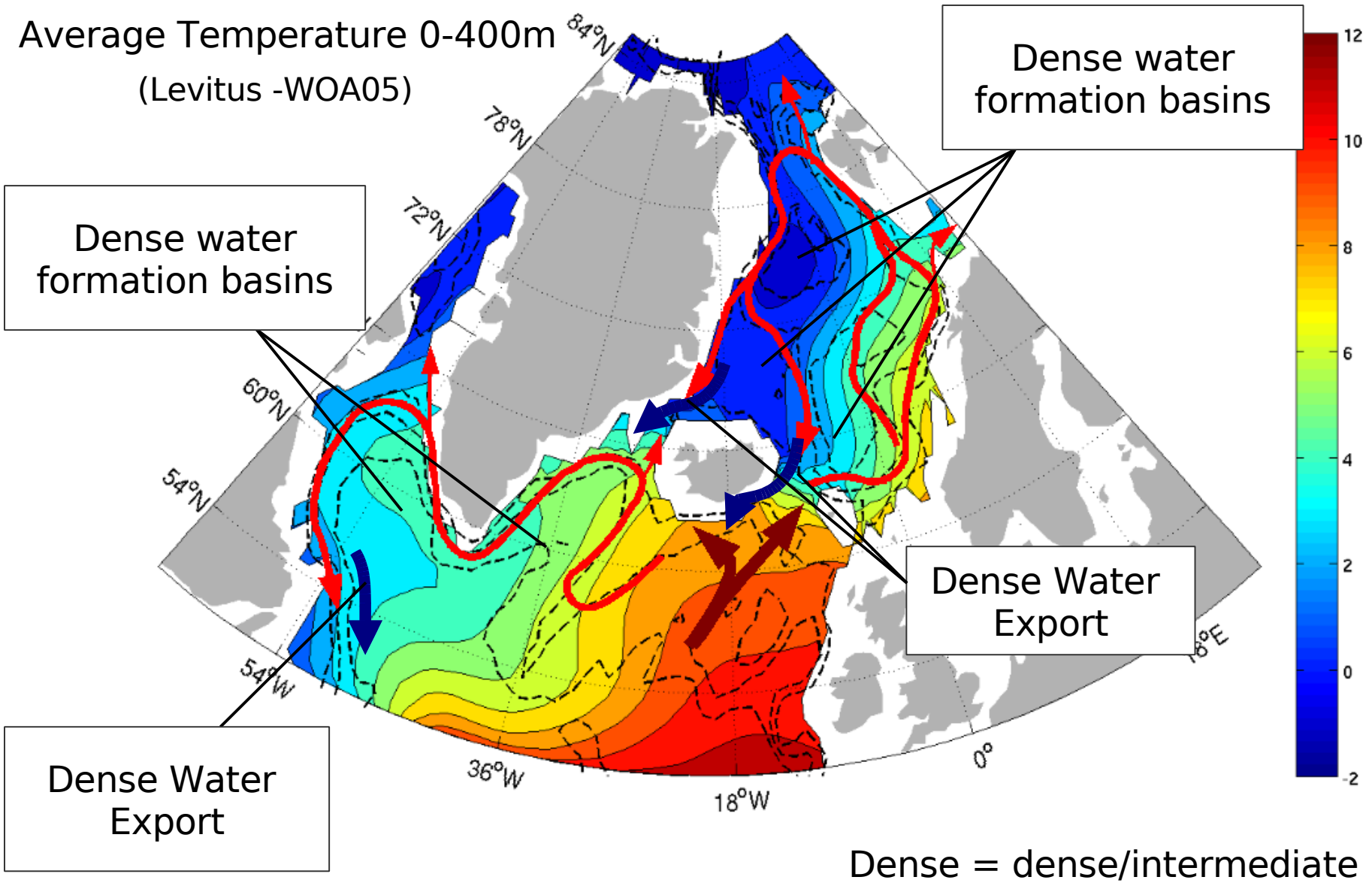
R.S. Pickart (WHOI)

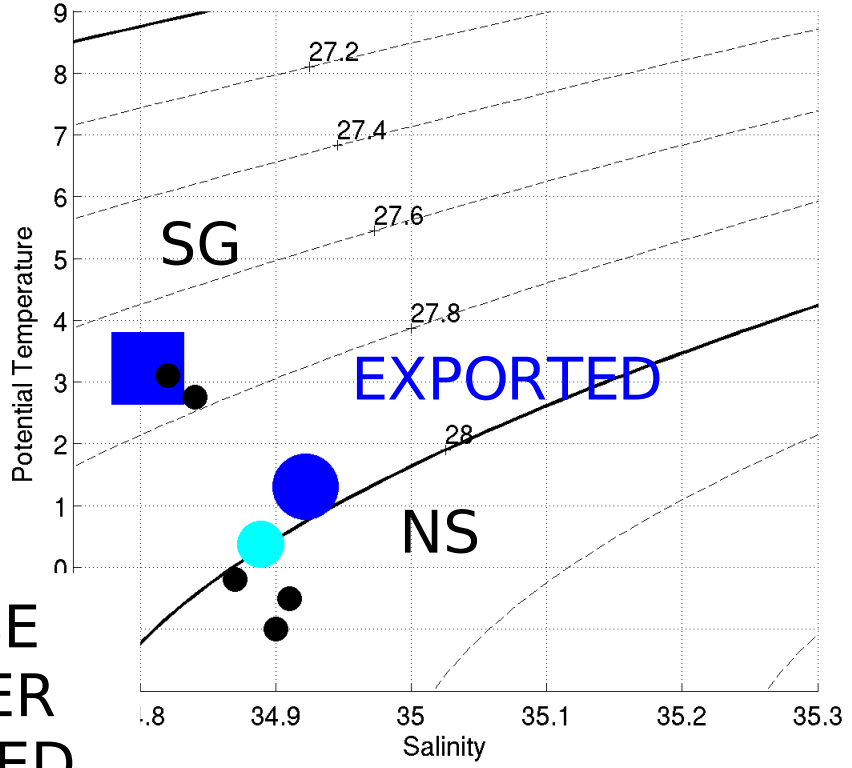


Warm to Cold Conversion in the North Atlantic



Circulation Redrawn from: *Bower et al. 2002; Jakobsen et al. 2003; Schott and Brandt 2007; Hansen and Østerhus 2000; Nost and Isachsen 2003; Lavender et al. 2004*

Dense Waters Formed and Exported

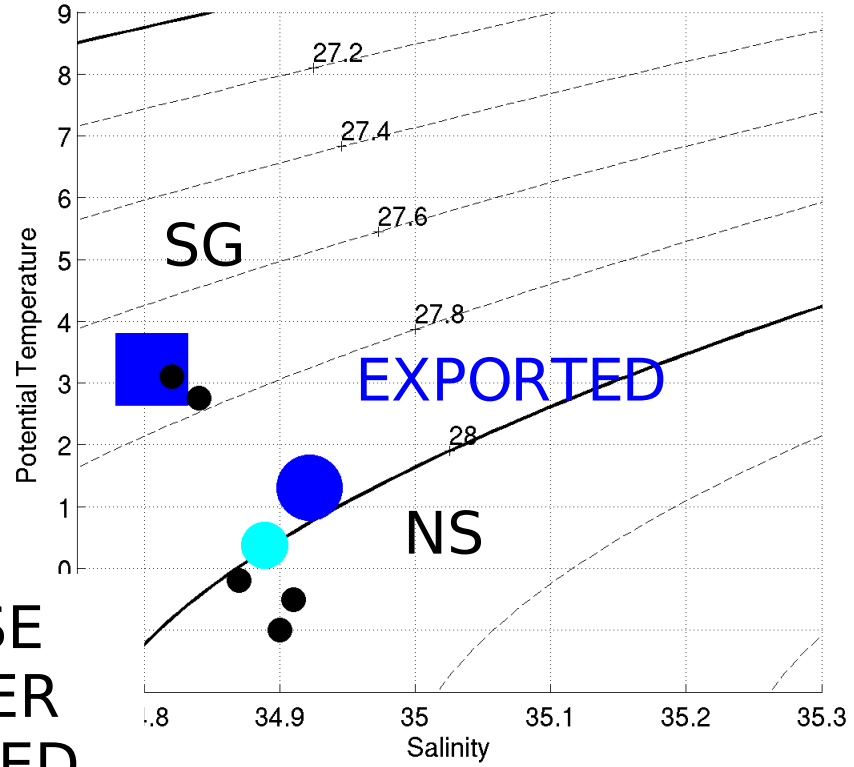


DENSE WATER FORMED

- uLSW, dLSW
- GSW, NSDW, NSAIW

Hansen and Østerhus 2000, Pickart and Spall 2007
Kieke et al. 2007, Lazier 1980, Eldevik et al. 2008
Schott and Brandt 2008; Pickart and Spall 2007

Dense Waters Formed and Exported



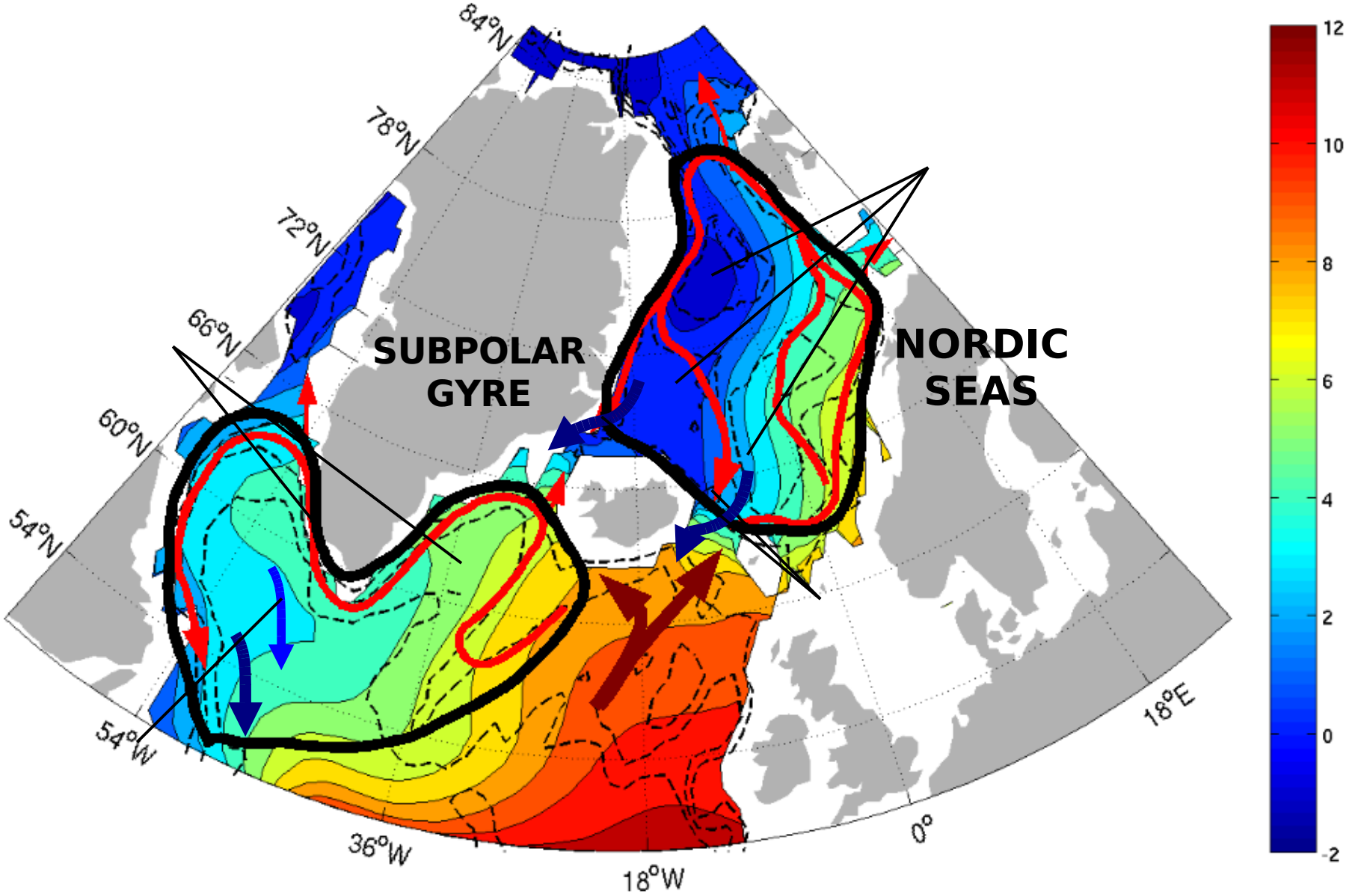
DENSE WATER FORMED

Question:

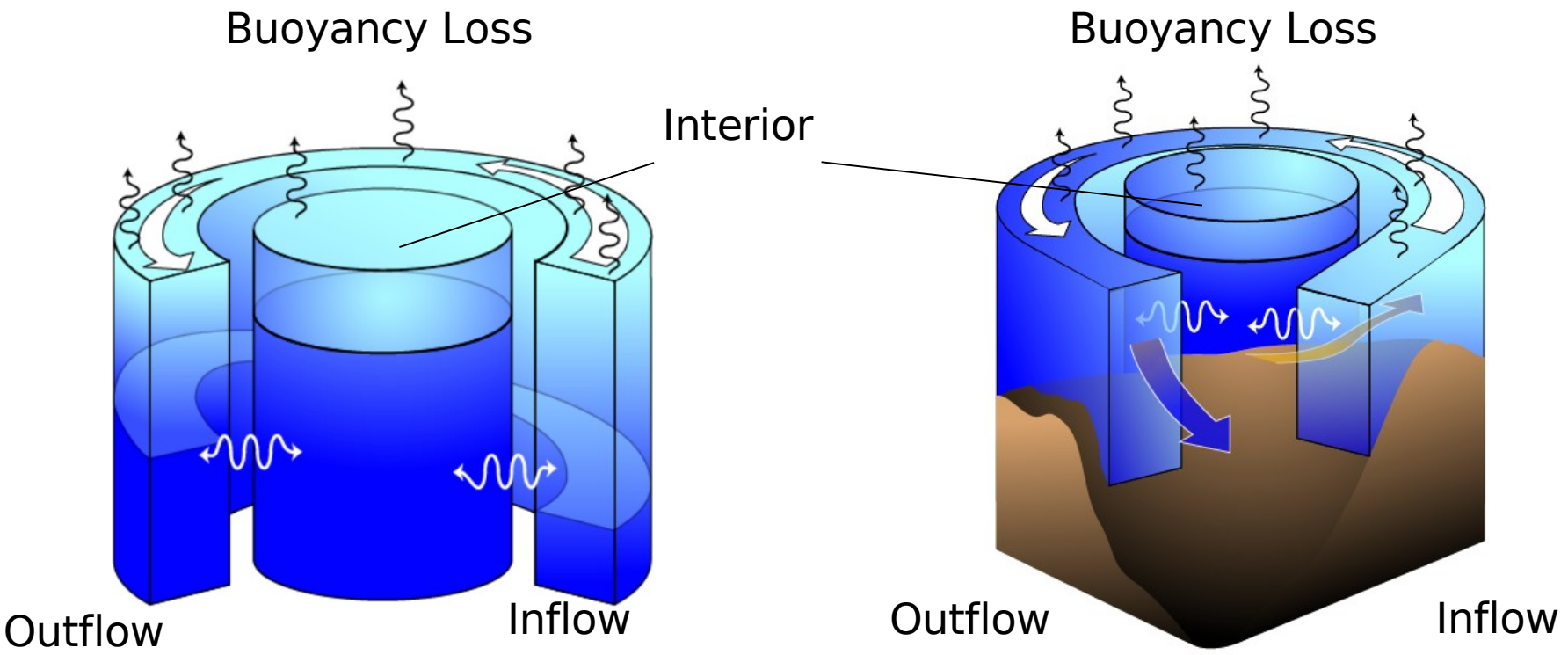
1. Why are NS **exported** dense waters denser than those from the SG?

2. Why are the dense waters **formed** in the NS denser than those of the SG?

Definition of the SG and NS



Method: Idealized Model for a Dense Water Formation Basin



Model: buoyancy conservation, mass conservation, geostrophy and parameterized eddy fluxes

Spall 2004, Straneo 2006a and b, Iovino et al. 2008

What controls the density of the formed and exported waters?

Properties of the **outflow** and **dense waters** formed depend on:

1) geographic parameters
2) inflow
3) forcing

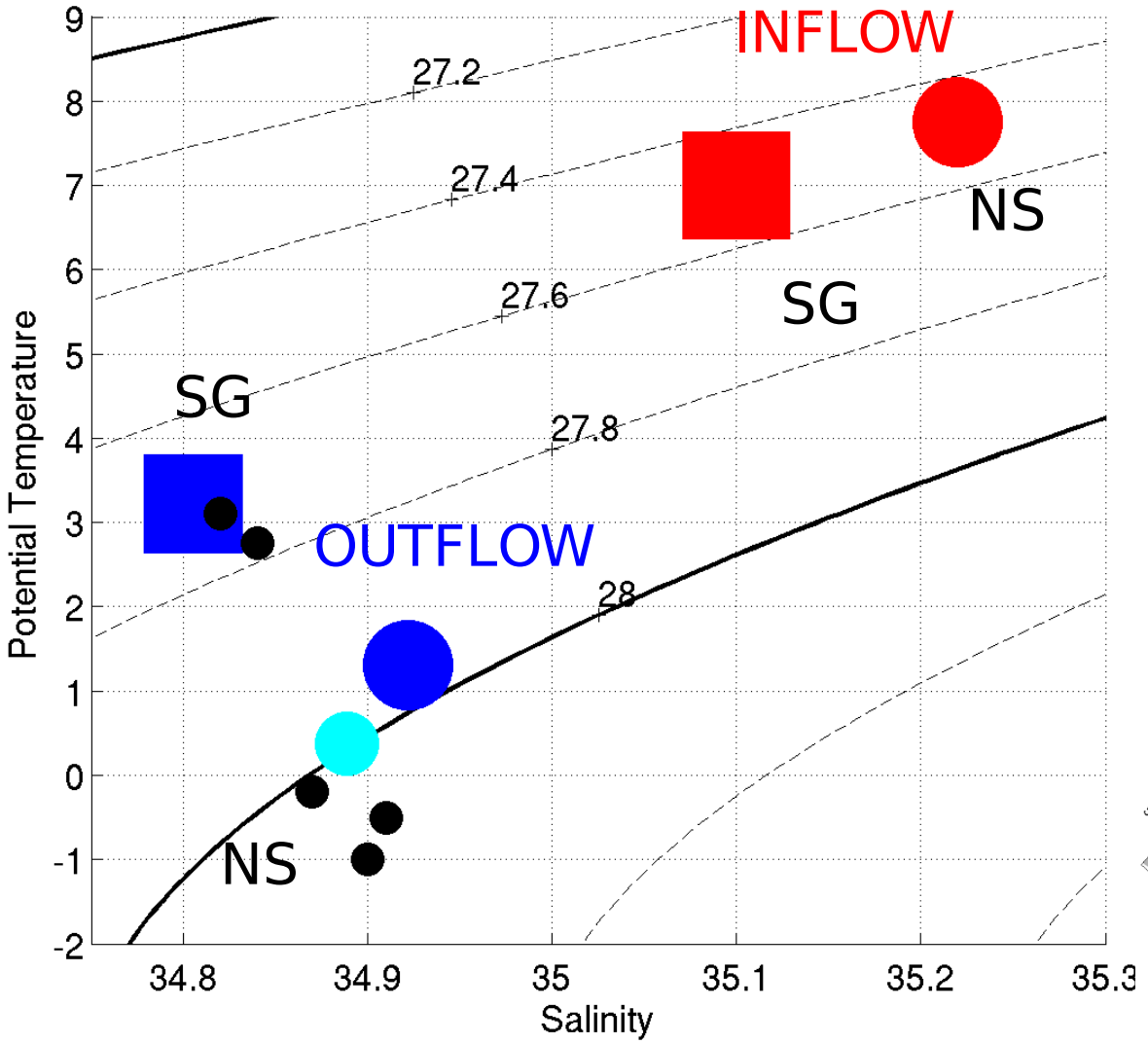
What controls the density of the formed and exported waters?

Properties of the **outflow** and **dense waters** formed depend on:

1) geographic parameters

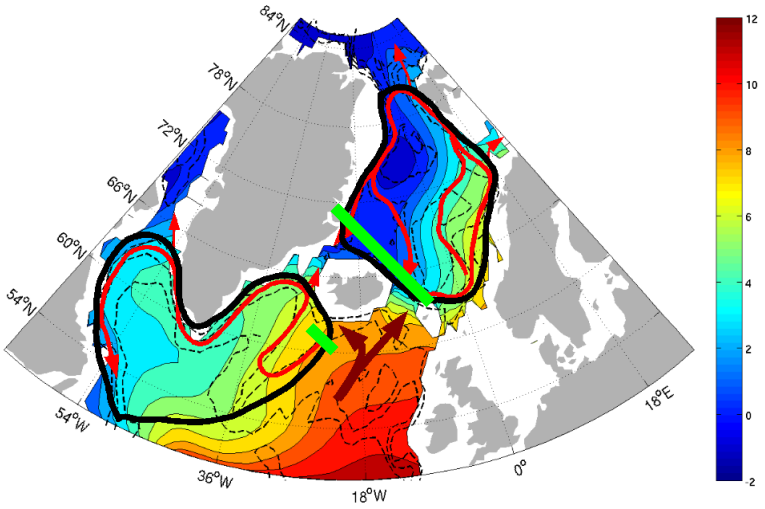
Subpolar Gyre	Nordic Seas
Area = 1.7 x 10^6 km^2	Area = 1.7 x 10^6 km^2
Radius ~ 740 km	Radius ~ 740 km
Perimeter ~ 4650 km	Perimeter ~ 4650 km
ϕ ~ 60° N	ϕ ~ 70° N

2. Inflow Properties and Transport



Subpolar Gyre
T = 12 (13-1) Sv
σ = 27.5

Nordic Seas
T = 8 Sv
σ = 27.5

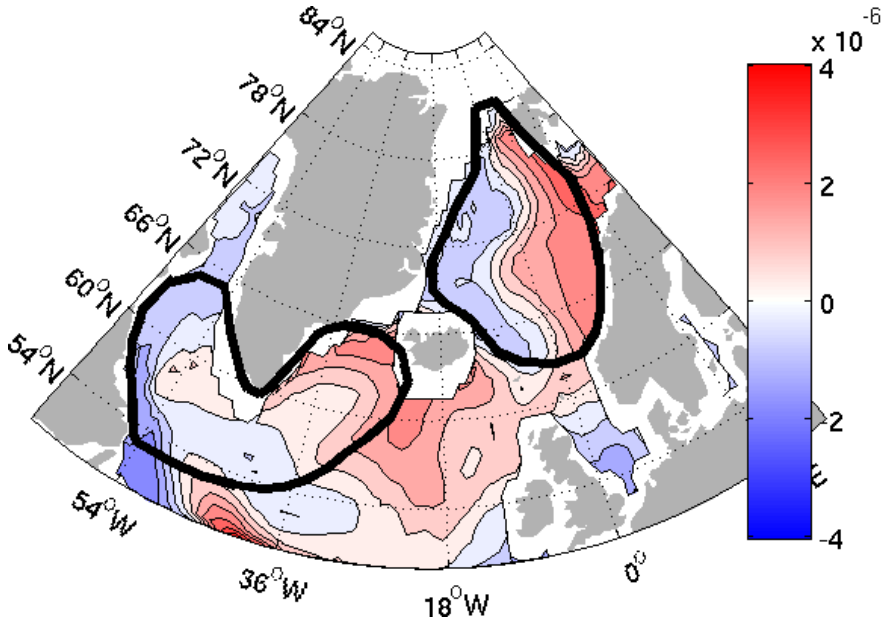


NS: Hansen and Østerhus 2000,
SG: Schott and Brandt 2008, Thierry et al. 2008

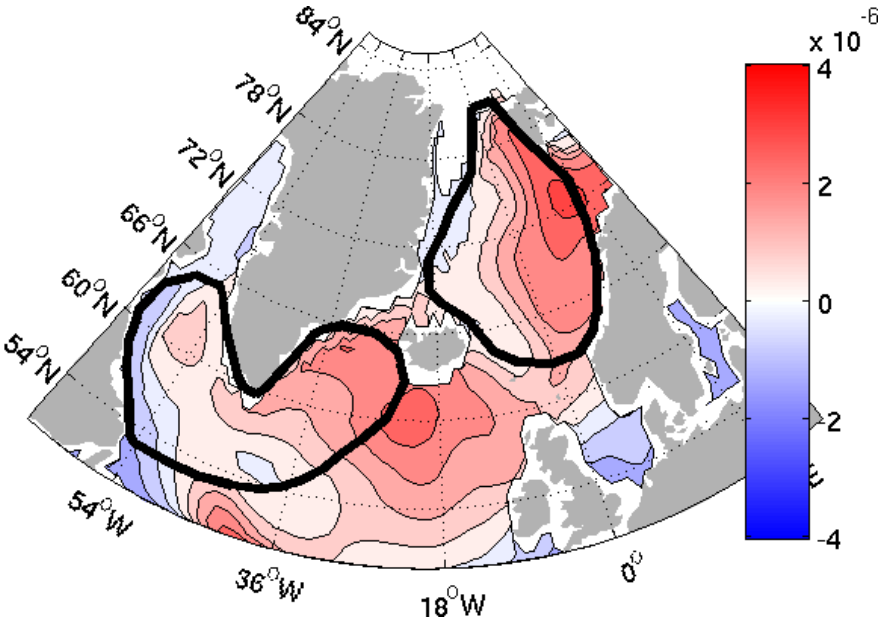
3. Air-Sea Forcing

Southampton Air-Sea Flux Climatology 1980-1993
Ship based observations

OAFLUX



SOC



Ratio Nordic Seas/Subpolar Gyre Buoyancy Loss

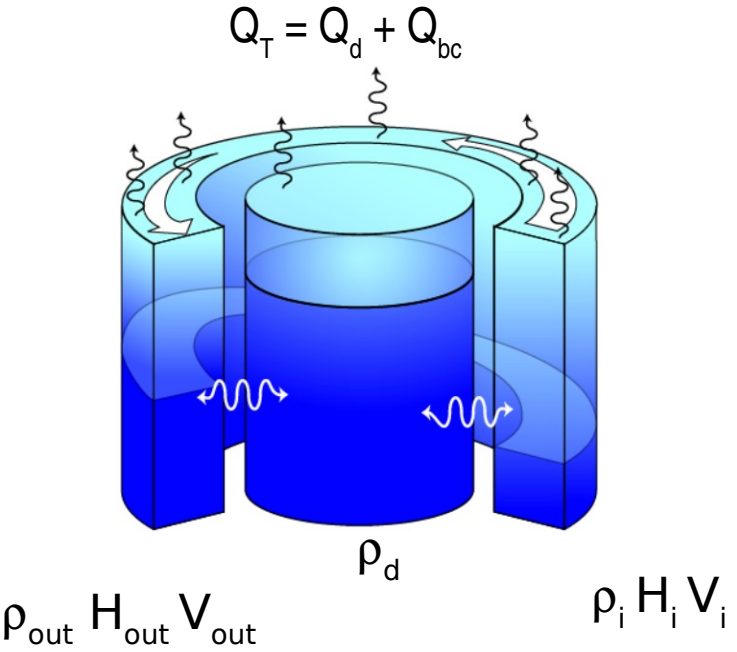
OAFLUX = 1.8
SOC = 1.6

OAFLUX (1984-1993) – Yu and Weller 2007; Zhang, Rossow and Lacis 1995

SOC (1980-1993) - Josey et al. 1999

Question 1: EXPORTED WATERS

Buoyancy Conservation: density outflow – inflow



modelled observed

$$\frac{(\rho_{out}-\rho_i)^{NS}}{(\rho_{out}-\rho_i)^{SG}} = \frac{Q_T^{NS}}{Q_T^{SG}}\ \frac{T^{SG}}{T^{NS}} \quad \approx \quad 2.55 \quad \sim \quad 2.38$$

	model	obs
NS ρ_{out}	27.98	27.96
SG ρ_{out}	27.70	27.71

The density difference in the exported waters is due to both:

i) reduced warm water inflow into the NS (due to the sill)

ii) larger buoyancy loss over the NS

Question 2: DENSE WATERS FORMED

The interior density depends on:

i) buoyancy loss over the **interior**

ii) the eddy fluxes

Assuming the buoyancy loss is uniform over the interior and boundary current :

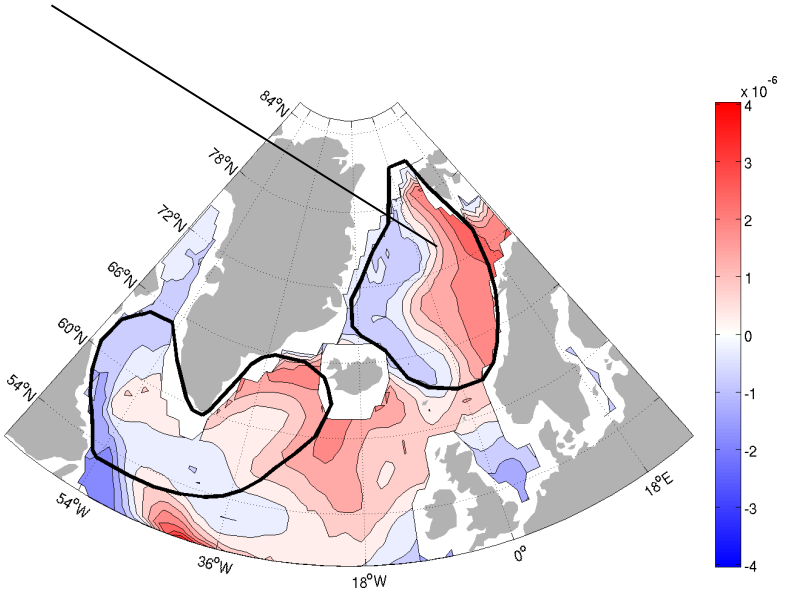
	Model	observed
SG ρ_d	27.76	27.74-27.78
NS ρ_d	28.25	28.0- 28.1

Model prediction works well
for the SG but not for the NS

Why?

Question 2: DENSE WATERS FORMED

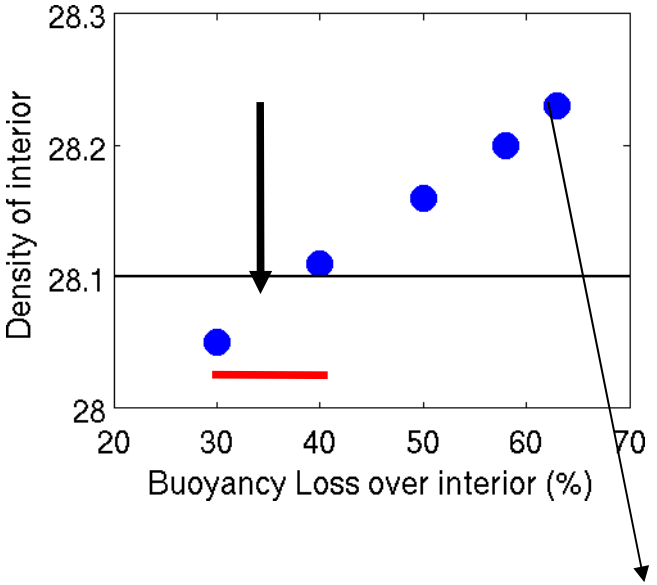
The bulk of the buoyancy loss in the NS occurs over the boundary current



Mauritzen 1996a and b; Isachsen et al. 2007

Question 2: DENSE WATERS FORMED

The bulk of the buoyancy loss in the NS occurs over the boundary current

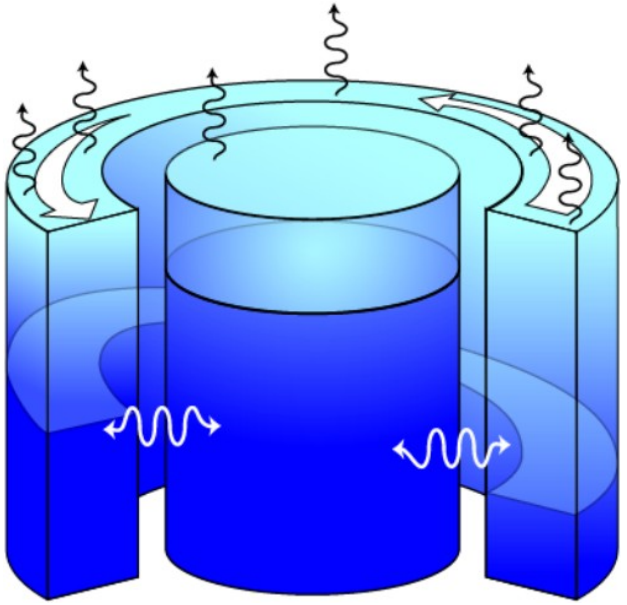


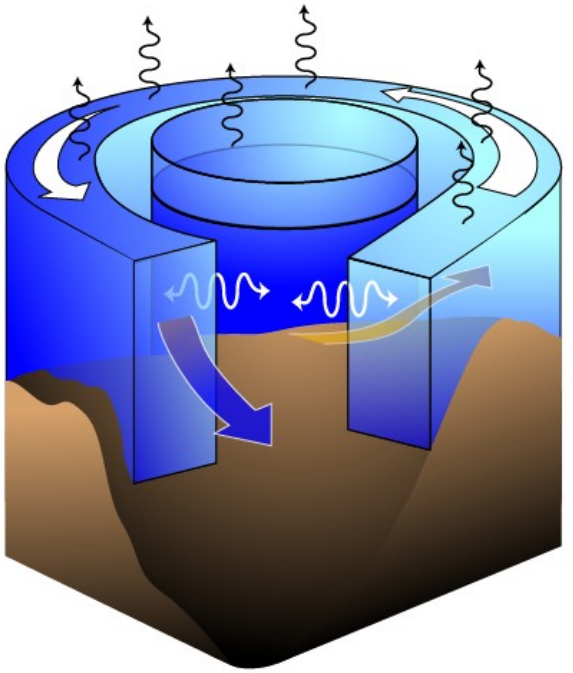
same buoyancy loss

Why are the dense waters formed in and exported from the Nordic Seas denser than those of the Subpolar Gyre?

EXPORTED:
greater buoyancy loss and of the smaller buoyancy transport in (due to the sill)

DENSE WATERS FORMED:
same reasons as for the exported but also – the density of the NS waters is strongly influenced by the fact that the bulk of the buoyancy loss occurs over the warm water pathway

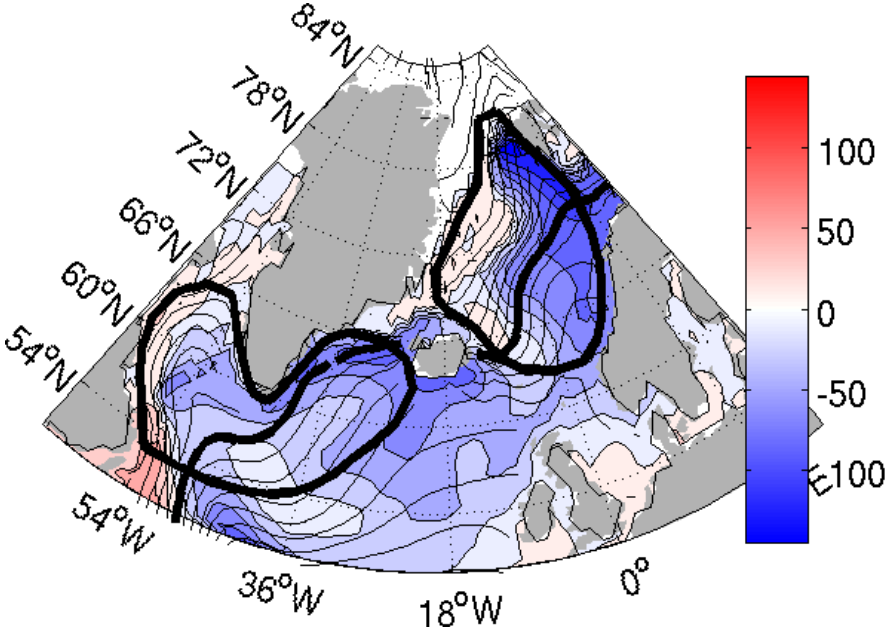




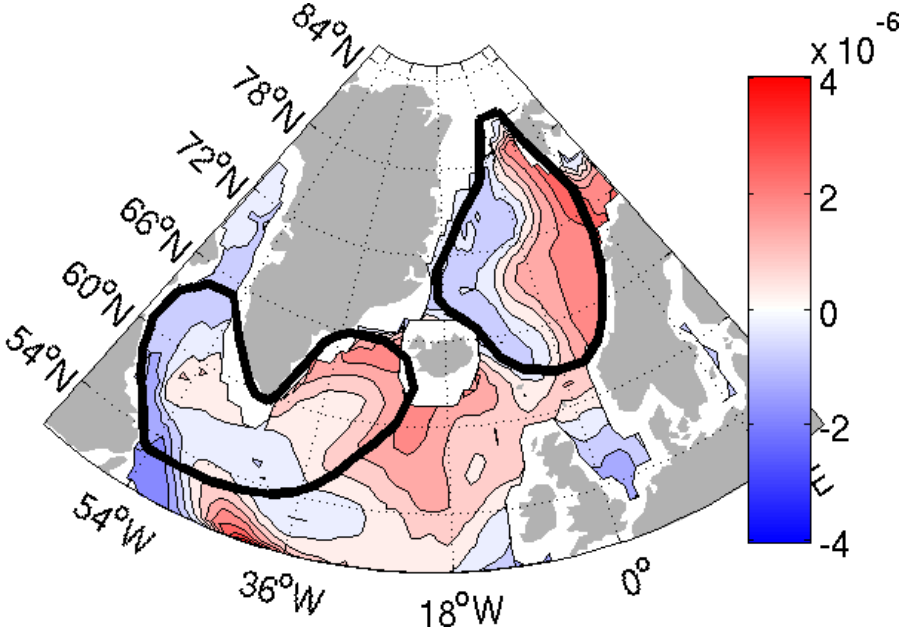
3. Air-Sea Forcing

OAFLUX CLIMATOLOGY 1984 -2000:
(optimal blending of satellite products, reanalyses products & COARE 3.0)

Annual Net Heat Loss (W/m^2)



Mean Density Flux ($kg/(m^2/s)$)

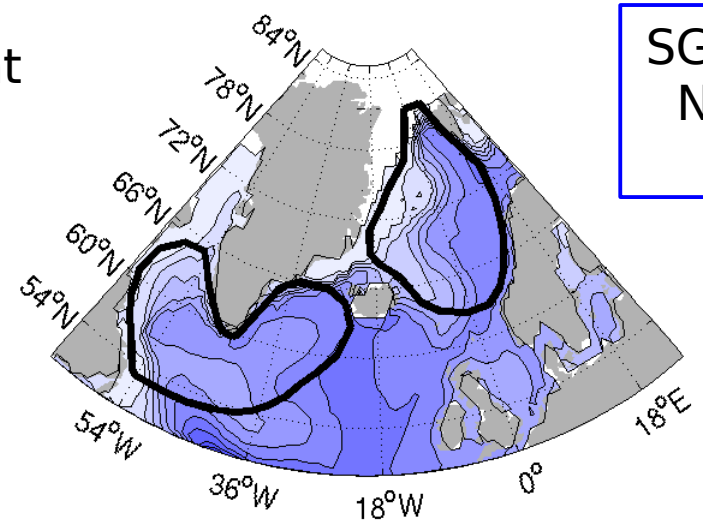


$$F_\rho = F_Q + F_{FW} \approx F_Q = -\frac{Q_{net}\alpha}{C_p}$$

Yu and Weller 2007; Zhang, Rossow and Lacis 1995 (LW + SW)

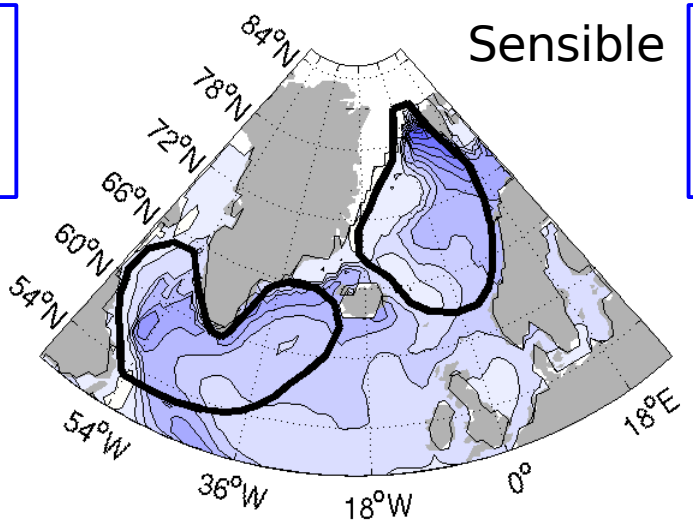
Mean Annual Heat Flux OAFLUX 1984-2004 (W/m²)

Latent



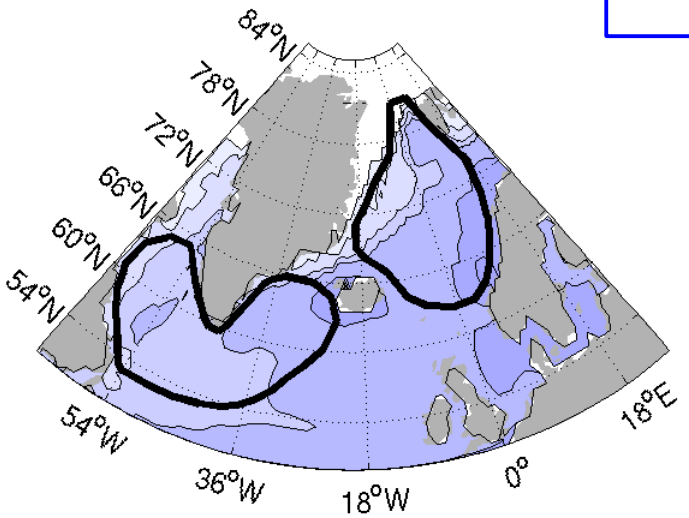
SG -51
NS -44

Sensible



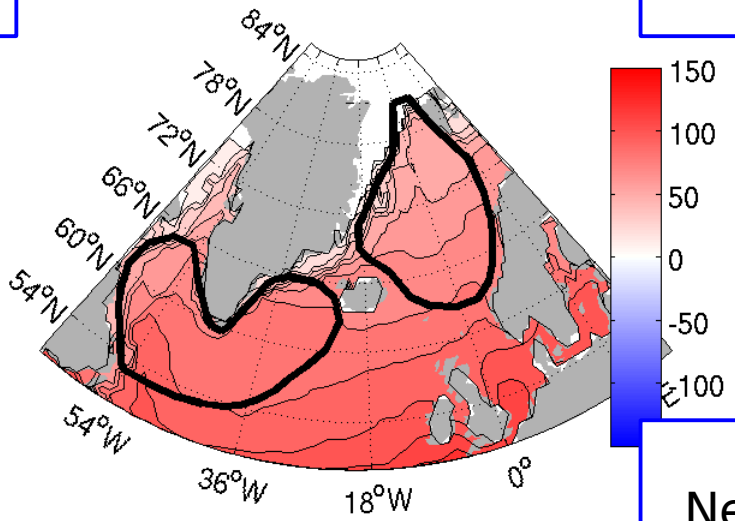
SG -33
NS -27

Longwave



SG -31
NS -33

Shortwave

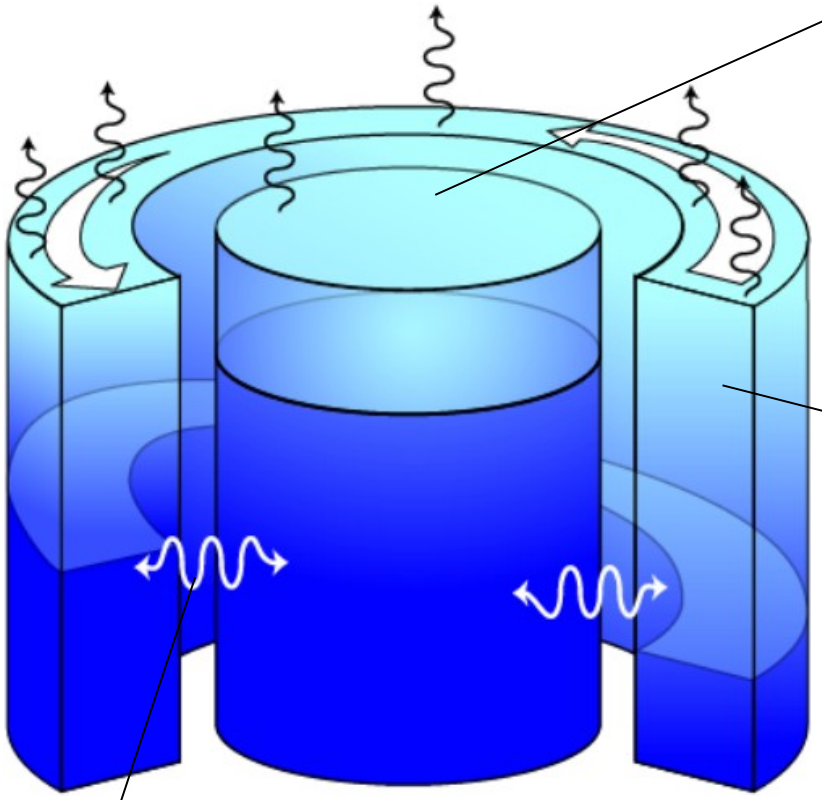


SG +83
NS +64

Net Fluxes
SG -31
NS -40

Yu and Weller 2007; Zhang, Rossow and Lacis 1995

Method: Idealized Model for a Dense Water Formation Basin



Dense Water Formation Region

- weak/no mean flow
- subject to cooling

Boundary Current

- advects light water in
- subject to cooling
- geostrophic

Eddy Fluxes

- interior/current exchange
- proportional to isopycnal gradient

Spall 2004, Straneo 2006a and b, Iovino et al. 2008