What Data Assimilation Increments of an Eddy-Permitting Global Ocean Reanalysis tell Us about Deep Convection in the Labrador Sea

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OUTLINES

Labrador Sea

- Circulation and seasonal convection cycle

- Role of Mesoscale Eddies

Simulations of Deep Ocean Convection in the Labrador Sea

- In eddy permitting model hindcasts (no assimilation)

- In GLORYS eddy permitting reanalysis

GLORYS Eddying Reanalysis

- Interpreting data assimilation increments

Conclusion

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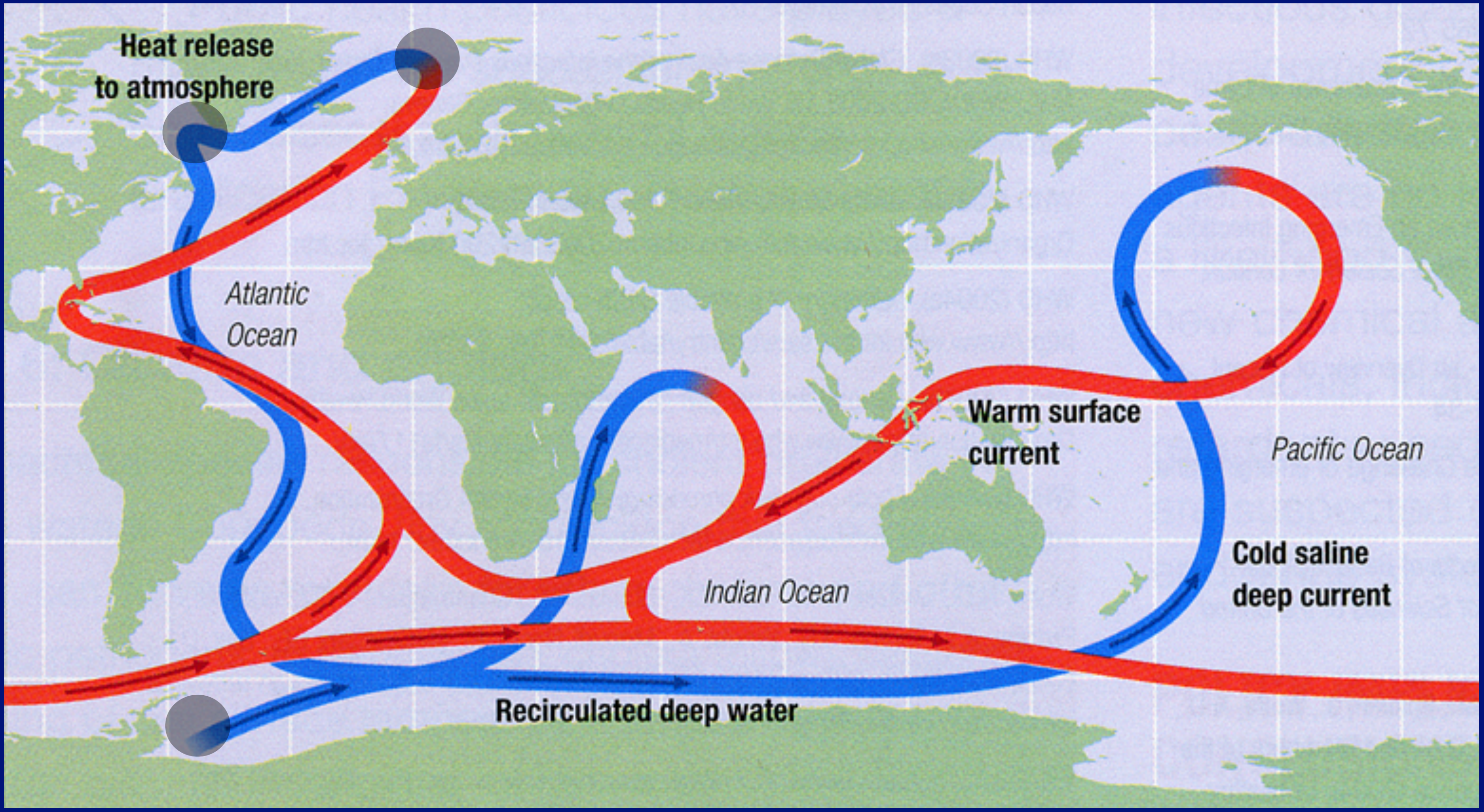
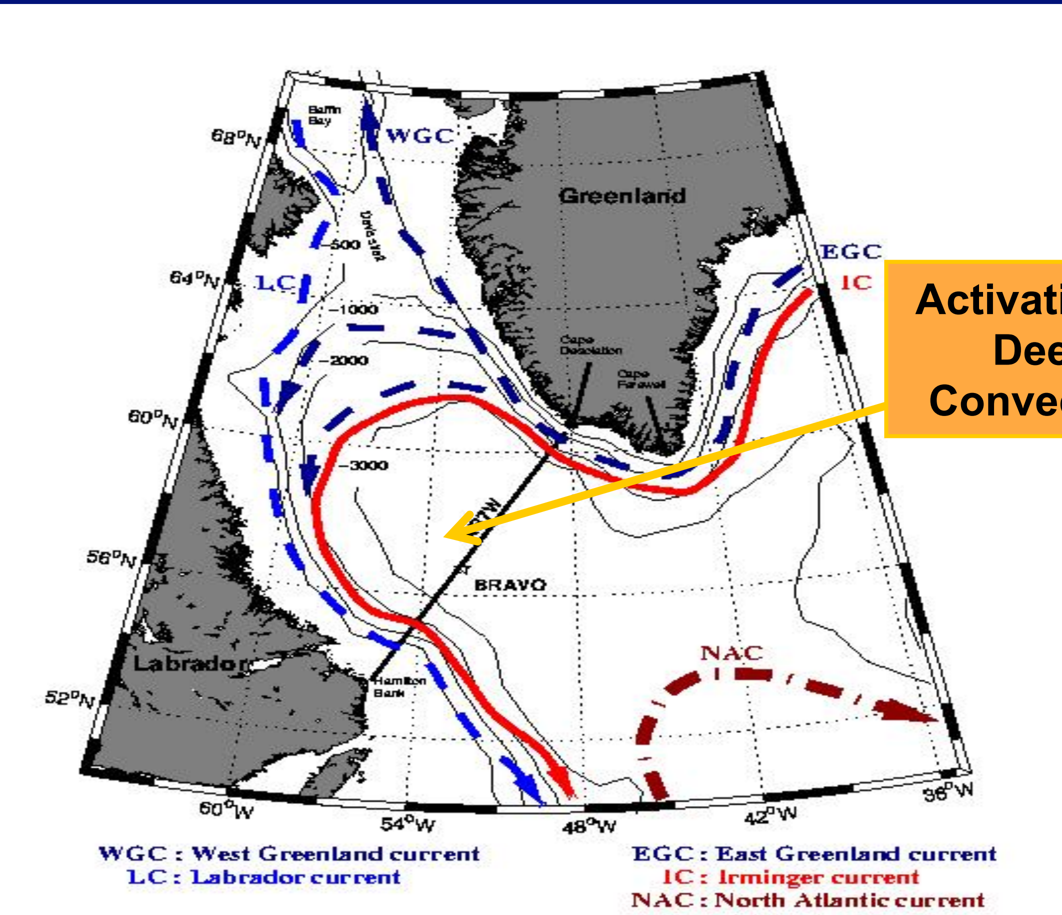
Labrador Sea

A key region for the global ocean meridional overturning circulation



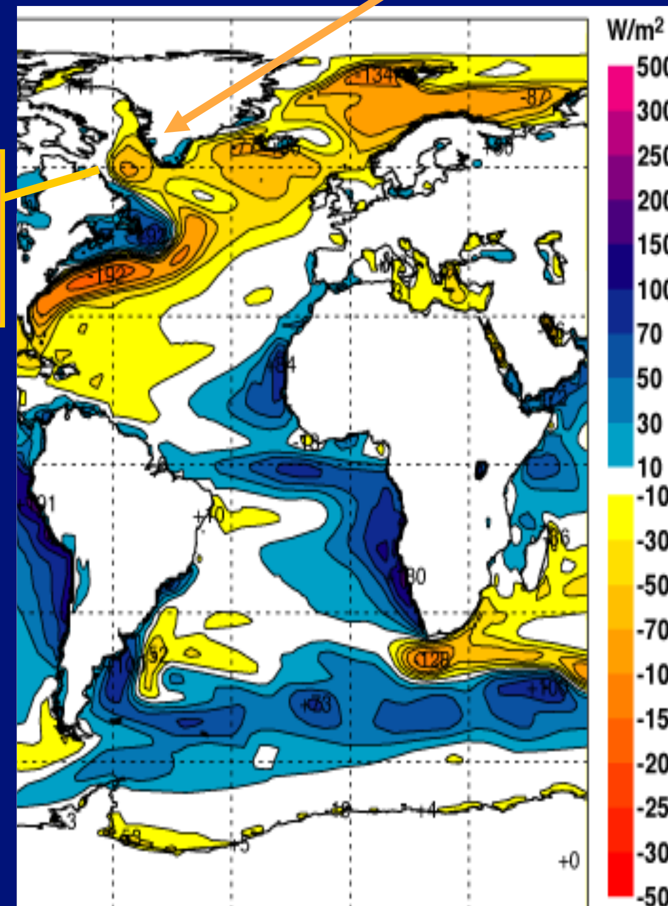
Labrador Sea:

Large scale circulation and atmospheric forcing



Activation of Deep Convection

Net ocean cooling : 70 $W.m^{-2}$ in annual mean

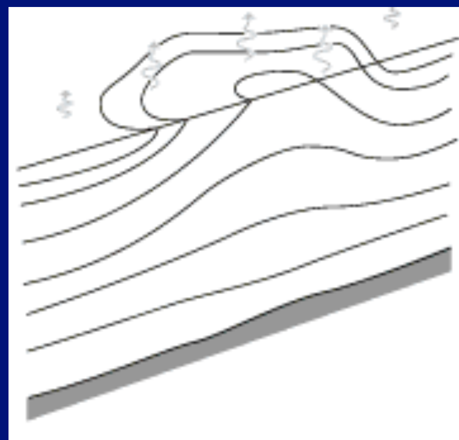


Net Air-Sea Flux

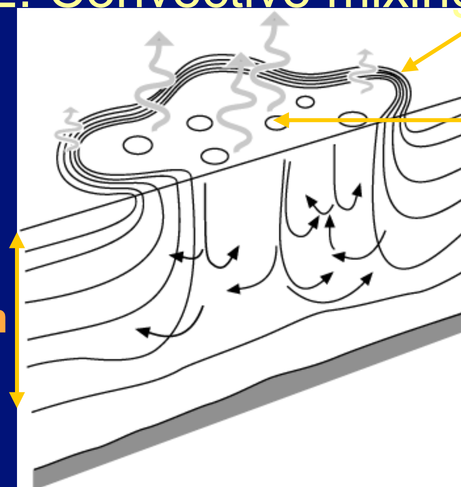
Labrador Sea:

Convection/Re-stratification seasonal cycle: a schematic

1. Pre-conditioning



2. Convective mixing



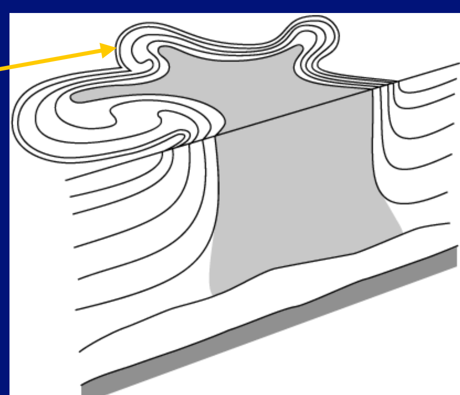
≈ 2000 m

Convective Chimney Ø 200 km

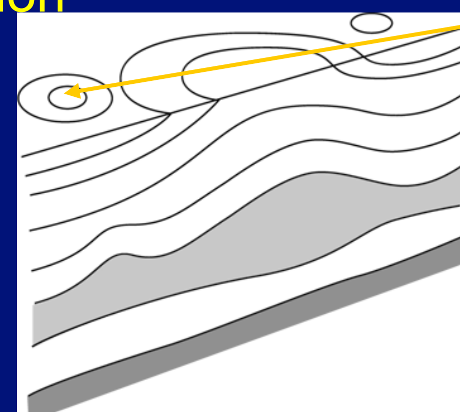
Convective plumes Ø 1 km

3. Re-stratification

Convective front



Baroclinic Instability

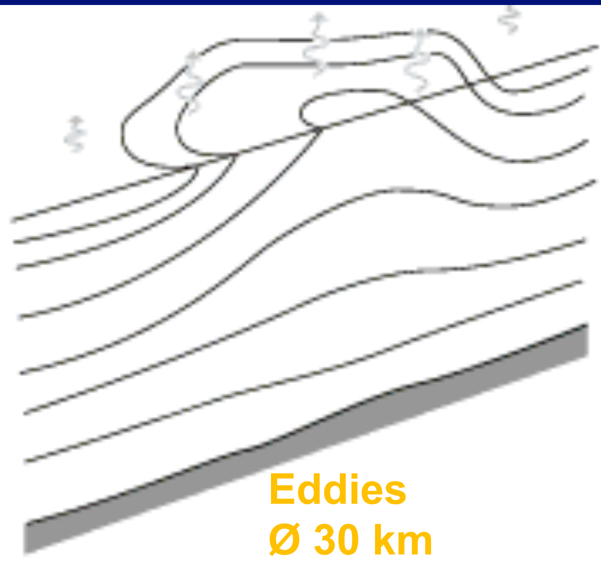


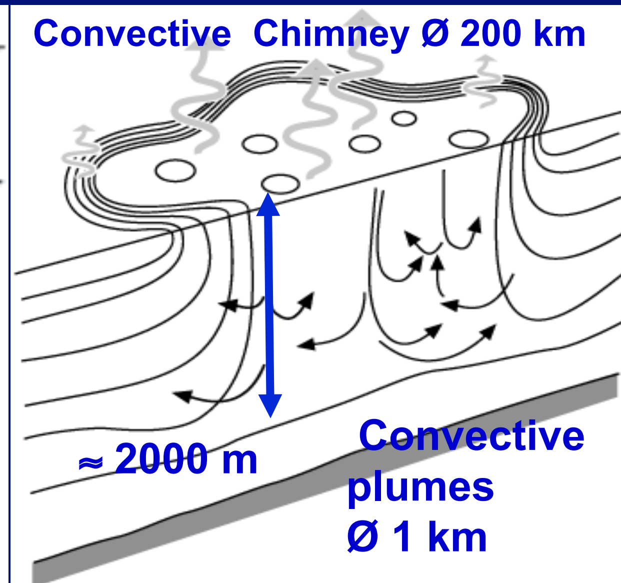
Eddies Ø 30 km

Marshall and Schott, 1999
Jones and Marshall, 1997

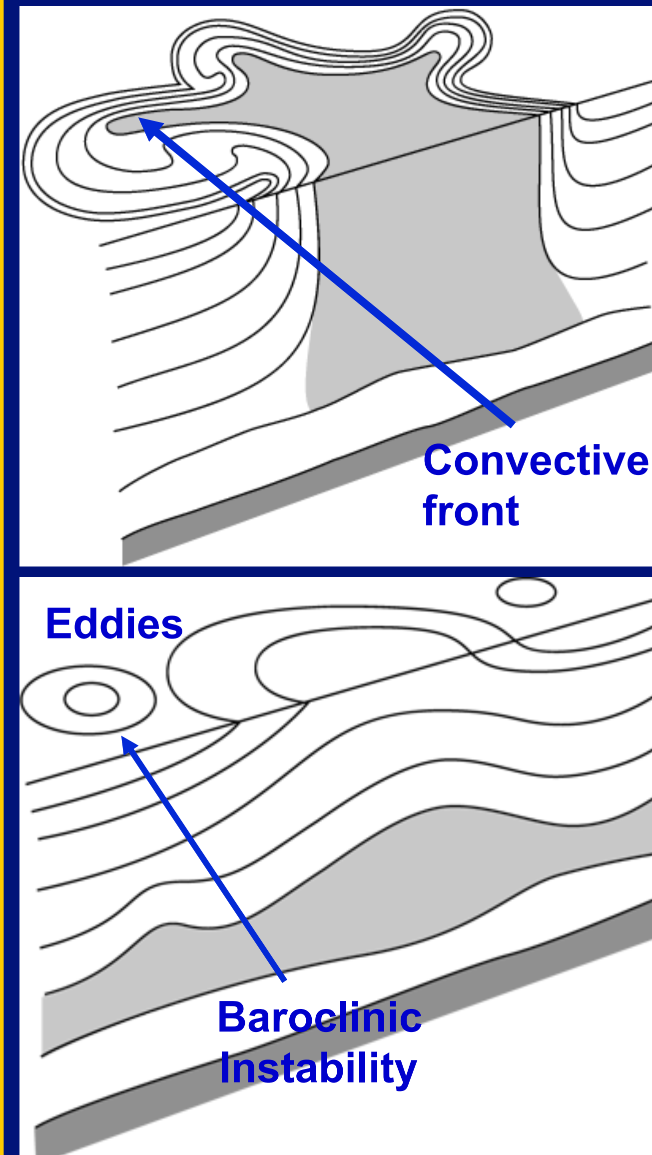
Labrador Sea:

Convection/Re-stratification seasonal cycle: a schematic





1. Pre-conditioning → 2. Convective mixing



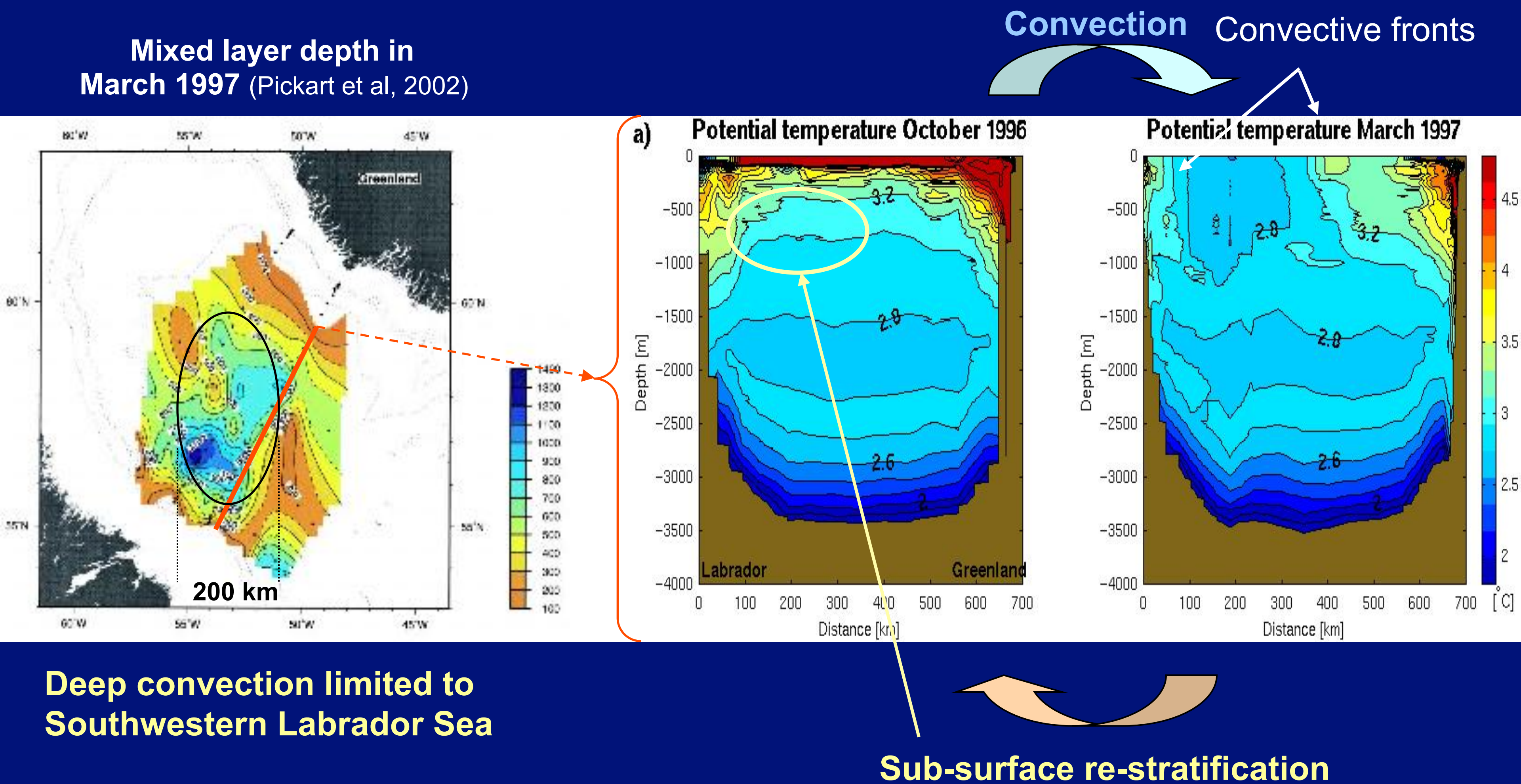
3. Re-stratification

Marshall and Schott, 1999
Jones and Marshall, 1997

Labrador Sea:

Convection/Re-stratification seasonal cycle: observations

Mixed layer depth in March 1997 (Pickart et al, 2002)



Deep convection limited to Southwestern Labrador Sea

Few winter observations of the 3-D field

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- **Role of Mesoscale Eddies**

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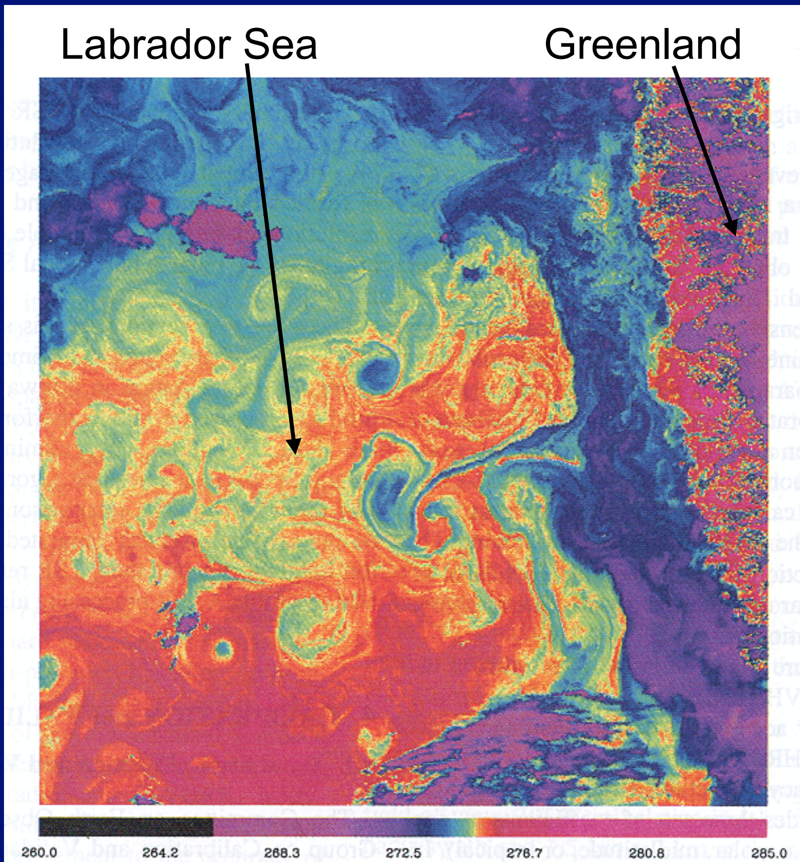
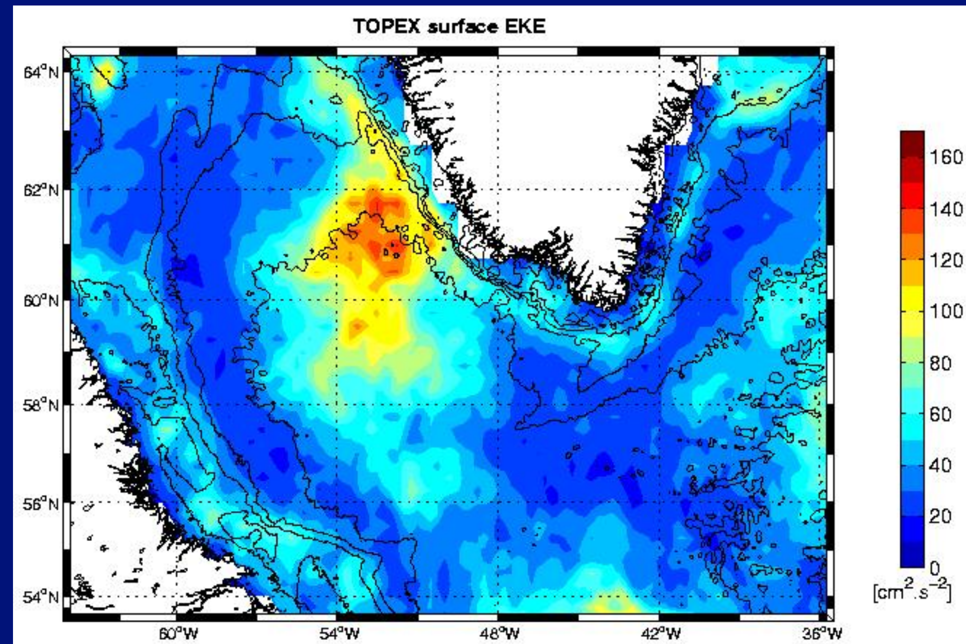
Labrador Sea:

Evidence of mesoscale eddies



Sea Surface Temperature (10th July 1992)

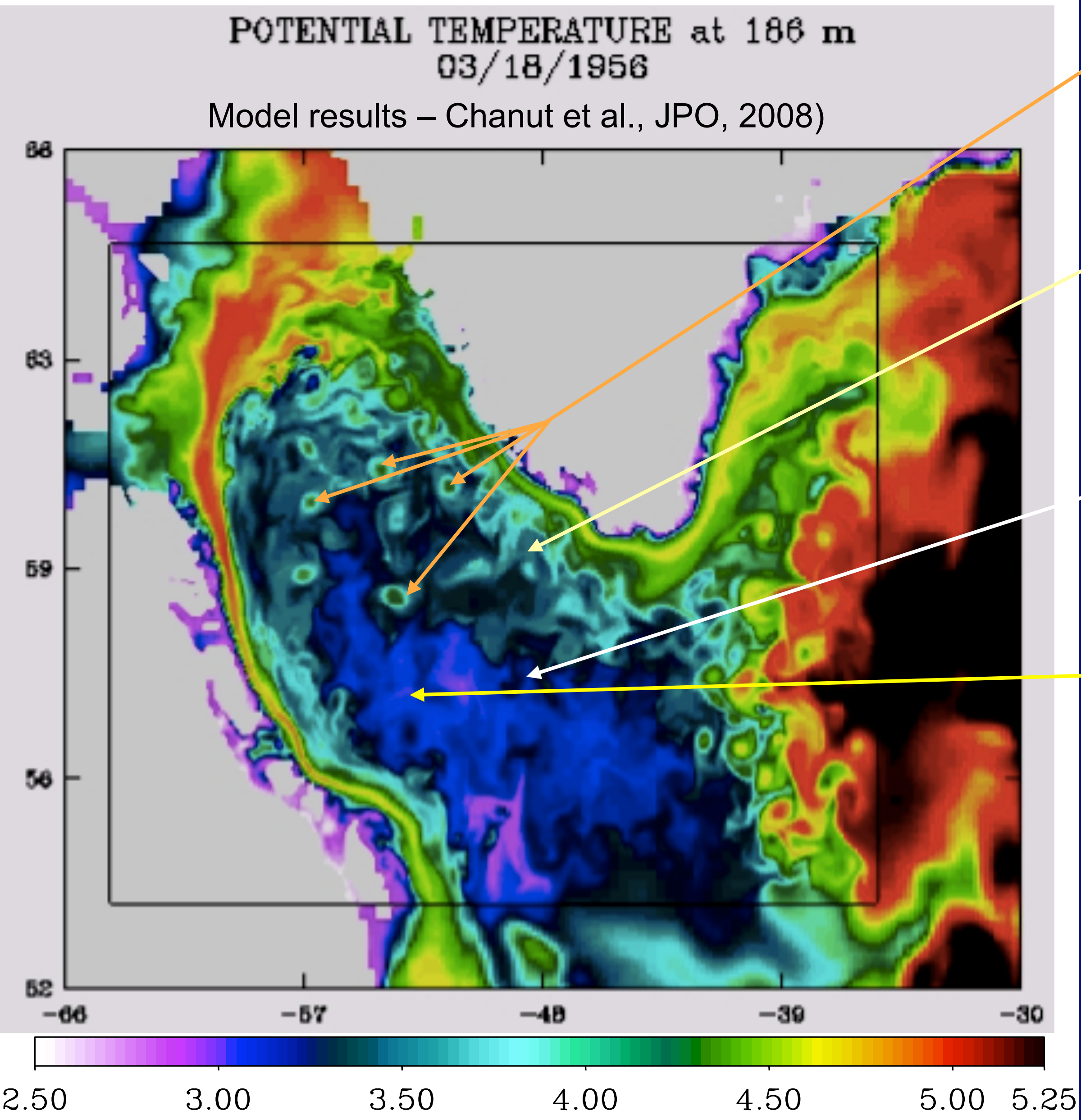


Eddy Kinetic Energy (altimetry)

(Ducet et al. 2000)

Labrador Sea:

Different types of eddies identified by generation process



Irminger Rings - IRs

Hz shear instability of WG Current at Cape Desolation

Boundary Current Eddies - BCEs

Continously generated by mixed baroclinic/barotropic instability of the boundary current

Convective front Eddies - CEs

Seasonal baroclinic instability of the convective front

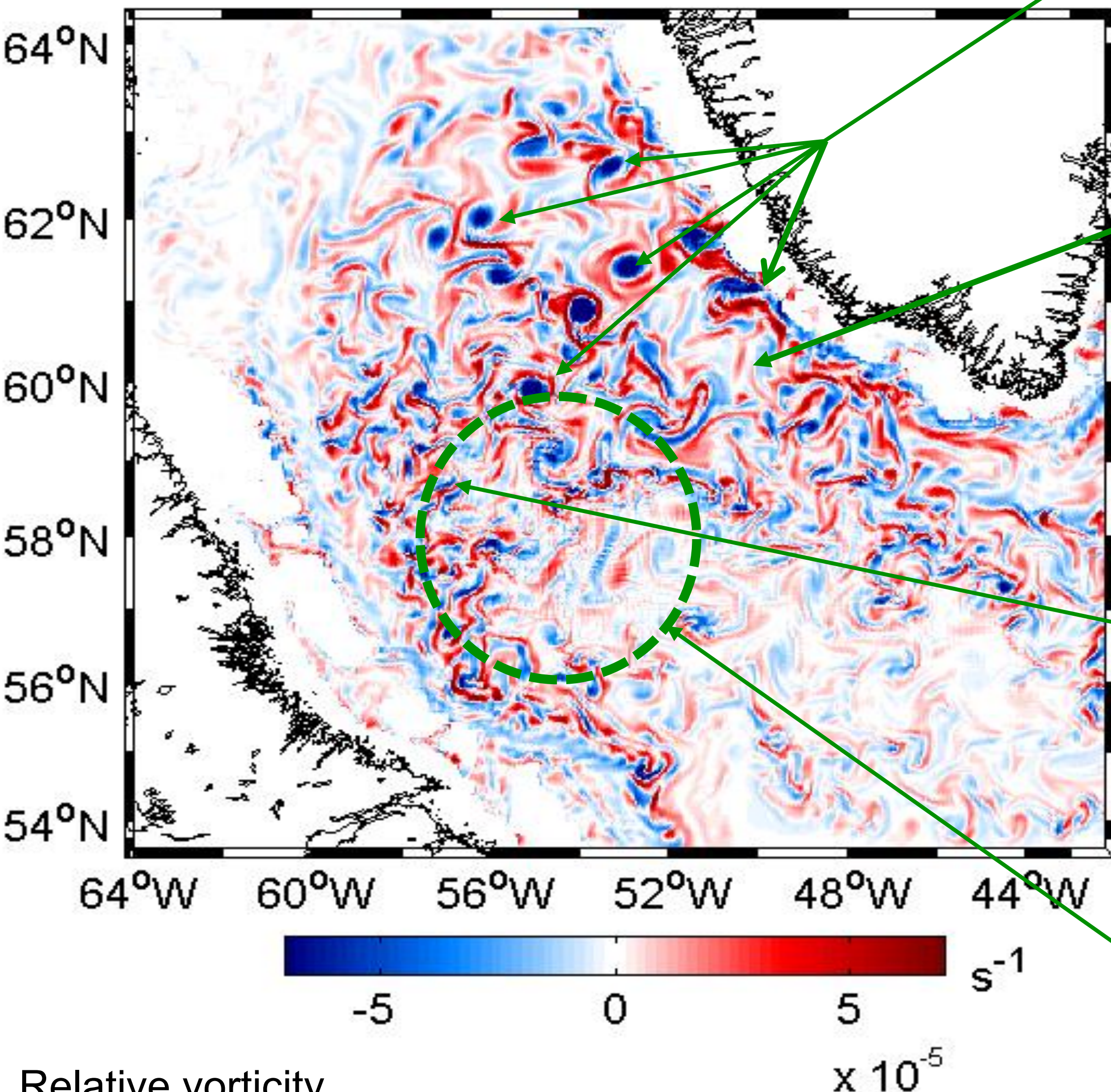
Region of deep convection

Influence of those respective eddies on the convection cycle?

Labrador Sea:

Role of mesoscale eddies

Model results – Chanut et al., JPO, 2008)



Relative vorticity

Irminger Rings - IRs
Prevent convection to occur in the Northern Labrador Sea

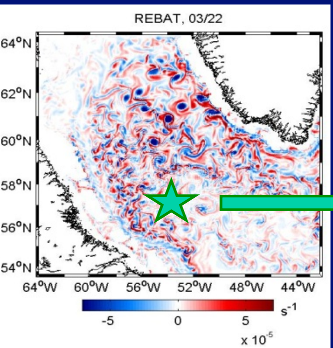
Boundary Current Eddies - BCEs
BCEs are continuously fluxing heat out of the boundary current in the interior

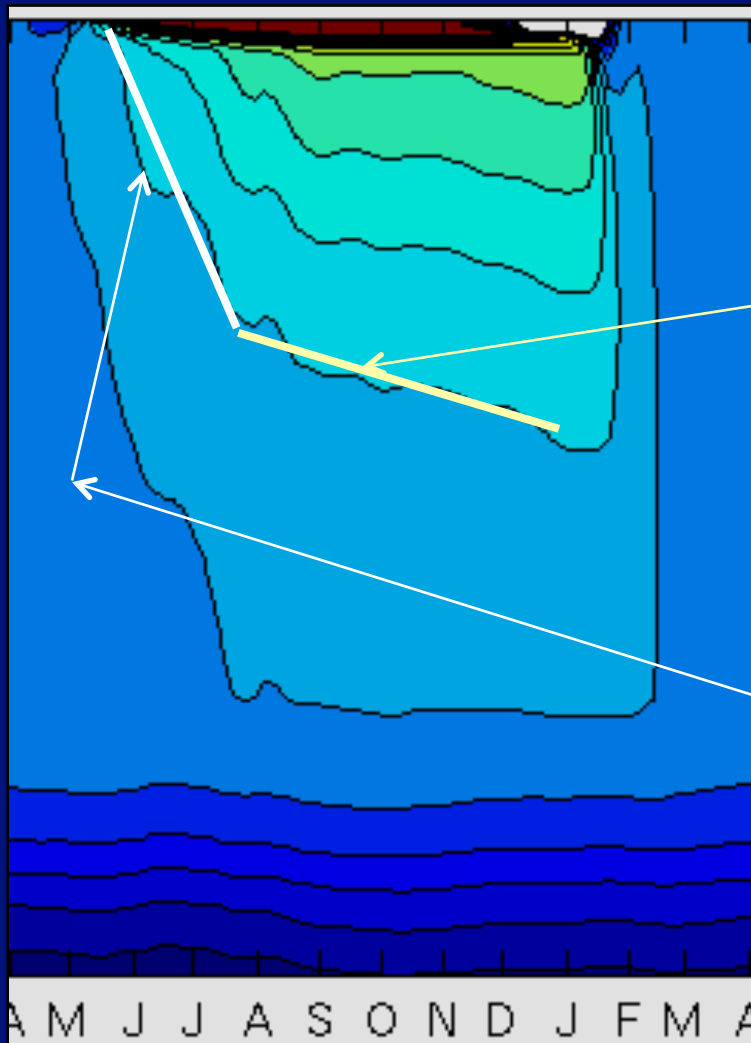
Convective front Eddies - CEs
CEs relay the BCEs to accelerate the flux of heat into the convection region in spring

Region of deep convection

Labrador Sea:

Role of mesoscale eddies





Seasonal variation of vertical temperature profile

~~***Irminger Rings*** **- IRs**
Prevent convection to occur in the Northern Labrador Sea~~

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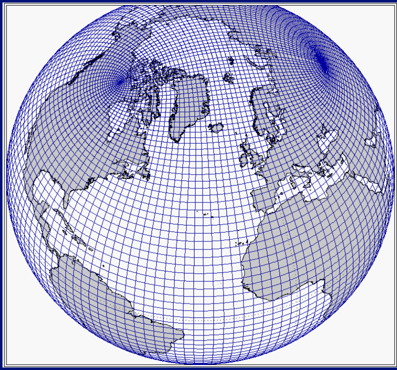
Eddy Permitting Models

- Resolution allows for the generation of mesoscale eddies

-Eddy statistics different from observed



Example: DRAKKAR ORCA025 configuration

NEMO3.2 OGCM + LIM2 EVP Sea-Ice model:

Resolution:

-Global 1/4° ORCA-type grid
1442x1021 grid points
- Hz grid: 25 km to 10 km.
- 46, 50, or 75 vertical levels
from 1 m at the surface
to 200 m at the bottom

Atmospheric forcing:

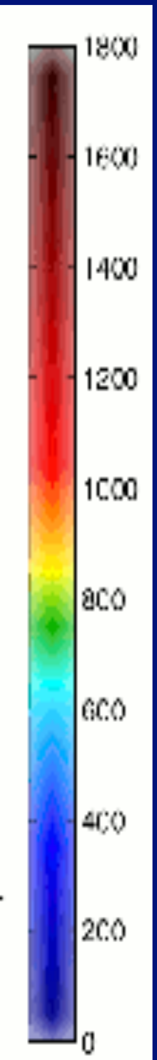
- Bulk Formulation
-ERA-Interim/ERA40
reanalysis products:

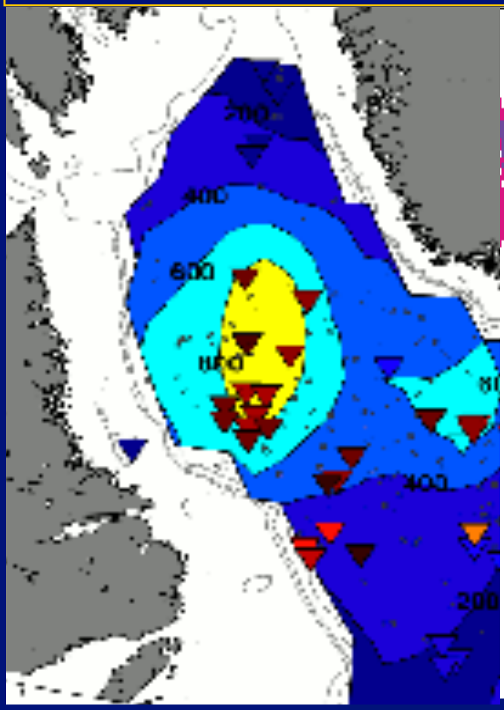
Eddy permitting (1/4°) models

- Greatly underestimate eddy generation in the Lab.Sea

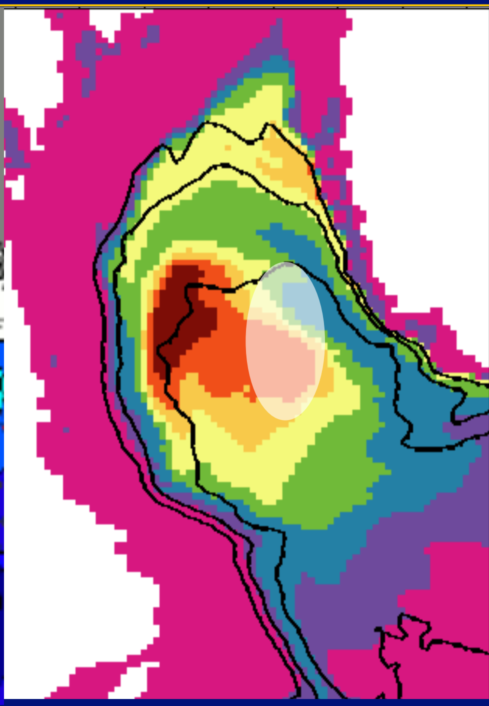
- Overestimates the convection depth

- Mis-locates the convective patch

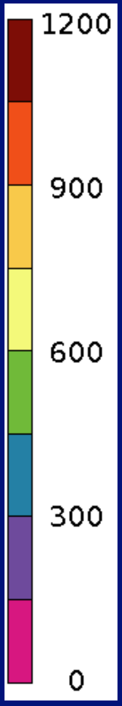




Observations

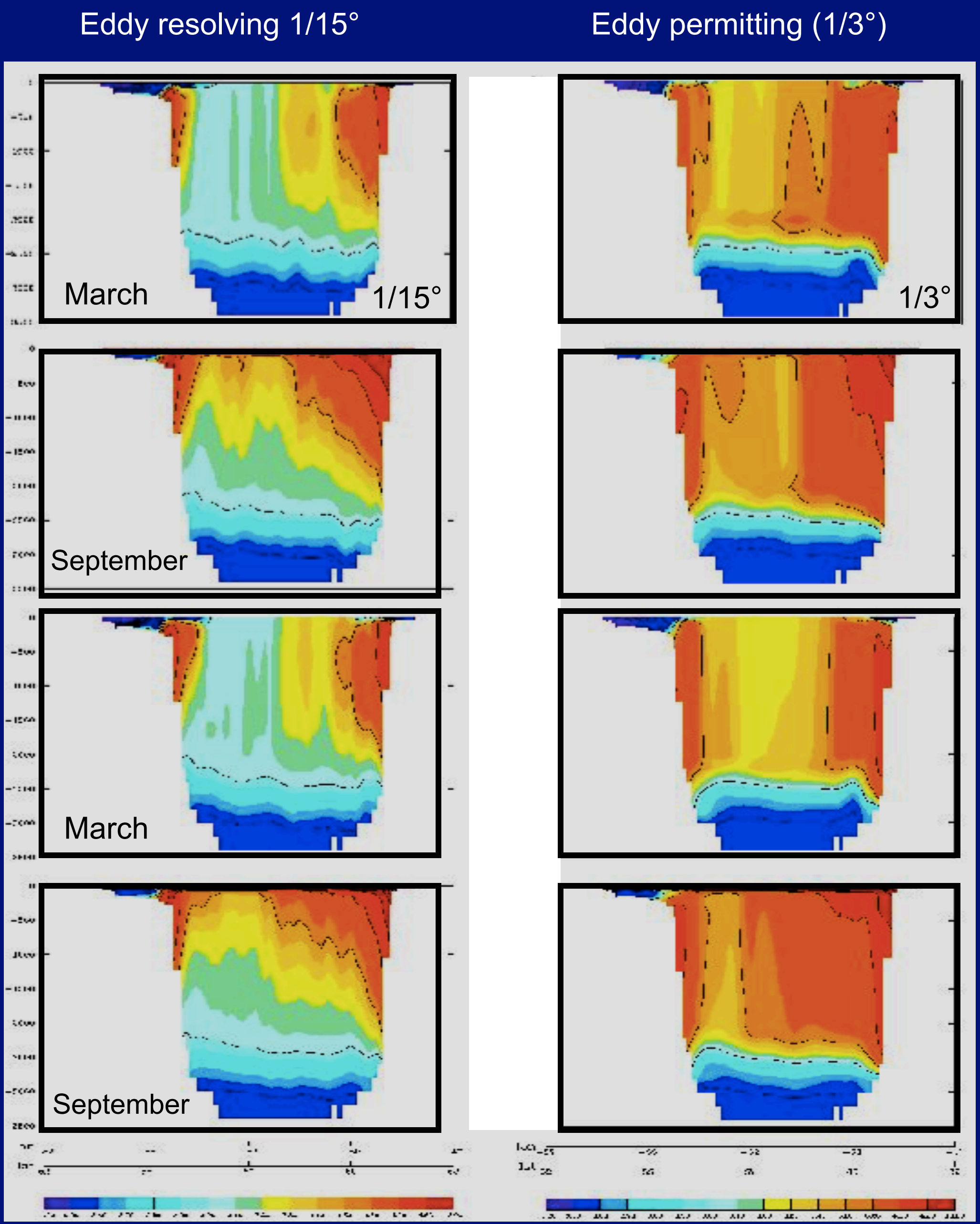


Model



Mixed Layer Depth (i.e. Convection Depth)

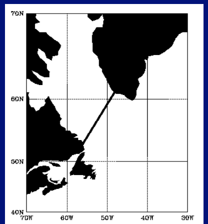
Re-stratification



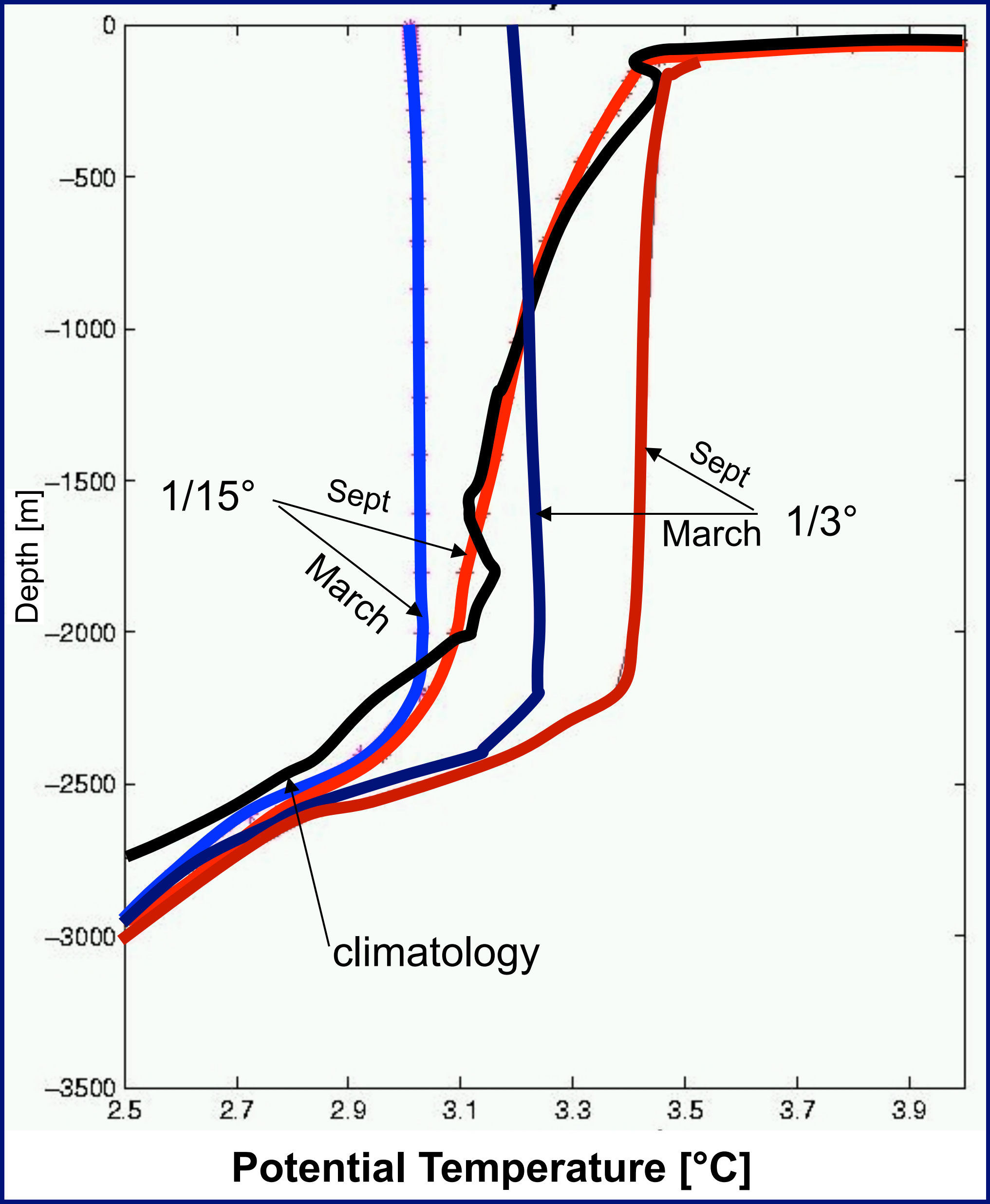
Eddy permitting models do not re-stratify the sub-surface ocean in summer

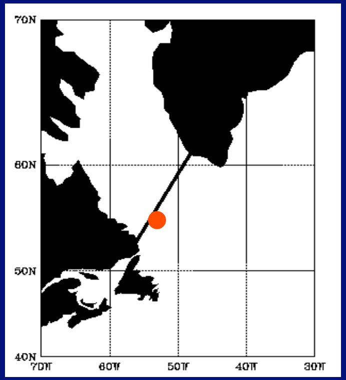
Consequences

- Ocean vertically homogeneous in fall
- Convection depth too deep the following year
- Large temperature (salinity) biases are induced in the long term



Re-stratification





No eddies (1/3°), no re-stratification in summer

Resolved eddies (in 1/15° grid) reconstruct the stratification during summer

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GLORYS (Global Ocean ReanalYsis and Simulations):

- Is a cooperative project between CNRS and Mercator-Ocean

- aims at producing global ocean/sea-ice reanalyses with an eddy permitting model (1/4°)

GLORYS1: 2002-2009

GLORYS2: 1993-2010

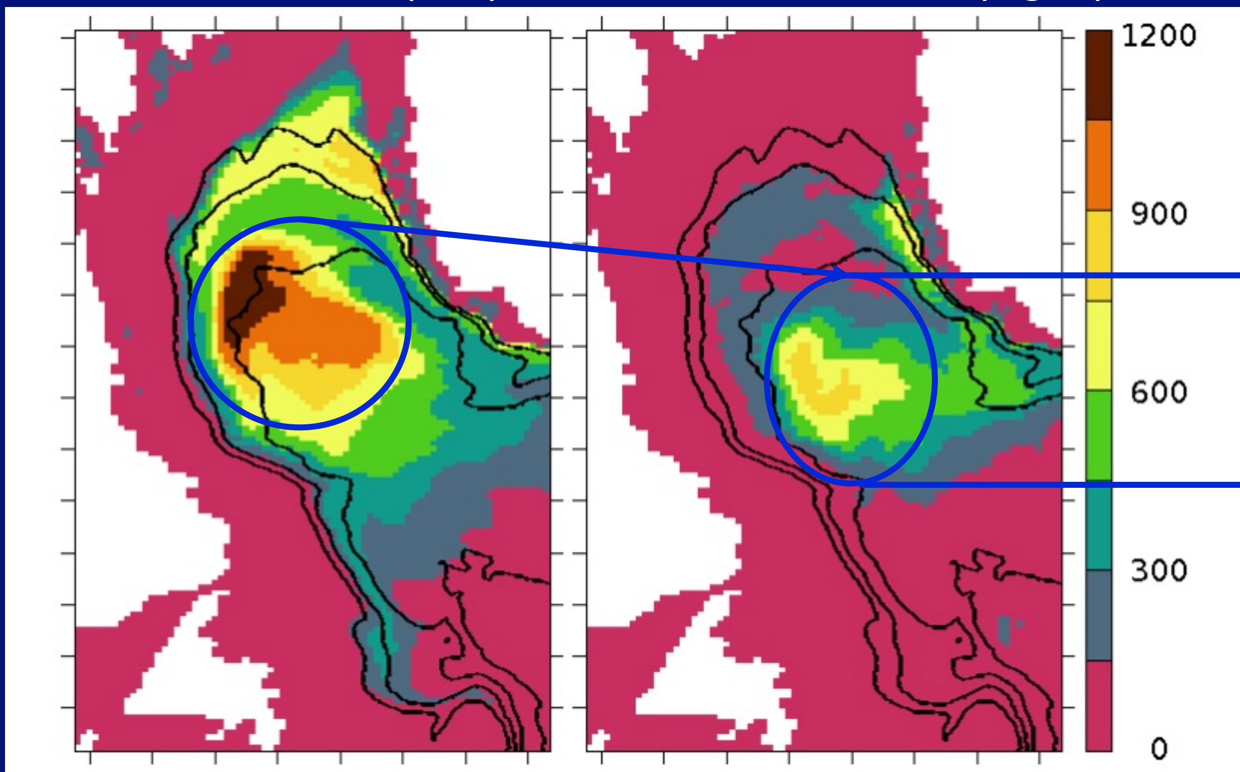
FREE RUN (no assimilation)

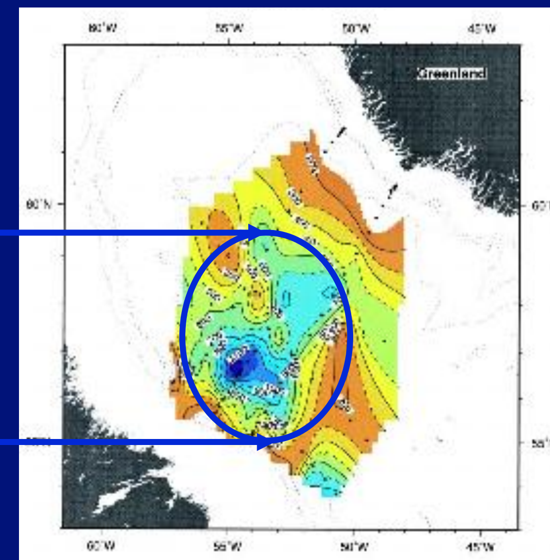
NEMO OGCM
Drakkar ¼° global configuration

Labrador Sea Convection Cycle in GLORYS1

JFM mixed layer depth (2002-2007 mean), in

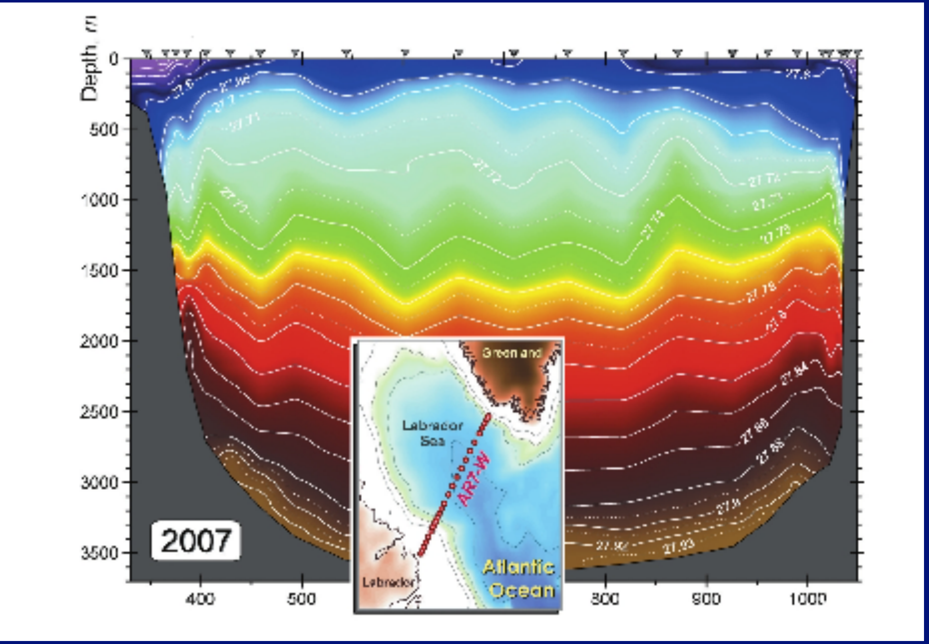
FREE RUN (left) **GLORYS1V1** (right).

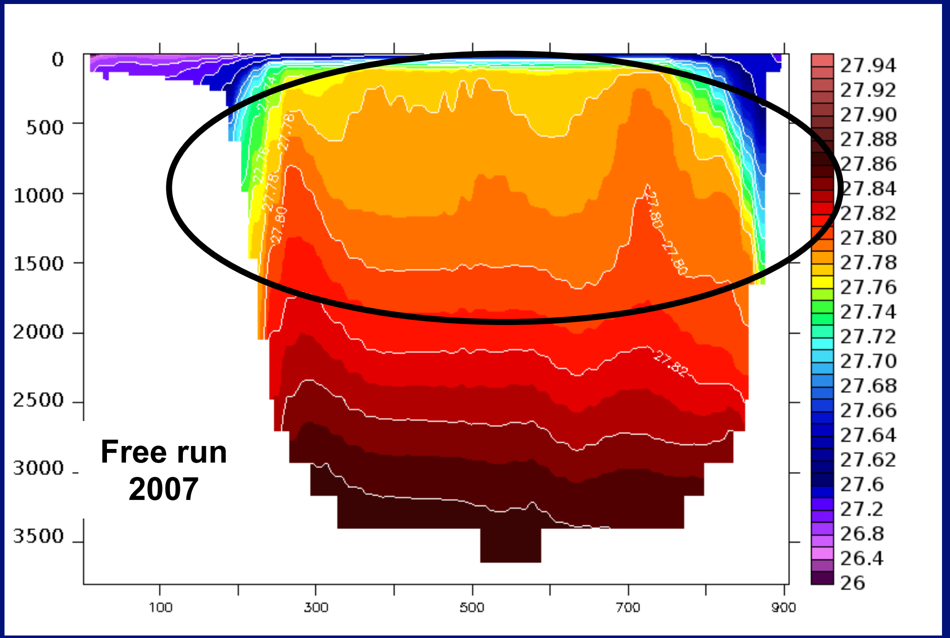




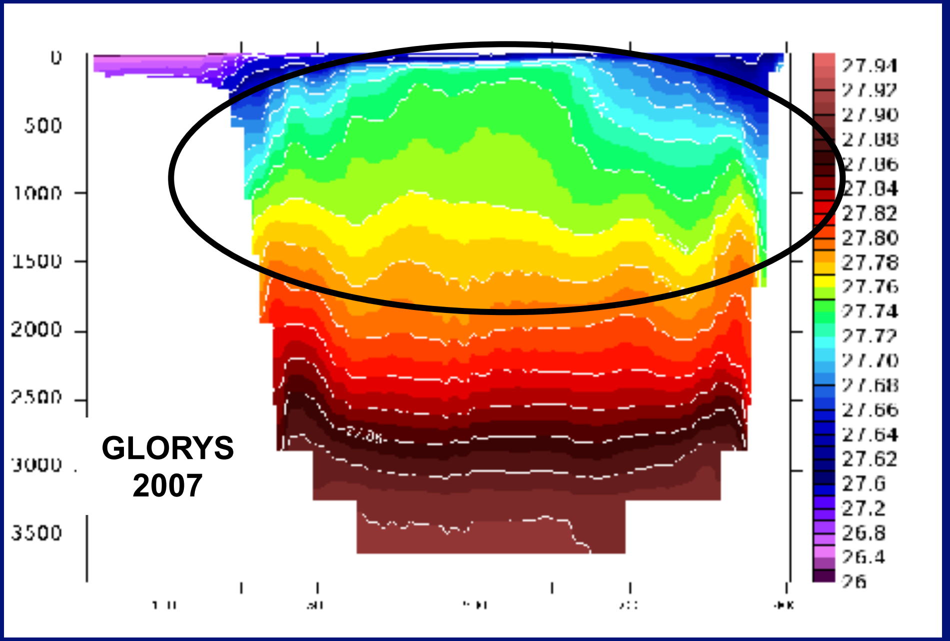
Assimilation improves the location of the Mixed Layer Depth

Labrador Sea Convection Cycle in GLORYS1

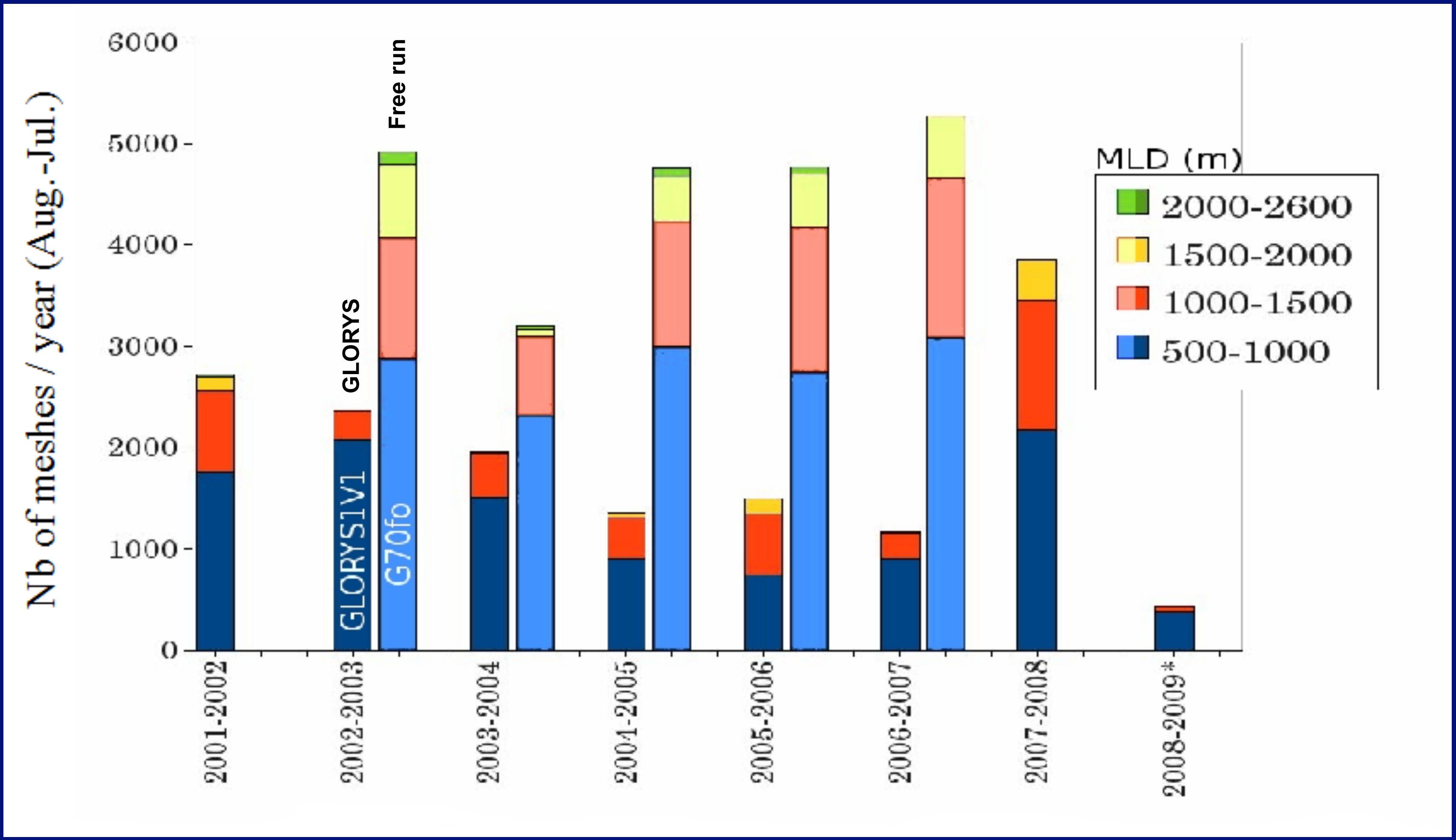




Data assimilation reconstructs the stratification in the sub-surface and deep ocean



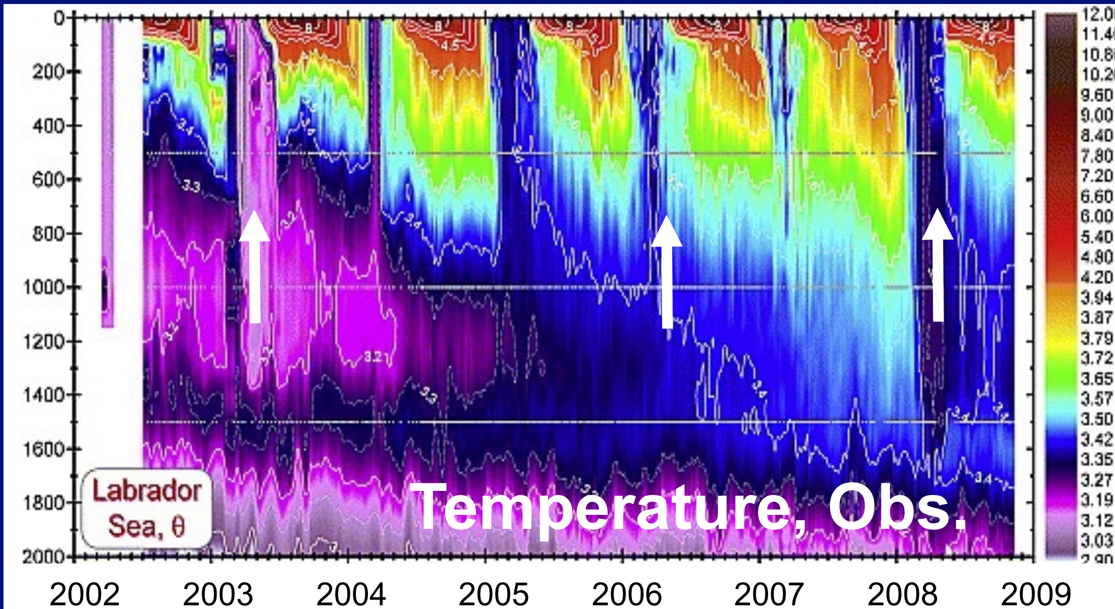
Labrador Sea Convection Cycle in GLORYS1

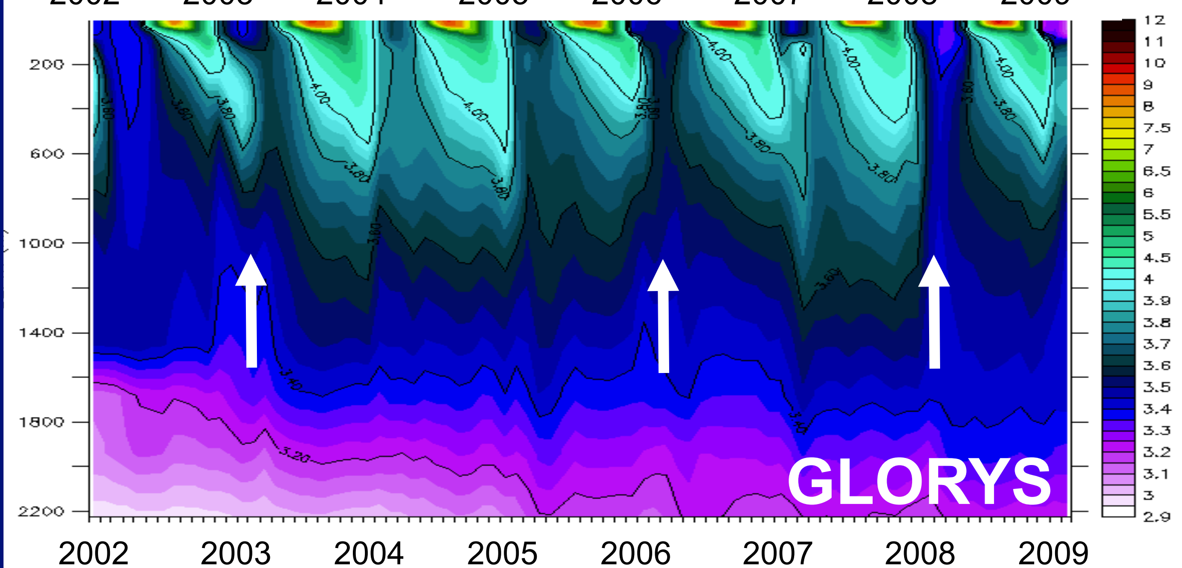


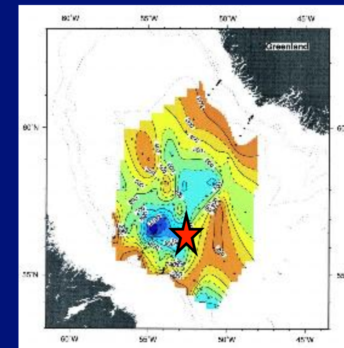
Events of very large winter convection depth are less frequent in GLORYS

Labrador Sea Convection Cycle in GLORYS1

Yashayaev & Loder, GRL, 2009







Data assimilation improves the representation of the Mixed Layer Depth

How? Where? When?

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Buoyancy budget of the convective patch

Surface buoyancy flux due to the atmospheric forcing

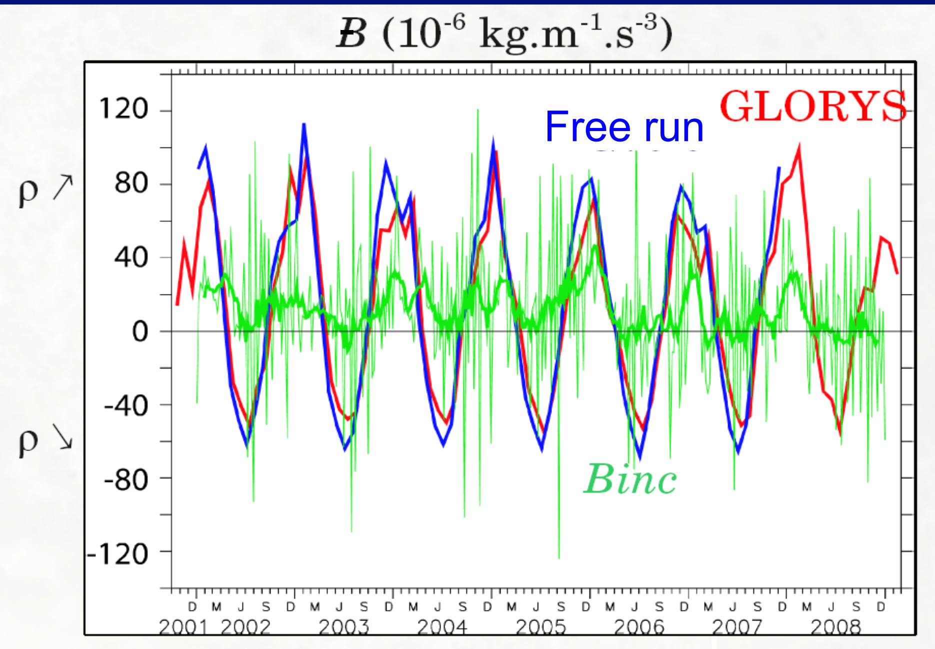
$$B = \frac{g\alpha}{c_p} Q_{net} - g\beta(E-P)s$$

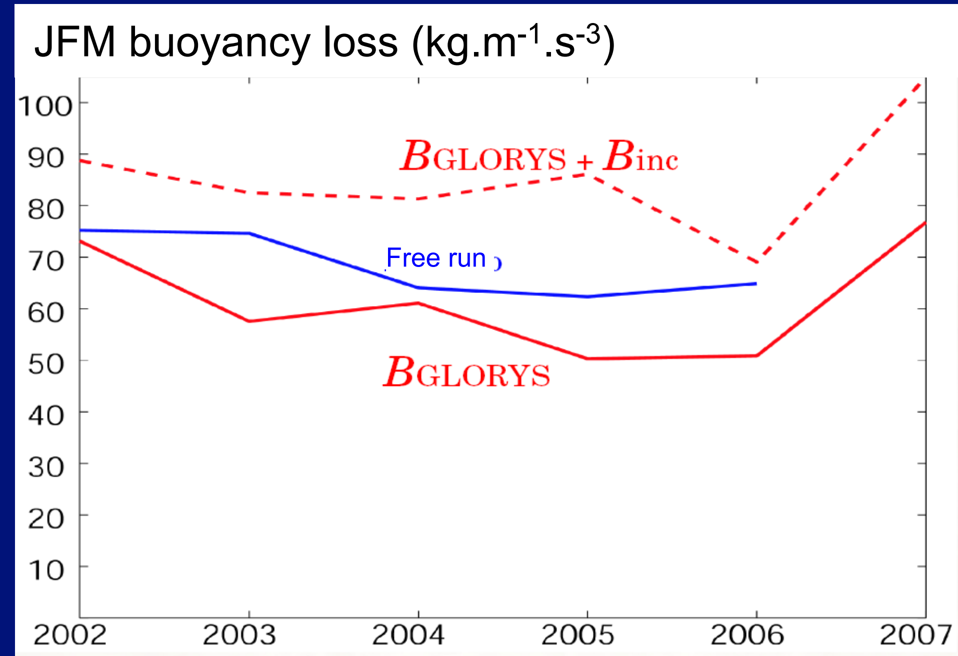
Buoyancy flux between 0-100m due to data assimilation increments

$$B_{inc} = \int_{-100}^{0} \rho g \alpha \left(\frac{\delta T(z)}{\delta t} \right)_{inc} dz - \int_{-100}^{0} \rho g \beta \left(\frac{\delta s(z)}{\delta t} \right)_{inc} dz$$

T,S assimilation increments

Buoyancy budget of the Labrador Sea





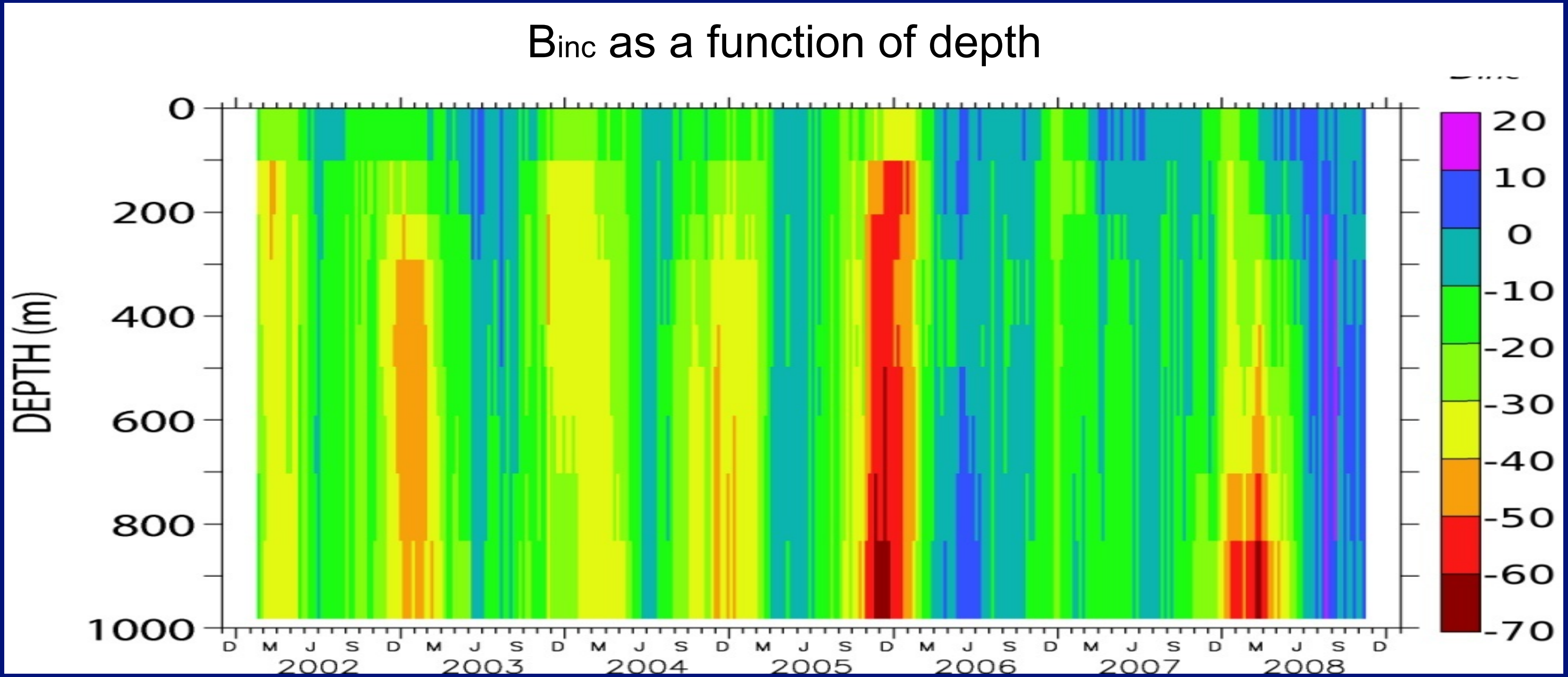
-Surface buoyancy fluxes are similar between GLORYS and Free run

-Increments provide a correction which:

-increases the winter buoyancy loss, and

- suggests that the ECMWF forcing could underestimate the winter heat loss.

Buoyancy budget of the Labrador Sea



Increments (B_{inc}) provide:

-a greater correction of the interior buoyancy

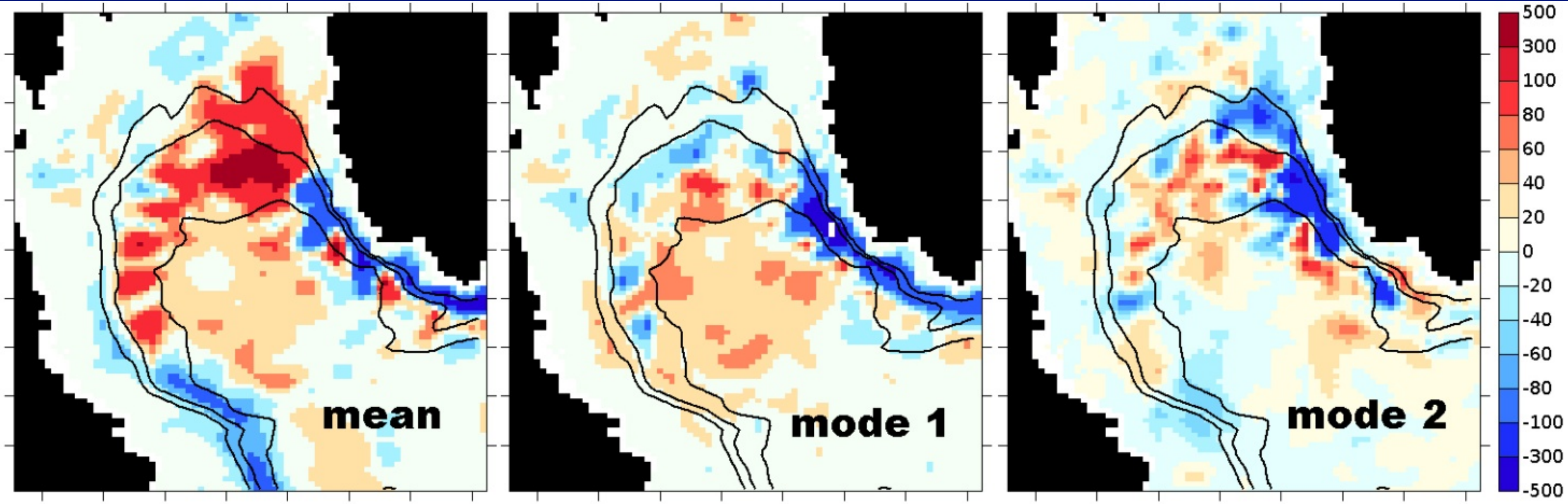
Why correction is more important at depth? Because:

- vertical mixing is not well parameterized in the model

- The lateral flux of mesoscale eddies is introduced by the data assimilation

EOF analysis of Temperature increments

Analysis of the Temperature increments between 80 m & 1000 m



Heat flux equivalent to temperature increments between 80 m and 1000 m depth. (W/m2)

Increments could be interpreted in terms of **heat transfer between the boundary current and the ocean interior**

EOF analysis of Temperature increments

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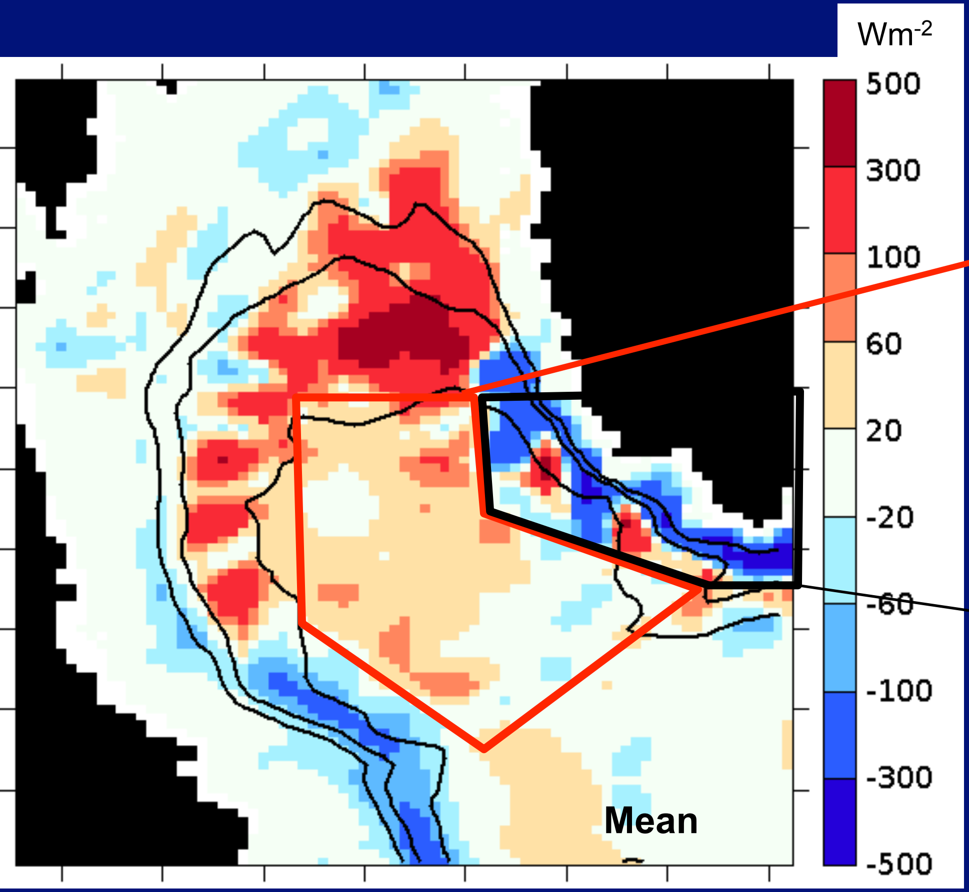

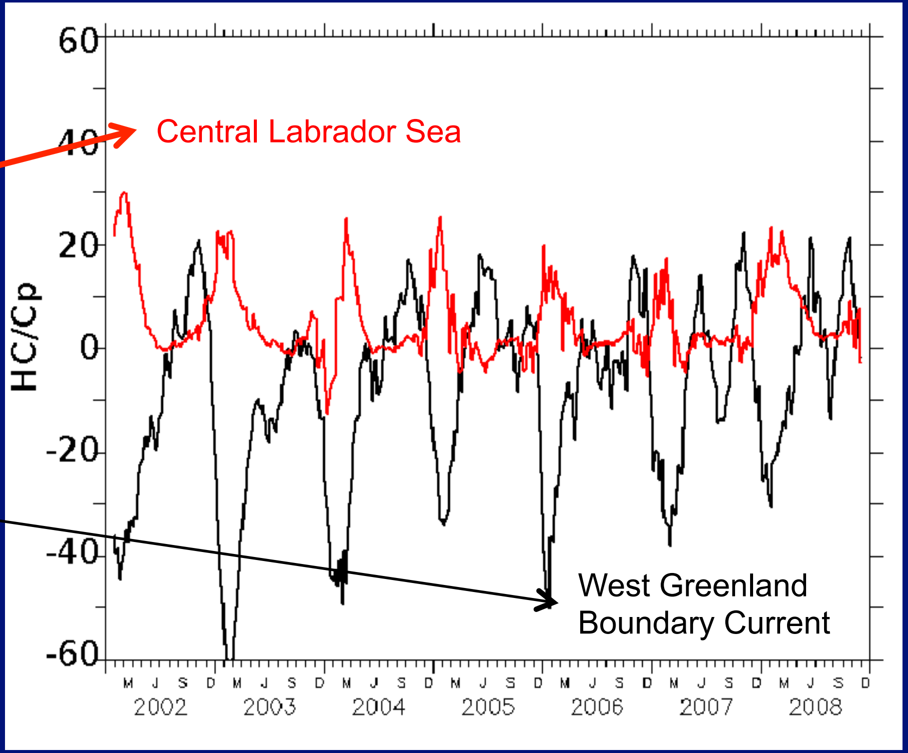

Anti-correlated variations of 80-1000m heat content betwwen interior and boundary current

EOF analysis of Temperature increments

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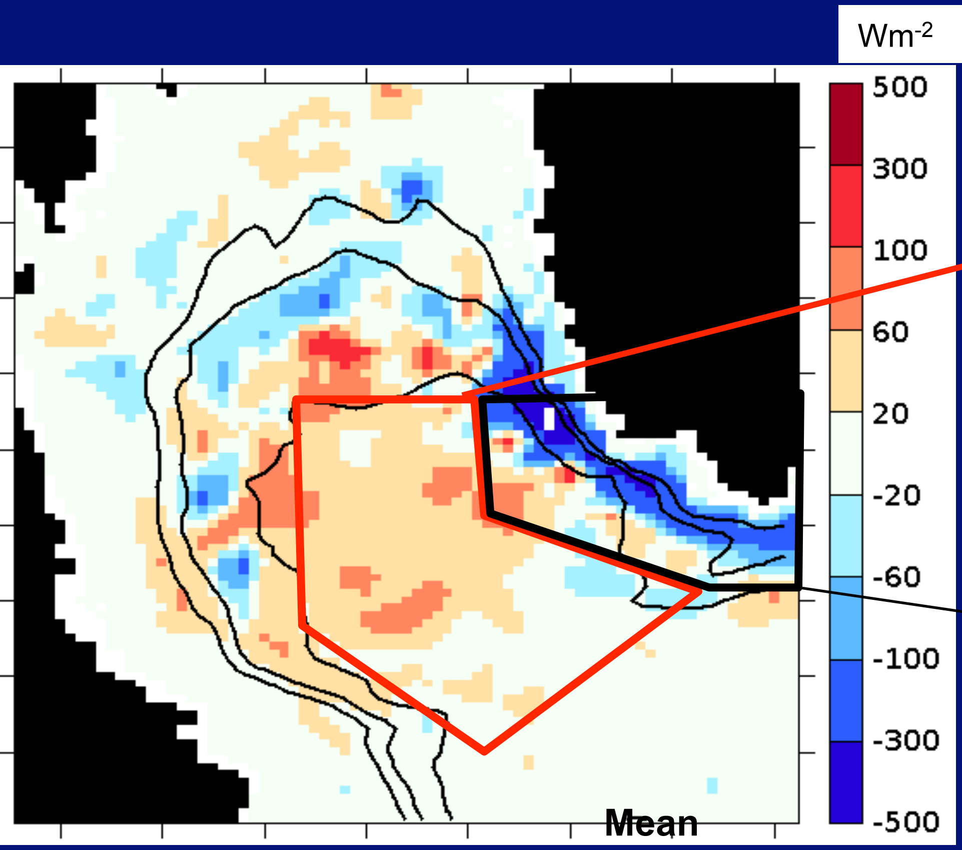

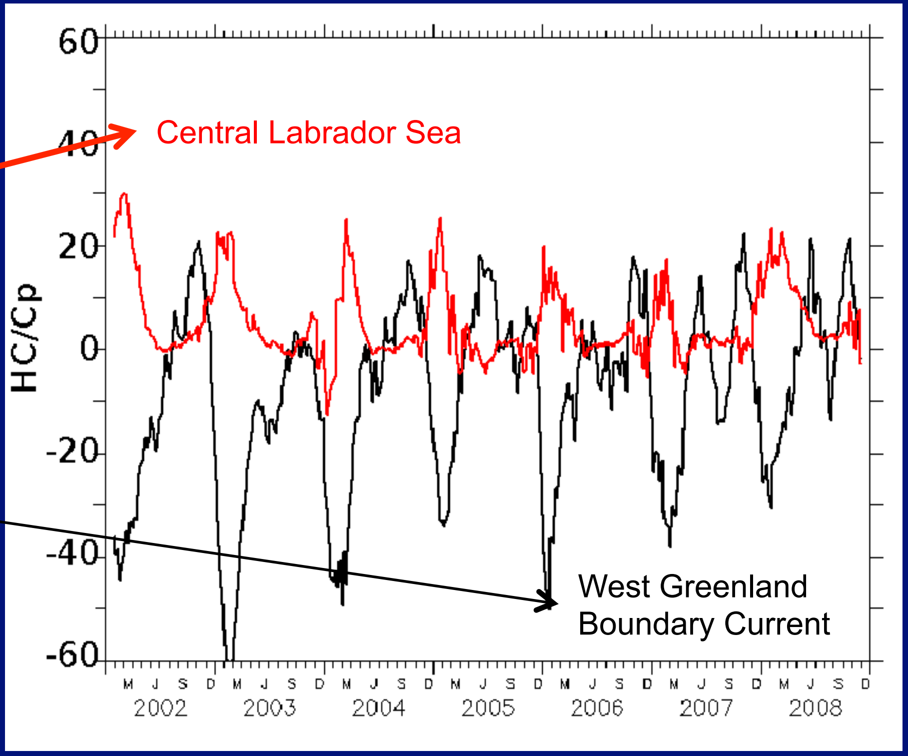

Anti-correlated variations of 80-1000m heat content betwwen interior and boundary current

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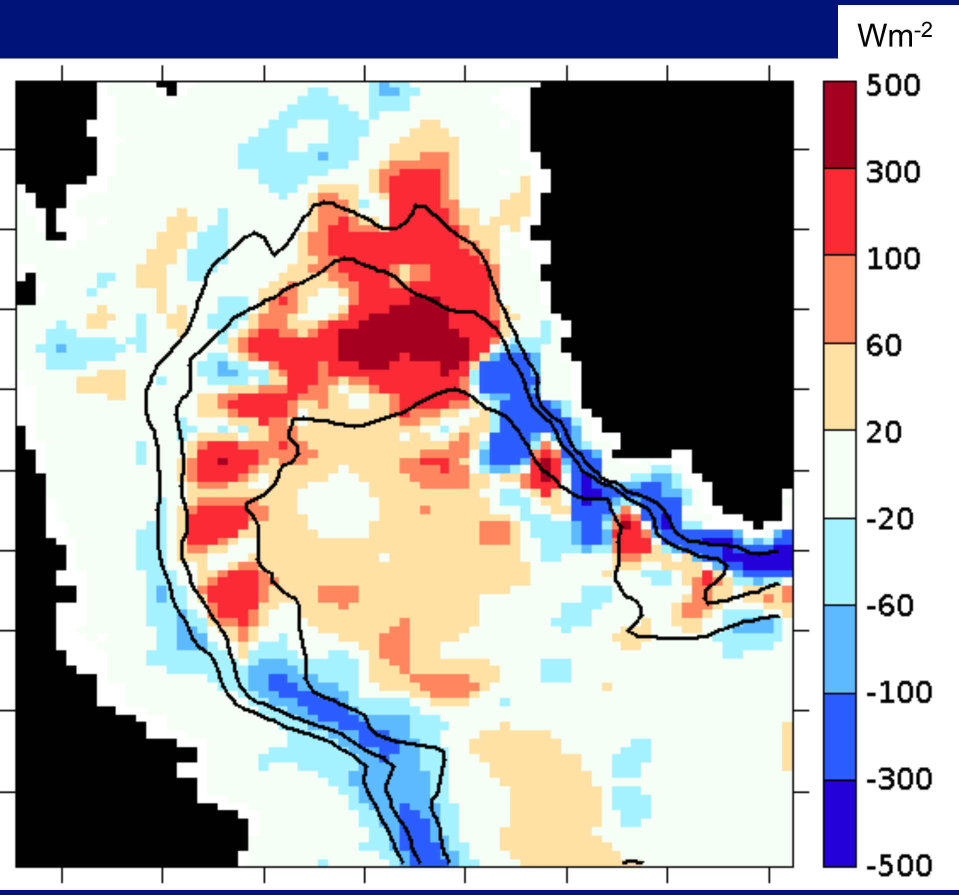
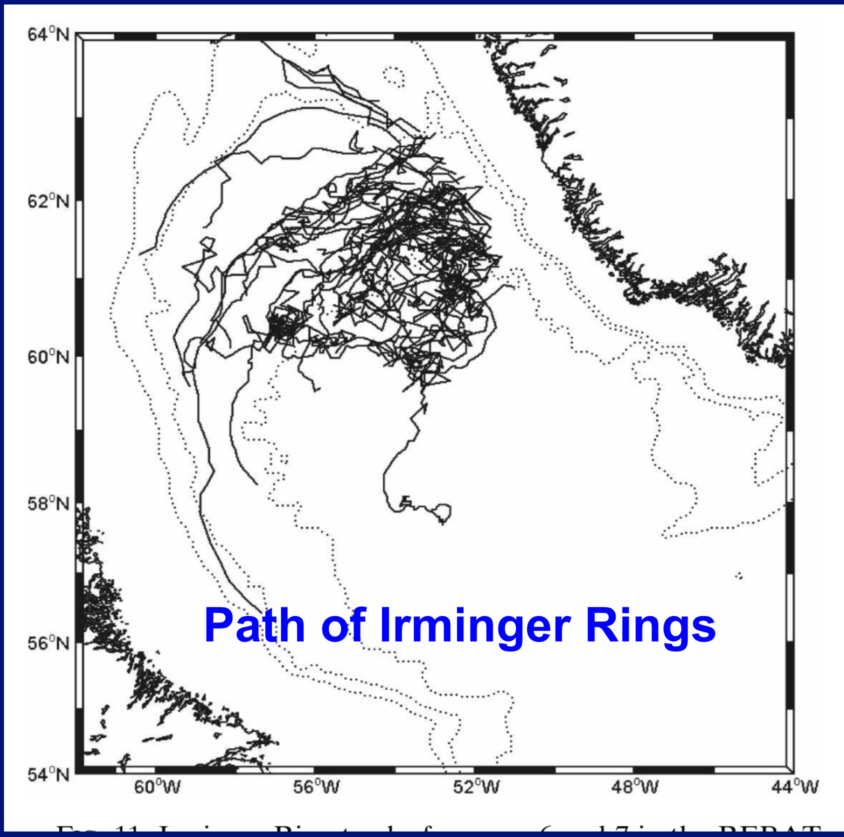
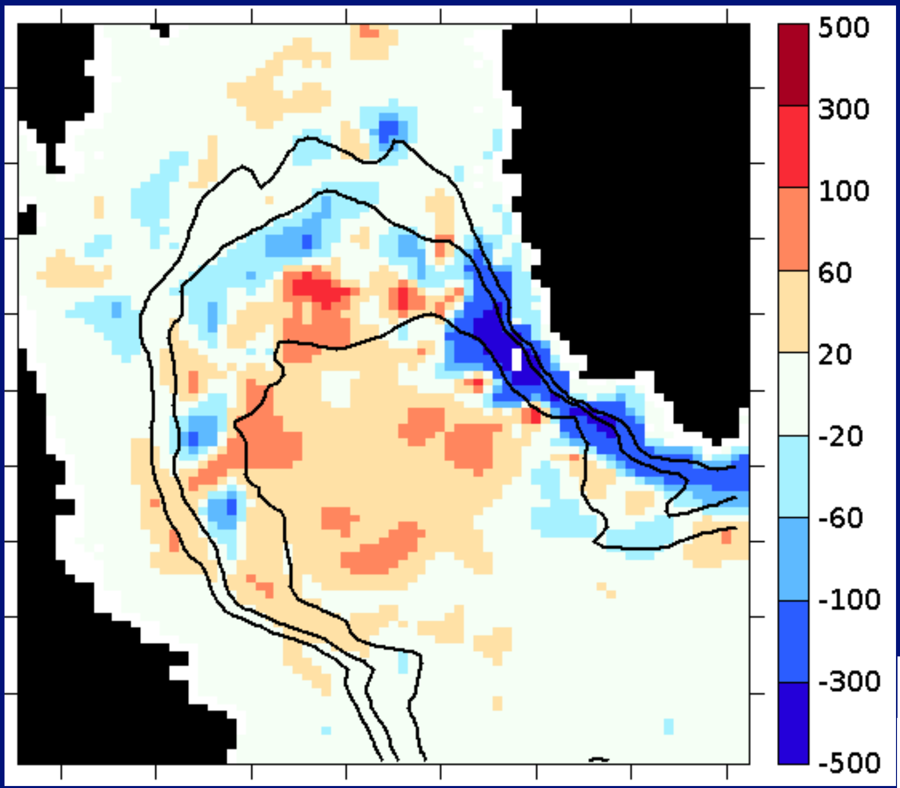
Analysis of the Temperature increments between 80 m & 1000 m

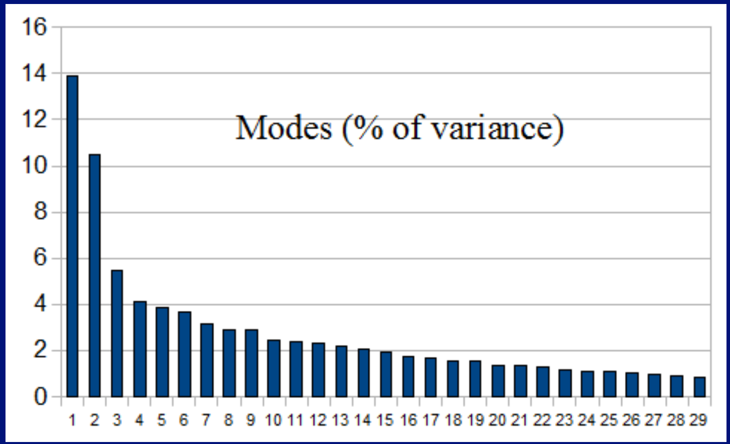


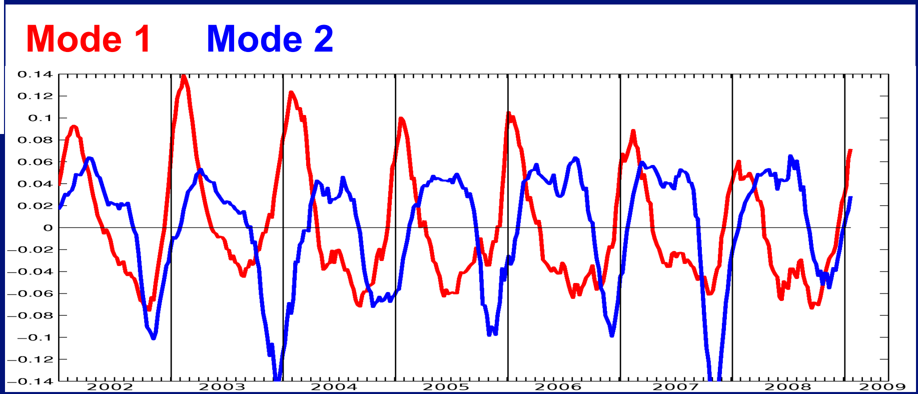


3D EOF of Temperature increments

Analysis of the Temperature increments between 80 m & 1000 m
Mode 1

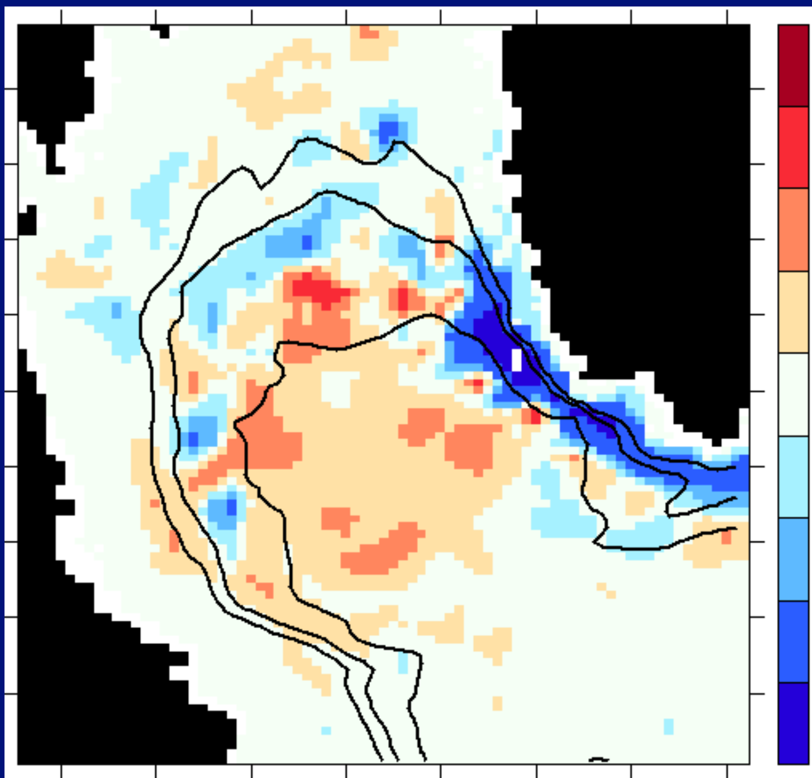


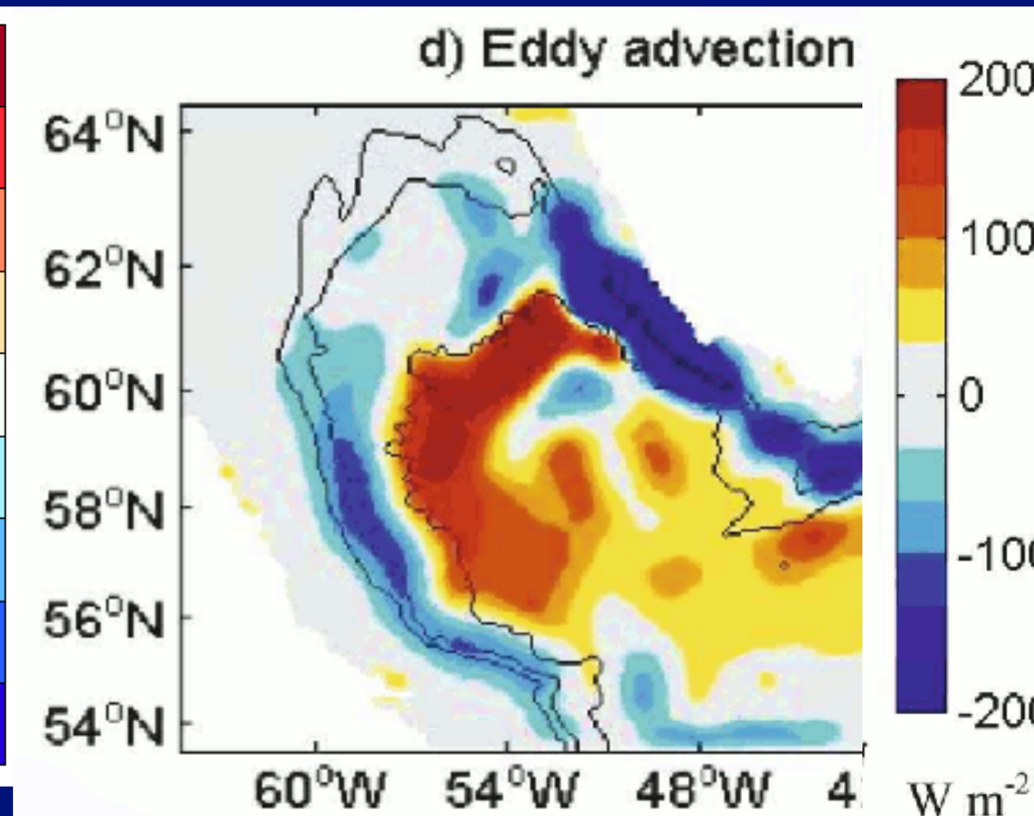




3D EOF of Temperature increments

Analysis of the Temperature increments between 0 m & 200 m
Mode 1





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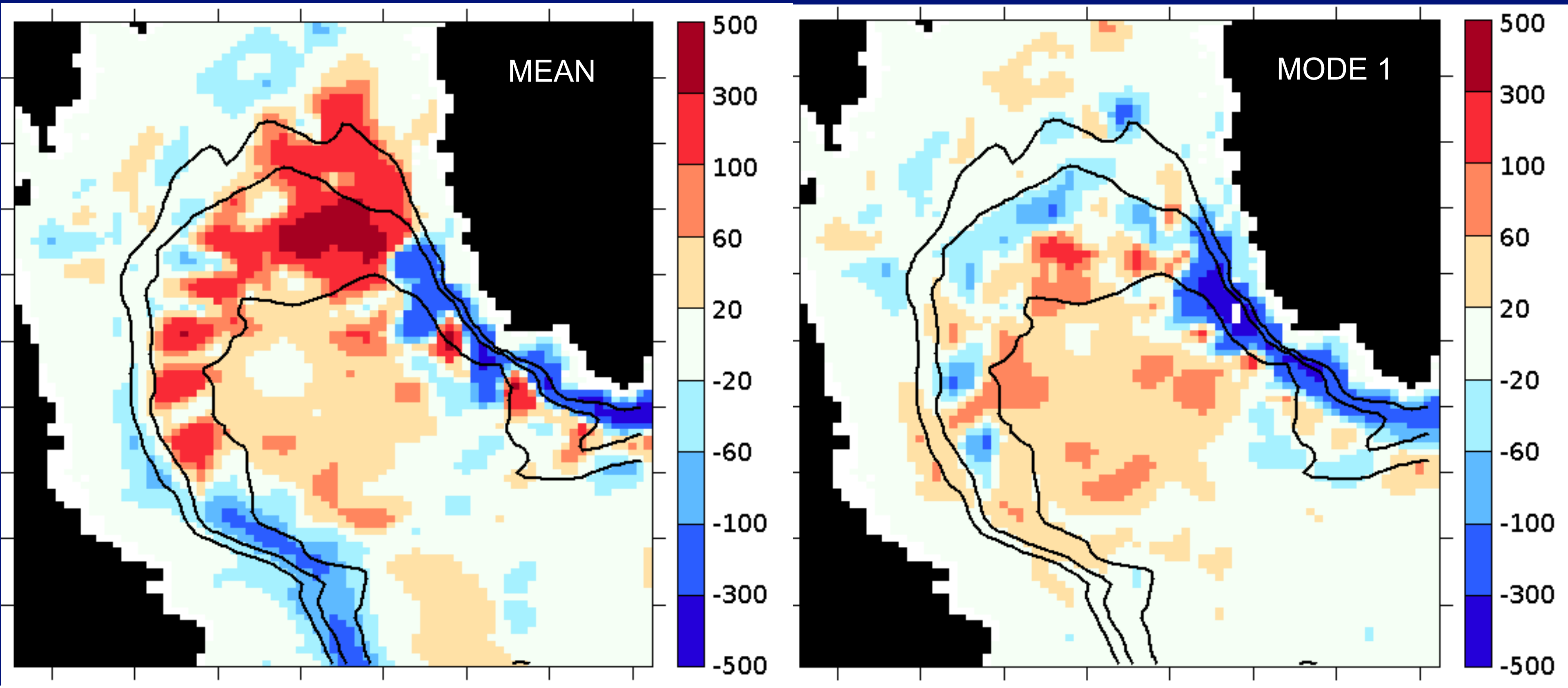

Heat flux equivalent to temperature increments between 80 m and 1000 m depth. (W/m2)

Effect of
Irminger Ring

Effect of
Convective and boundary current Eddies

Increments are consistent with eddy fluxes produced by very high resolution models

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- Eddy permitting models in the Lab Sea

  - do not reproduce realistically the deep convection cycle

- Data assimilation enables a realistic convection cycle,

  - allows the summer re-stratification of the whole water column.

- Temperature assimilation increments

  - exhibit spatial patterns and time variability similar to the eddy fluxes diagnosed in very high resolution models

  - suggest that model flaws in the Lab Sea are less due to

    flaws in the atmospheric forcing

    than to a poor representation of the various types of mesocale eddies.