On the interplay between downwelling, eddies and deep convection in the Labrador Sea

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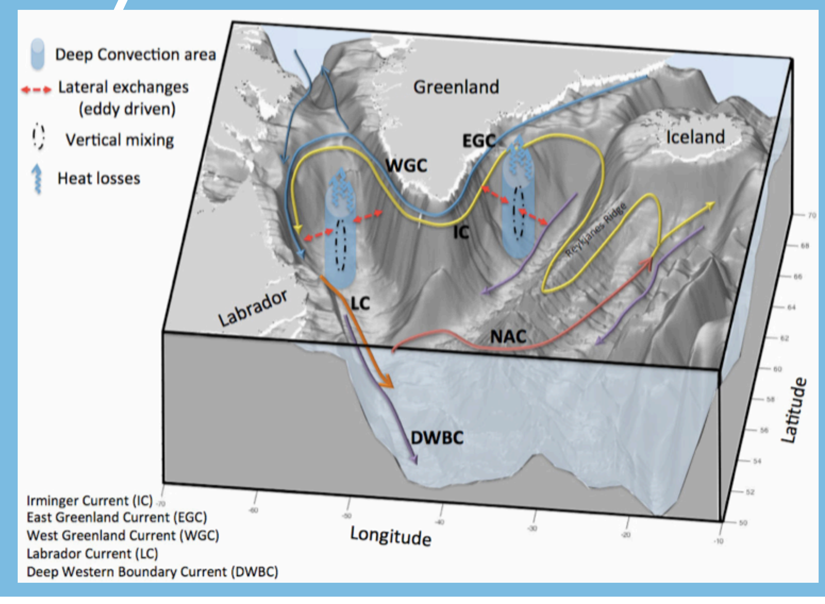
Exchange between interior and boundary current via eddies

Eddies play an important role for the cycle of deep convection and restratification in the Labrador Sea. The surface heat loss is compensated by heat advection by the boundary current, which penetrates into the interior via eddies (Spall, 2004; Straneo, 2006).

In this study we investigate the influence of the eddies on:

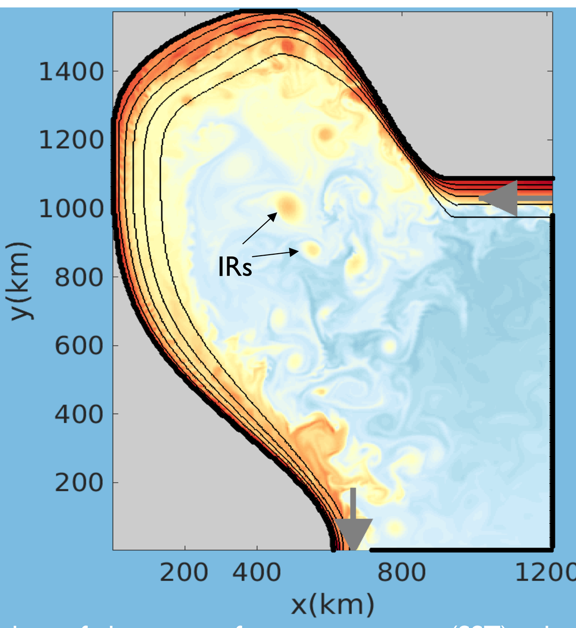
- the downwelling
- the deep convection in a marginal sea

In addition, the sensitivity of the characteristics of the deep convection and the downwelling with respect to surface fluxes is examined.



Idealized Model

Large eddies (known as Irminger Rings, IRs) are formed near the west coast of Greenland due to a topographic narrowing. These eddies transfer heat between the boundary current and the interior (Fig. 1).



MITgcm :
No-slip condition
40 vertical levels
Δx = 3.75 km
$f_0 = 1.16 \times 10^{-4}\ s^{-1}$
$\beta = 1.4 \times 10^{-11}\ (ms)^{-1}$
$\rho_0 = \rho_0\,[1-\alpha(T-T_{ref})]$

Open boundaries:
East: inflow is specified
South:: Orlanski radiation conditions

Forcing:
Temporal and spatially varying surface heat flux.

Fig.1: Snapshot of the sea surface temperature (SST) taken after a 15 year spin-up. Black lines denote topography contours with intervals of 500m.

Simulations: REF, COLD and WARM

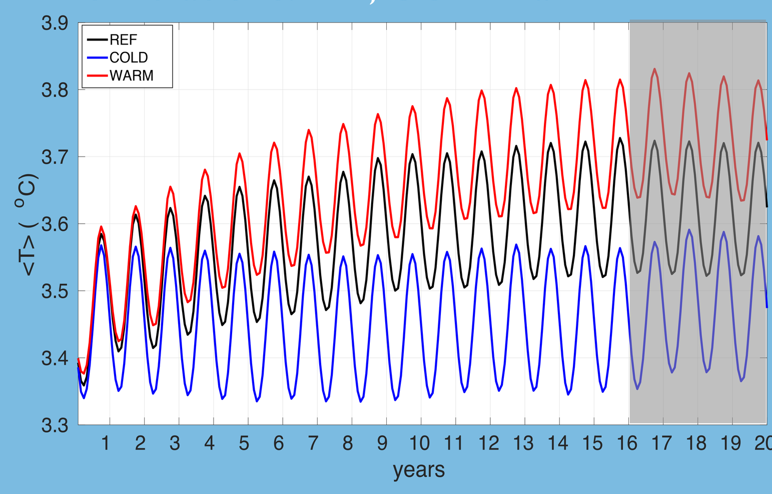


Fig.2: Timeseries of the basin-mean temperature of the simulations. We vary the winter surface heat loss by 50% to get conditions for a colder and warmer wintertime regime. Shaded area denotes the years under consideration.

Deep Convection and Downwelling in the basin

- the model reproduces the winter mixed layer depths seen in observations (Fig. 4)
- deepest MLD do not coincide with regions of maximum heat losses ⇒ IRs transfer heat (Fig.4)

proper representation of the eddy activity in models is a key element for representing the dynamics of the Labrador Sea.

The boundary current loses heat along its path (rising of isopycnals)→ sinking in the boundary current (Straneo, 2006)

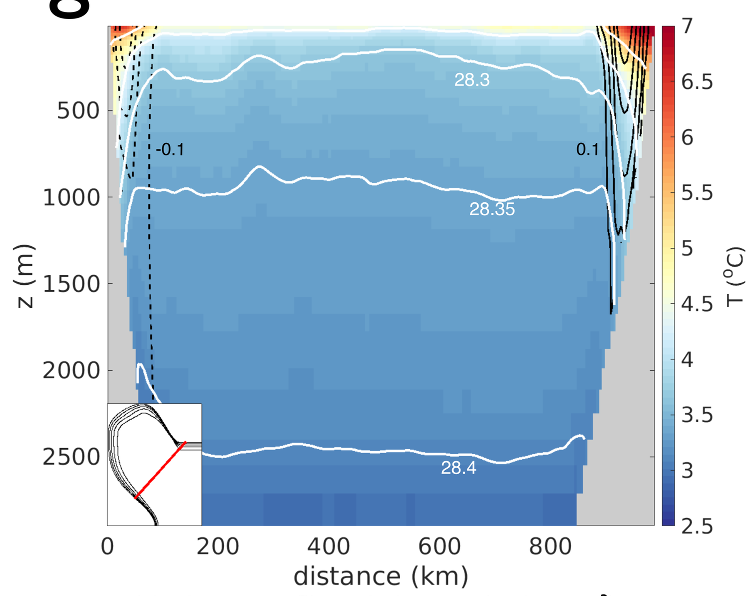


Fig.5: Late spring (May) mean temperature (shading, in °C) and density (in kg m⁻³) over a section indicated by the red line in the inset figure. Positive (negative) velocity contours (c.i. = 0.1 cm s⁻¹) are shown in black solid (dashed) lines.

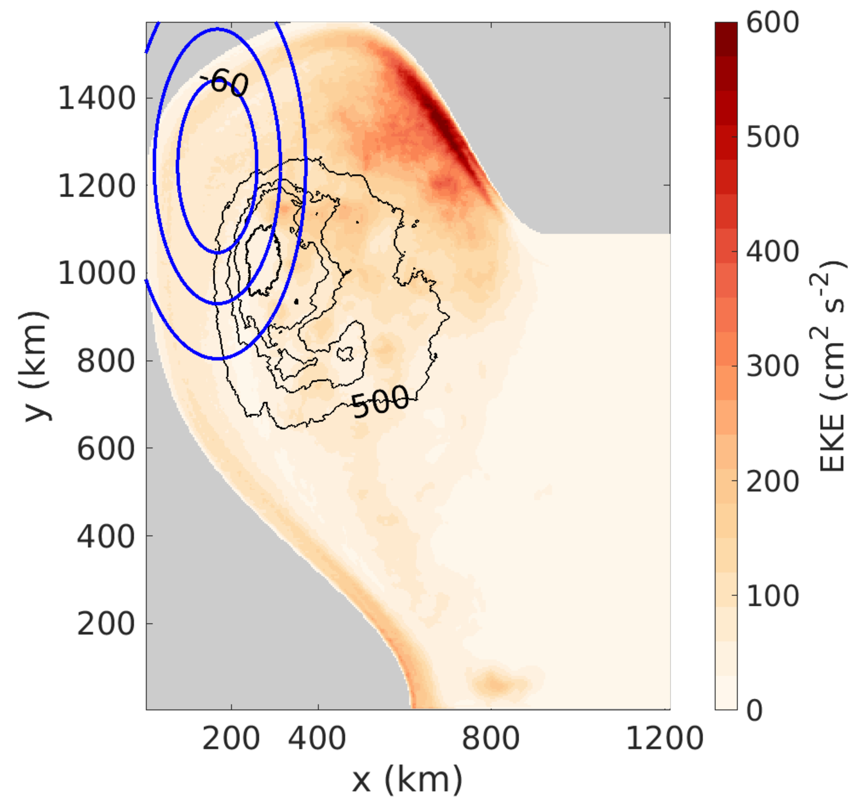


Fig.4: Mean eddy kinetic energy (EKE, shading) and the winter mixed layer depth (MLD, contours c.i. = 500 m). Blue lines denote the annual mean surface heat fluxes in W m⁻². All have been calculated from a five year average after a 15 year spin-up (shaded area in Fig.2).

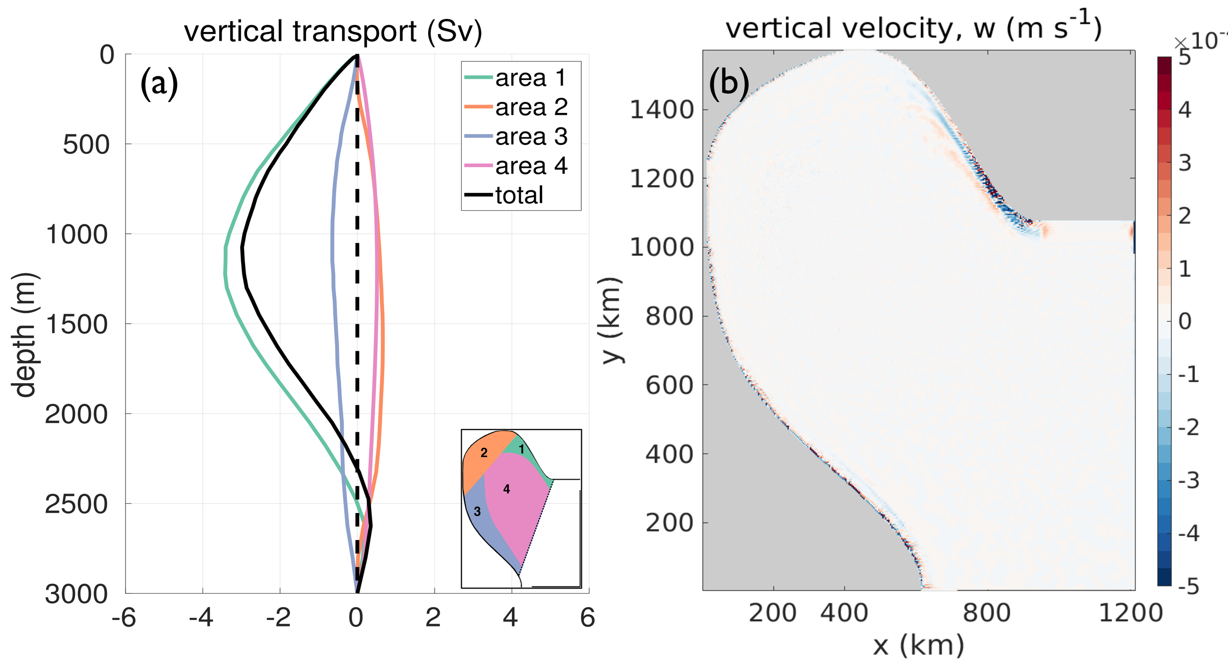


Fig.6: (a) Vertical transport over the four areas, indicated in the inset figure in (a), and total domain. (b) Vertical velocity at 1000m depth for the REF simulation.

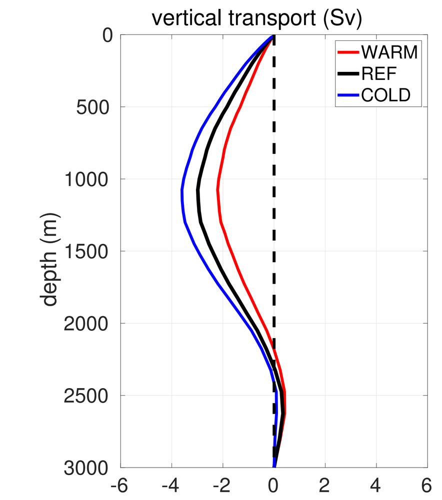
- total downwelling in the basin of 3.0 Sv (at a depth of 1000 m, Fig.6a)
- net downward transport takes place in areas 1 and 3 (Fig. 6a)
- the downwelling is concentrated close to the boundary (Fig. 6b)

Conclusions

- Eddies are important for deep convection since they determine its location and extent, together with the surface heat flux.
- Enhanced downwelling is seen along the lateral boundaries in regions of enhanced eddy activity.

Sensitivity to surface forcing

The interior is cooled by increased surface heat flux
→ the horizontal density gradients between the interior and the boundary current increases
→ the boundary current becomes more unstable (Fig.7a)
→ the lateral eddy heat flux increases (Fig. 7c-e)
It is this chain of events that leads to a negative feedback on the convection depth



- the magnitude of the downwelling in the model is positively correlated with the magnitude of the surface heat flux (Fig.8)

Fig.8: Vertical transport integrated horizontally over the whole domain for all the simulations depth space.

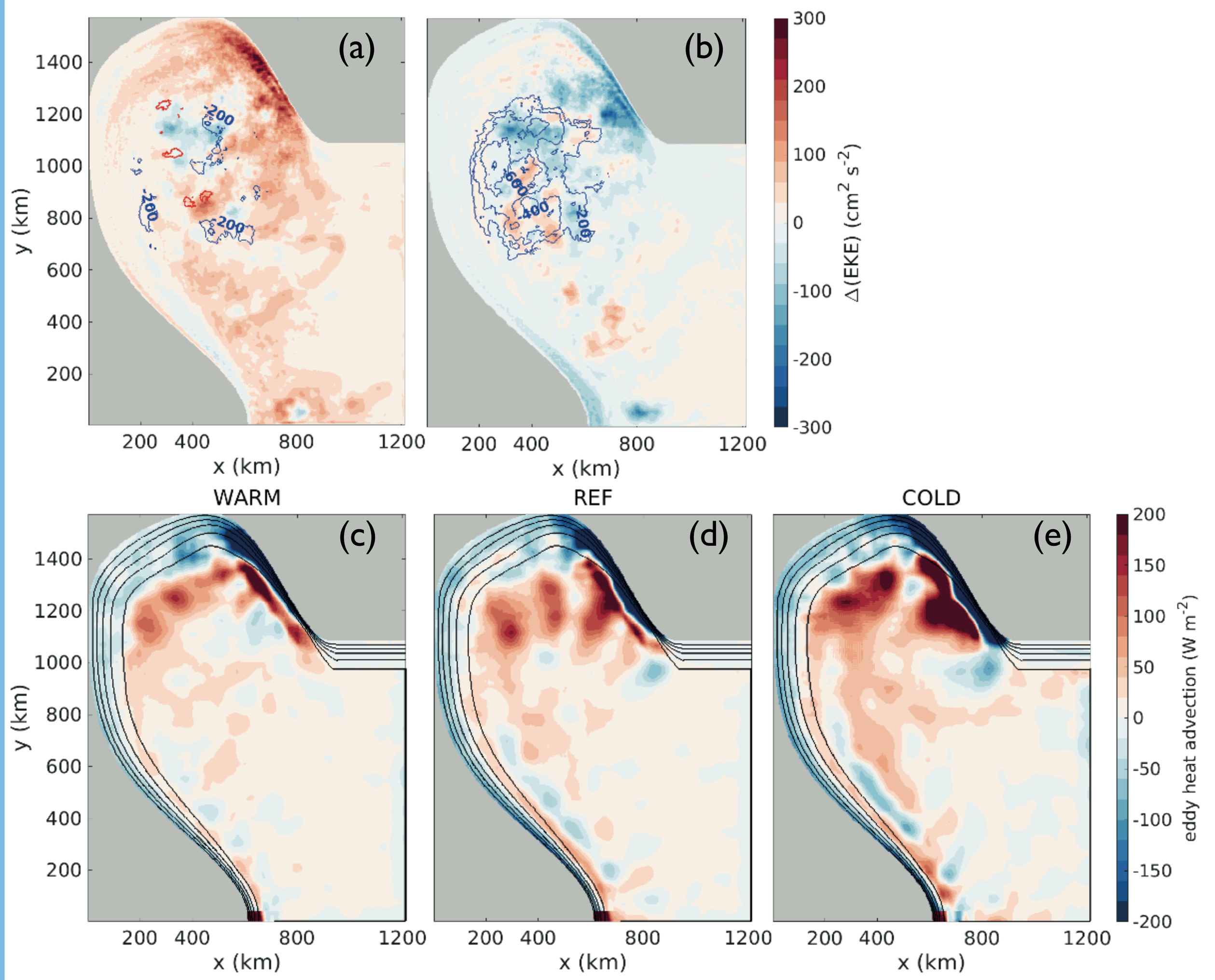
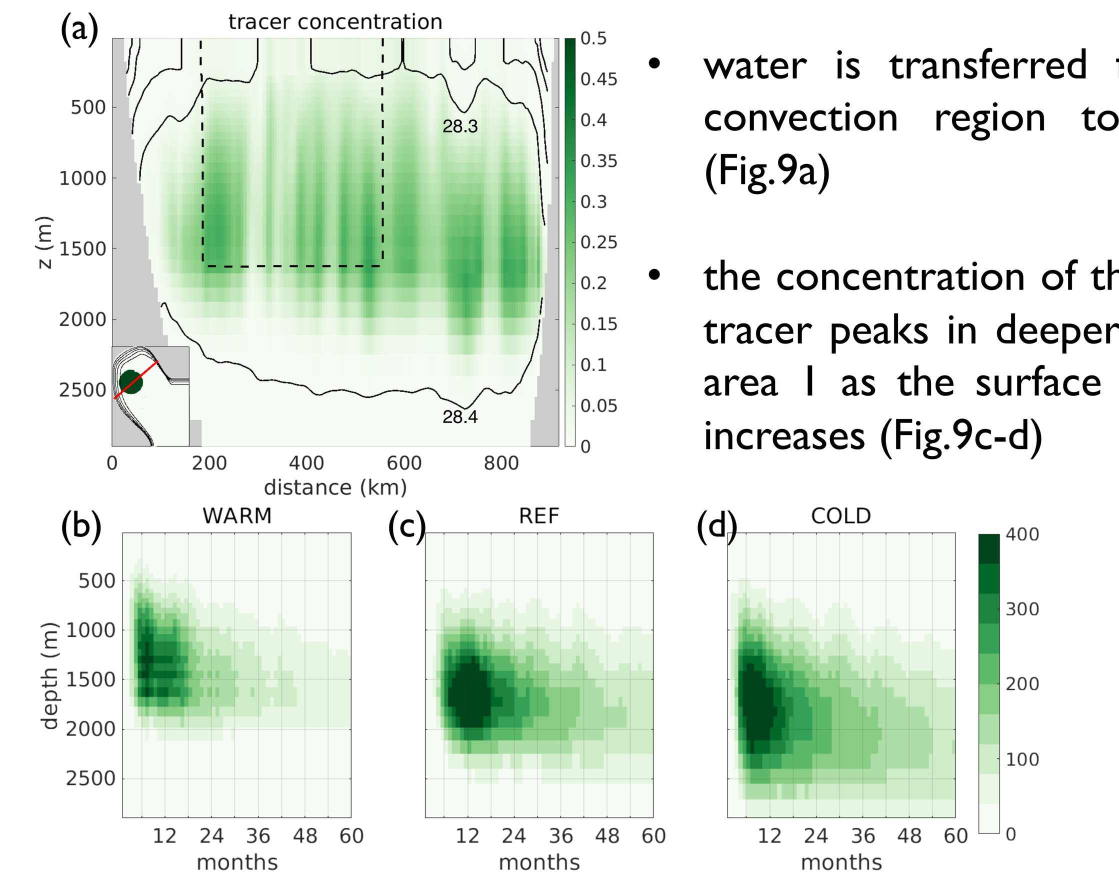


Fig.7: Anomalies from REF simulation of EKE (in cm² s⁻², shading) and MLD (in m, contours) for (a) COLD and (b) WARM. Depth integrated eddy advection of heat (in W m⁻²) for (c) WARM, (d) REF and (e) COLD.



- water is transferred from the convection region to area 1 (Fig.9a)
- the concentration of the passive tracer peaks in deeper layers in area 1 as the surface heat loss increases (Fig.9c-d)

Fig.9: (a) Cross section of a snapshot of the vertical distribution of the passive tracer at the end of year 16 for REF, indicated by the red line in the inset figure, superimposed on the isopycnal surfaces (in kg m⁻³, black contours). The passive tracer released at the beginning of year 16 in the convection area (dashed lines). The inset figure shows the initial concentration of the tracer. Time evolution of the concentration of passive tracer in depth integrated over area 1 for (b) WARM, (c) REF and (d) COLD.

Conclusions

- Indirect link between the variations in surface heat flux and the process of convection.
- Lateral heat fluxes associated with the eddy field determine the amount of sinking that takes place.

Key points

I. Eddies affect:
- the location of convection
- the magnitude of downwelling at the boundary

II. Enhanced downwelling along the lateral boundaries and not where convection is deepest

III. Dense water is transported from the interior towards the lateral boundaries.

References:
Spall, M.A. (2004). Boundary Currents and Watermass Transformation in Marginal Seas*. Journal of Physical Oceanography, 34(5):1197–1213.
Spall, M.A. (2010). Dynamics of Downwelling in an Eddy-Resolving Convective Basin. Journal of Physical Oceanography, 40(10):2341–2347.
Straneo, F. (2006). On the Connection between Dense Water Formation, Overturning, and Poleward Heat Transport in a Convective Basin*. Journal of Physical Oceanography, 36(9):1822–1840.

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