Decadal variability of eddy temperature fluxes in the Labrador Sea

Christopher Danek[1] (cdanek@awi.de), Patrick Scholz[1], Gerrit Lohmann[1]
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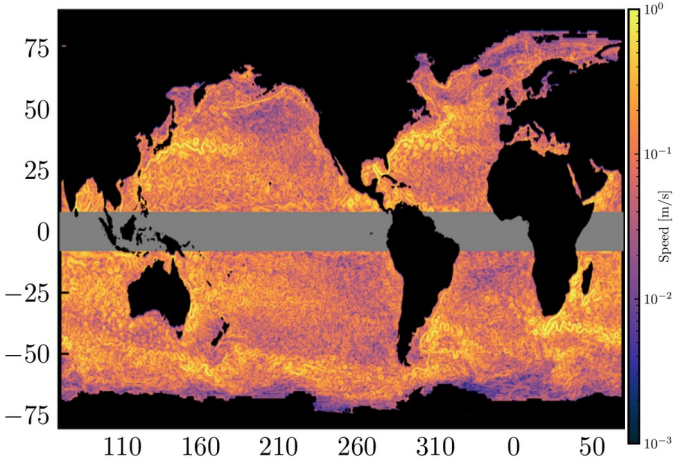
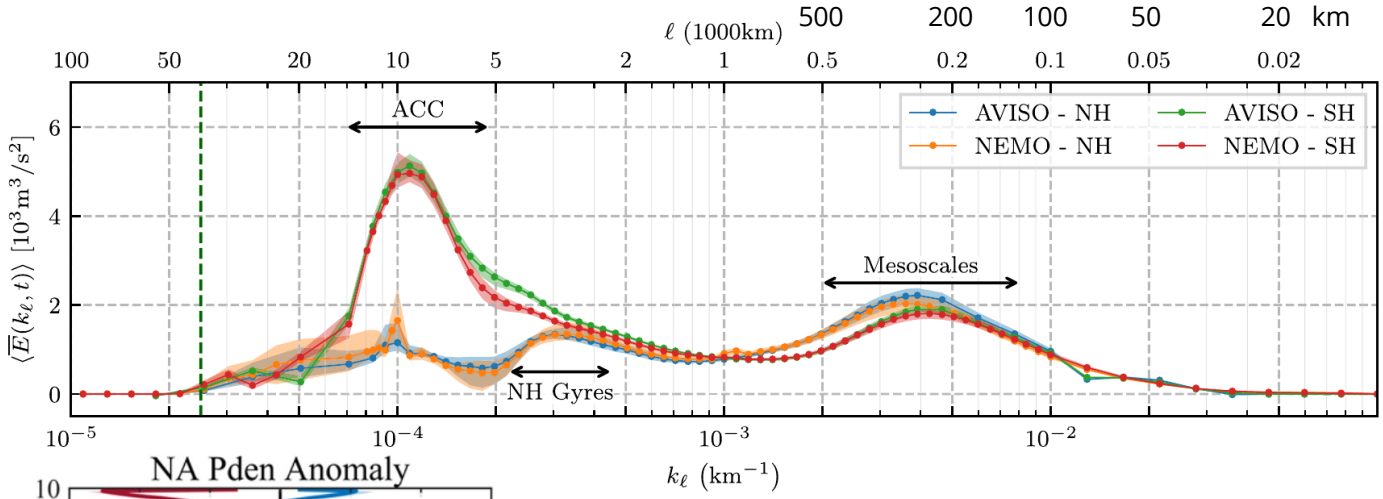
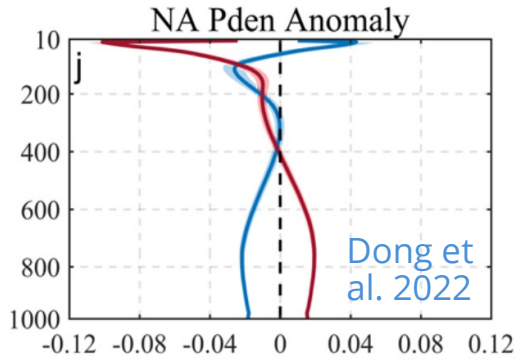
Satellite geostrophic velocity snapshot and wavenumber spectrum from Storer et al. 2022:







- mixed layer and pycnocline depth (Gaube et al. 2019, Chen et al. 2021)
- nutrients/plankton/carbon (e.g. reviews McGilliCuddy Jr. 2016 and Mahadevan 2016)

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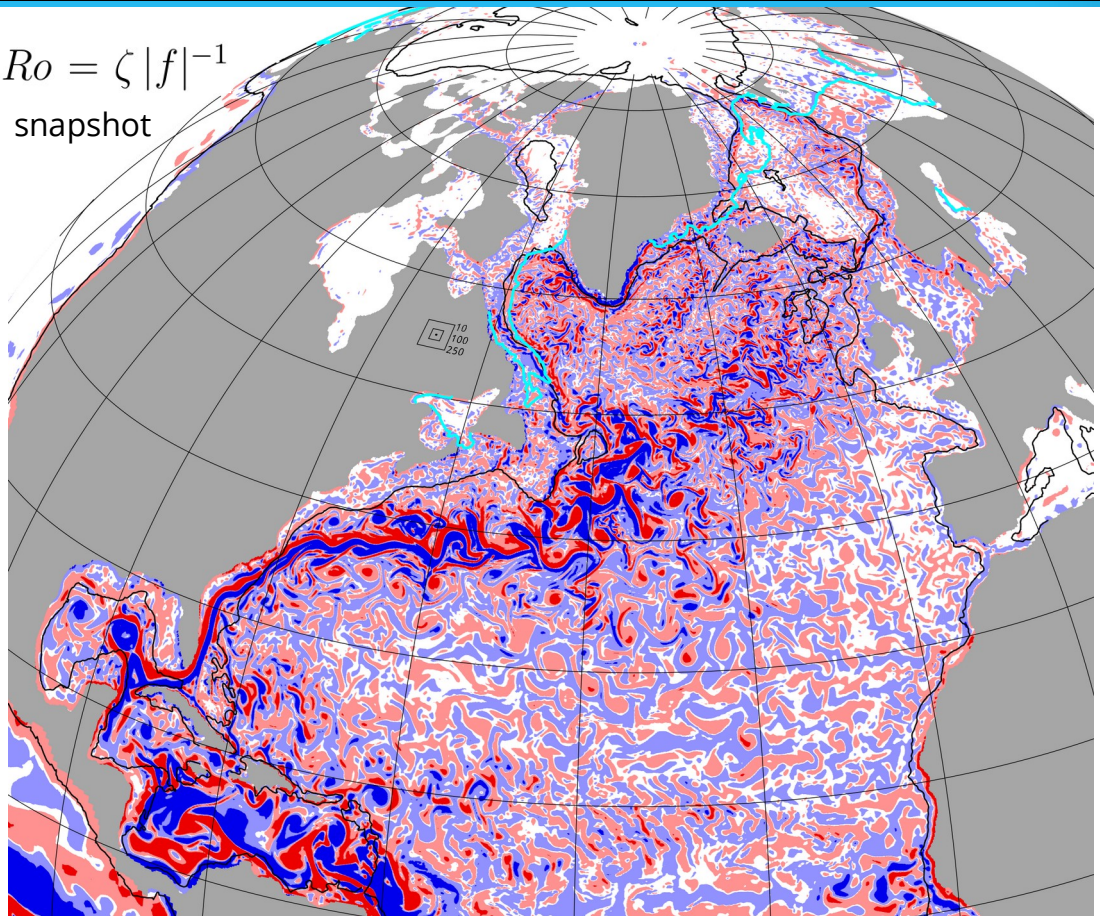
$$Ro = \zeta |f|^{-1}$$

snapshot



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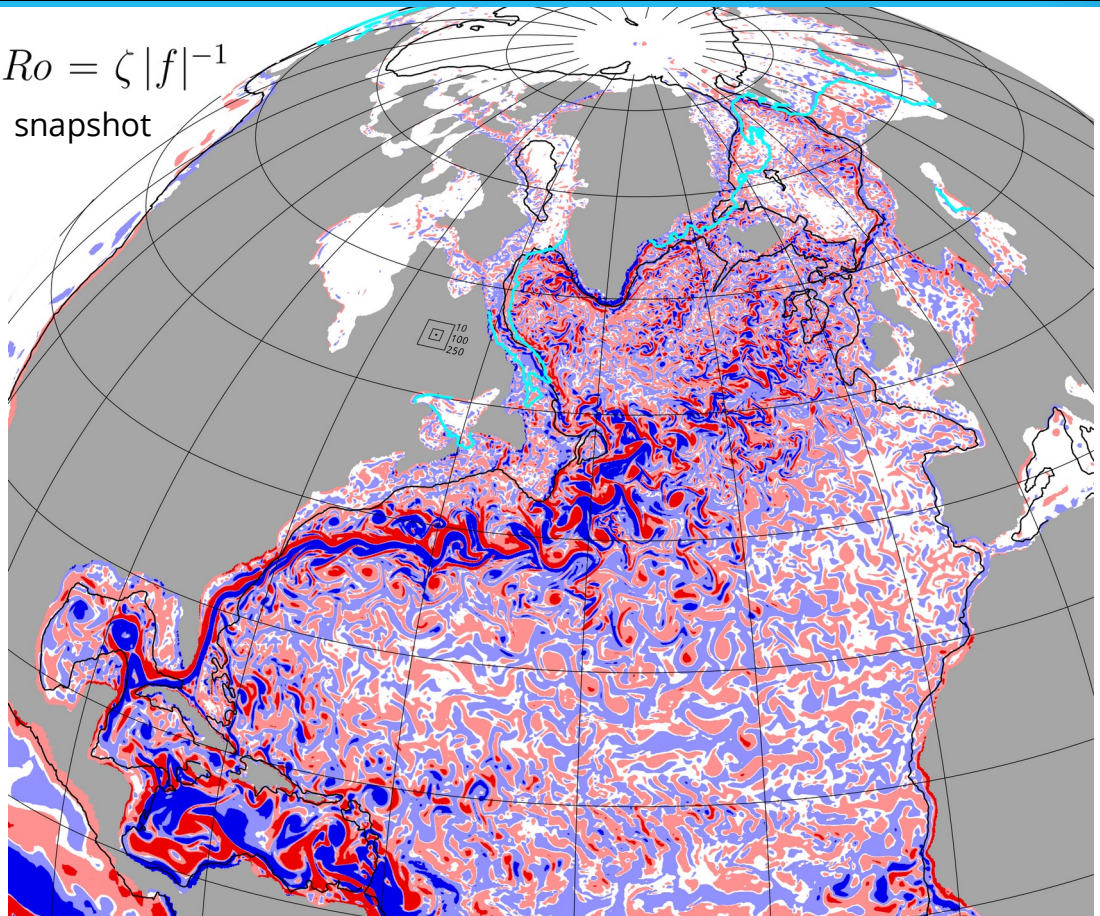

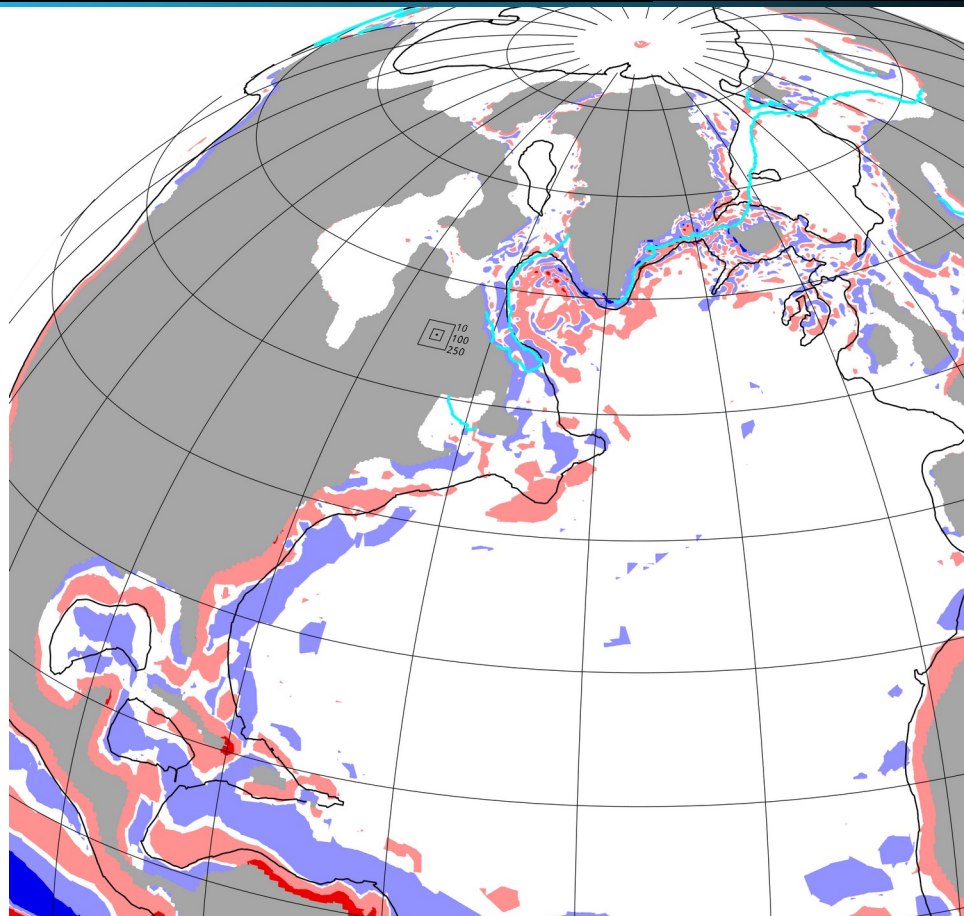

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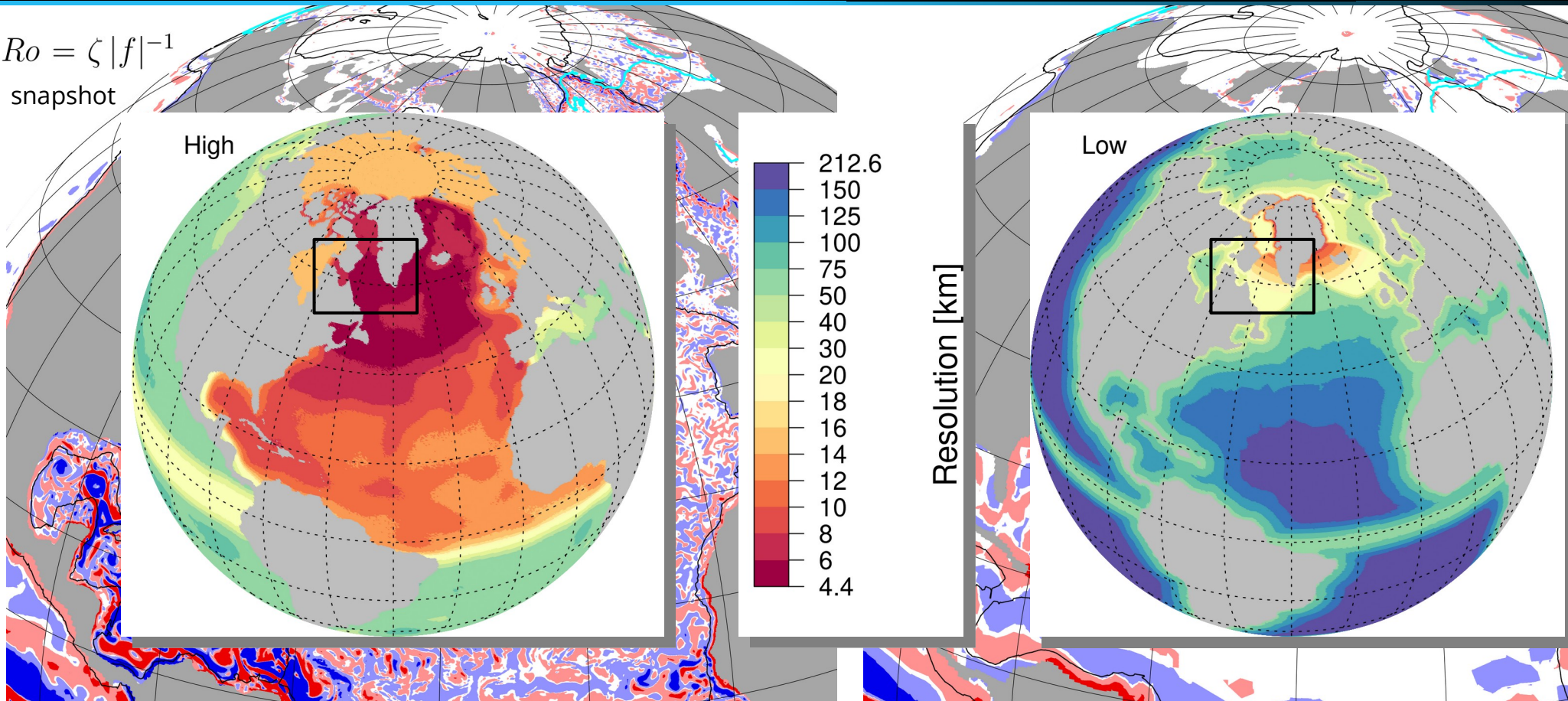

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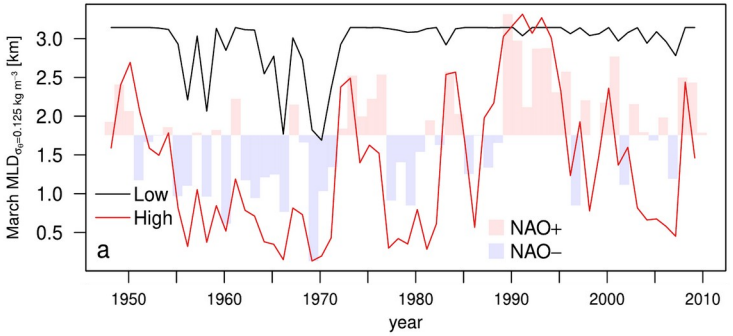

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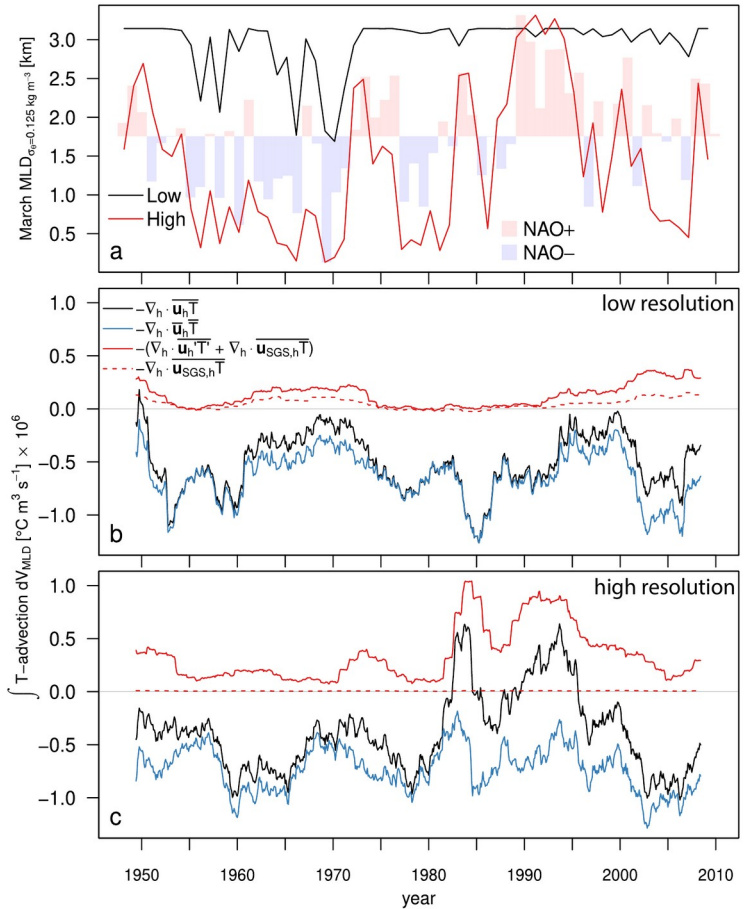

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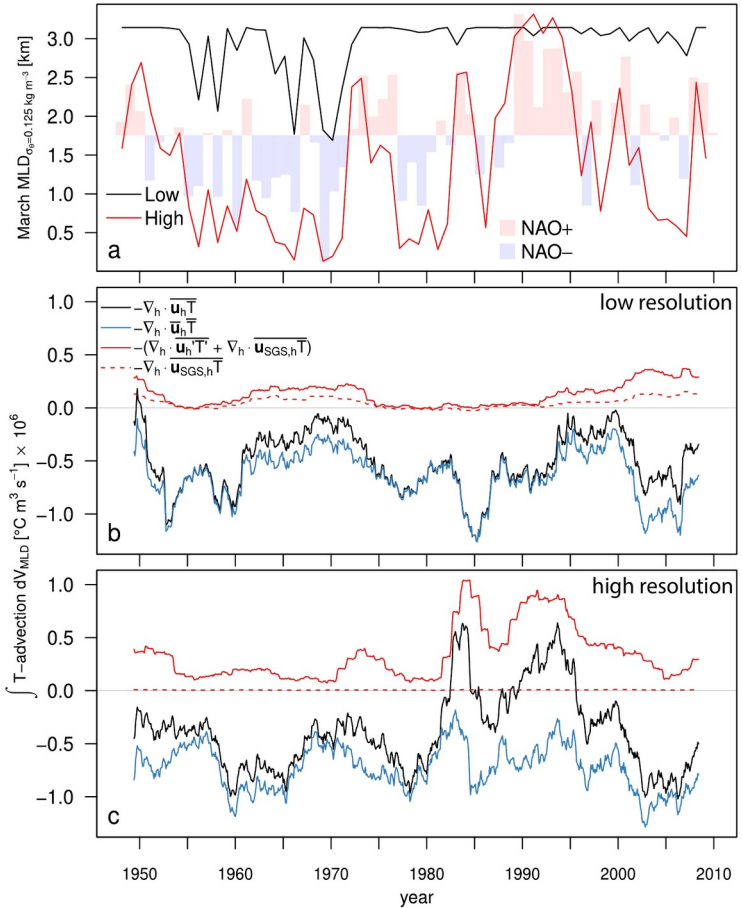
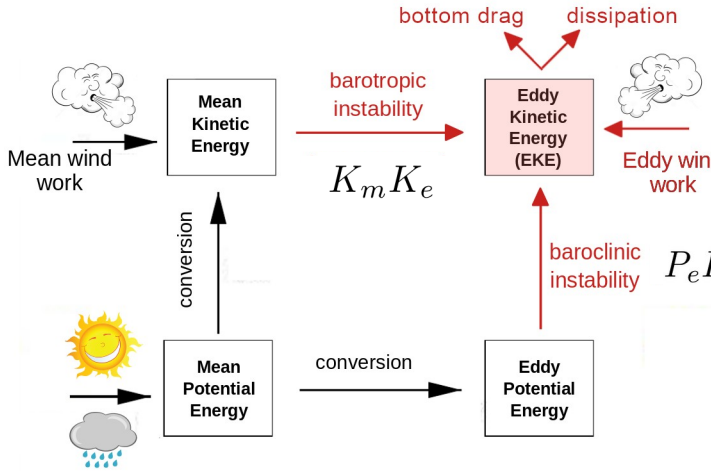


Lorenz Energy Cycle (Section 12.2 in Olbers et al. 2012):

$$\partial_t \int \mathrm{EKE}\,\mathrm{d}V = \int (F_e K_e + \mathrm{drag})\,\mathrm{d}A + \int (K_m K_e + P_e K_e + \mathrm{dissipation})\,\mathrm{d}V$$



$$K_m K_e = \mathrm{HRS} + \mathrm{VRS}$$
$$\mathrm{HRS} = -\overline{u'^2}\,\partial_x \overline{u} - \overline{u'v'}\,\partial_y \overline{u} - \overline{u'v'}\,\partial_x \overline{v} - \overline{v'^2}\,\partial_y \overline{v}$$
$$\mathrm{VRS} = -\overline{u'w'}\,\partial_z \overline{u} - \overline{v'w'}\,\partial_z \overline{v}$$

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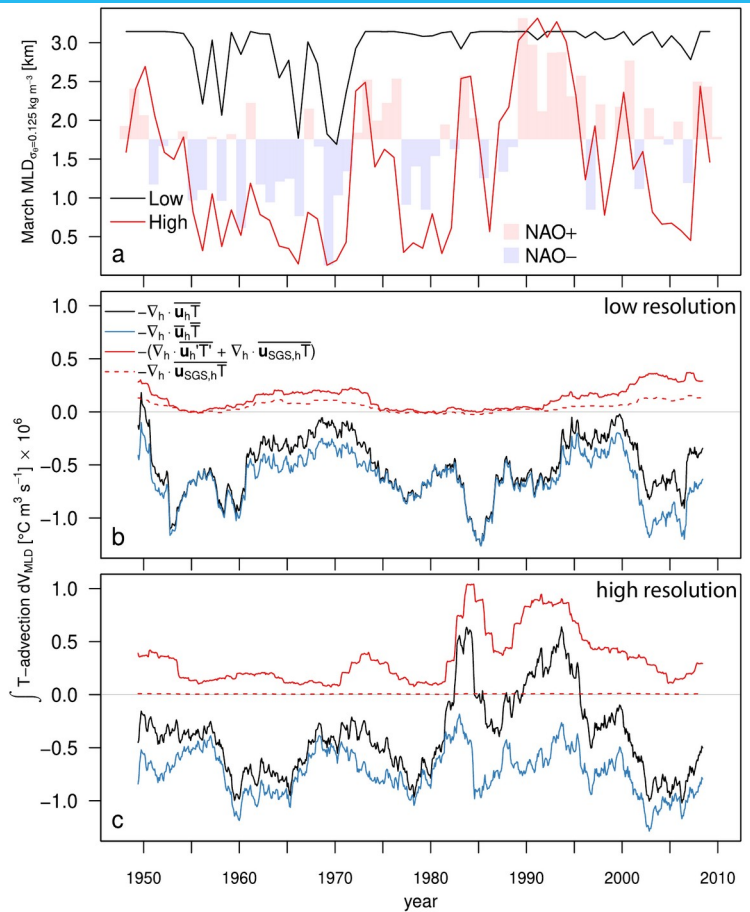
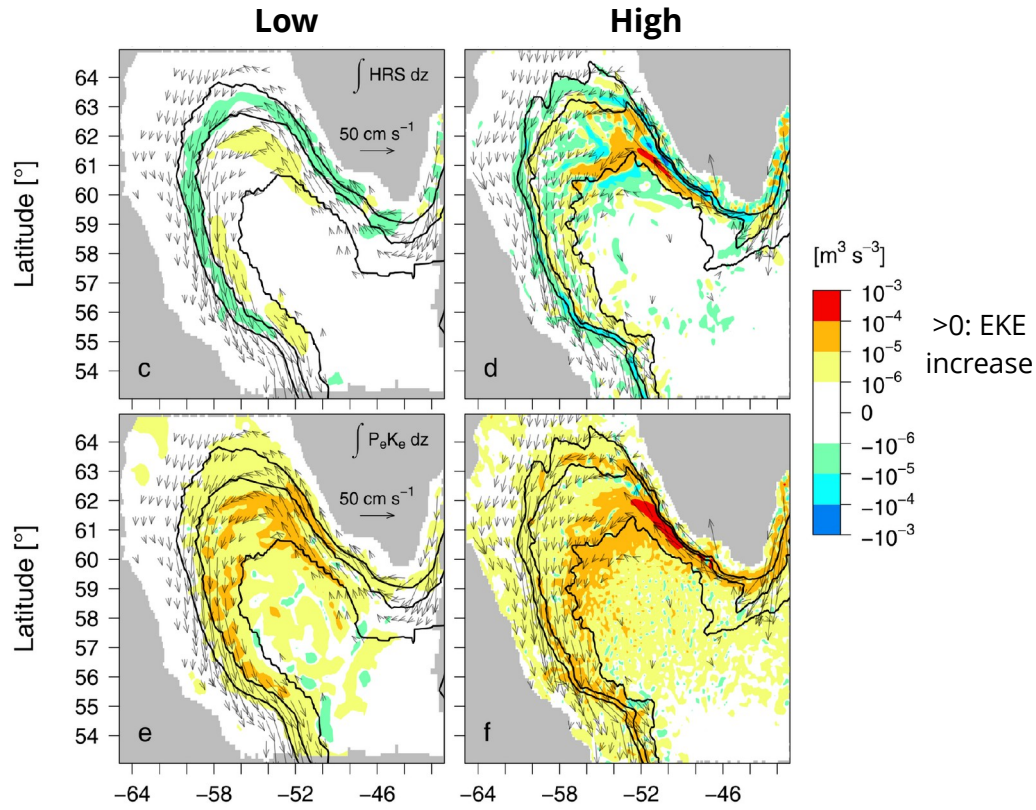


Lorenz Energy Cycle (Section 12.2 in Olbers et al. 2012):

barotropic instability
HRS

baroclinic instability
$\overline{w'b'}$



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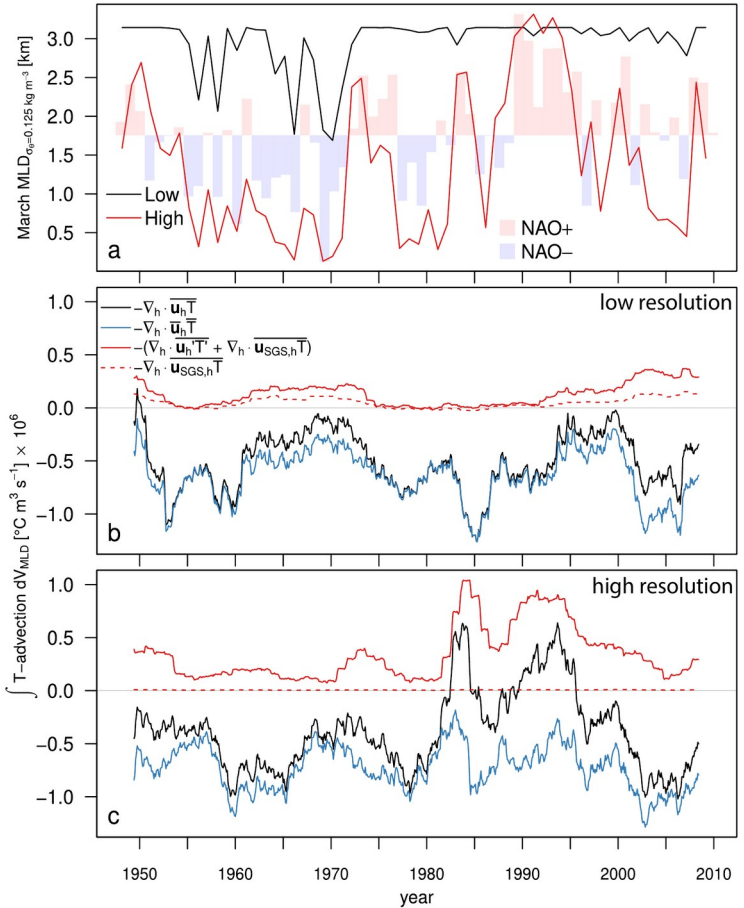
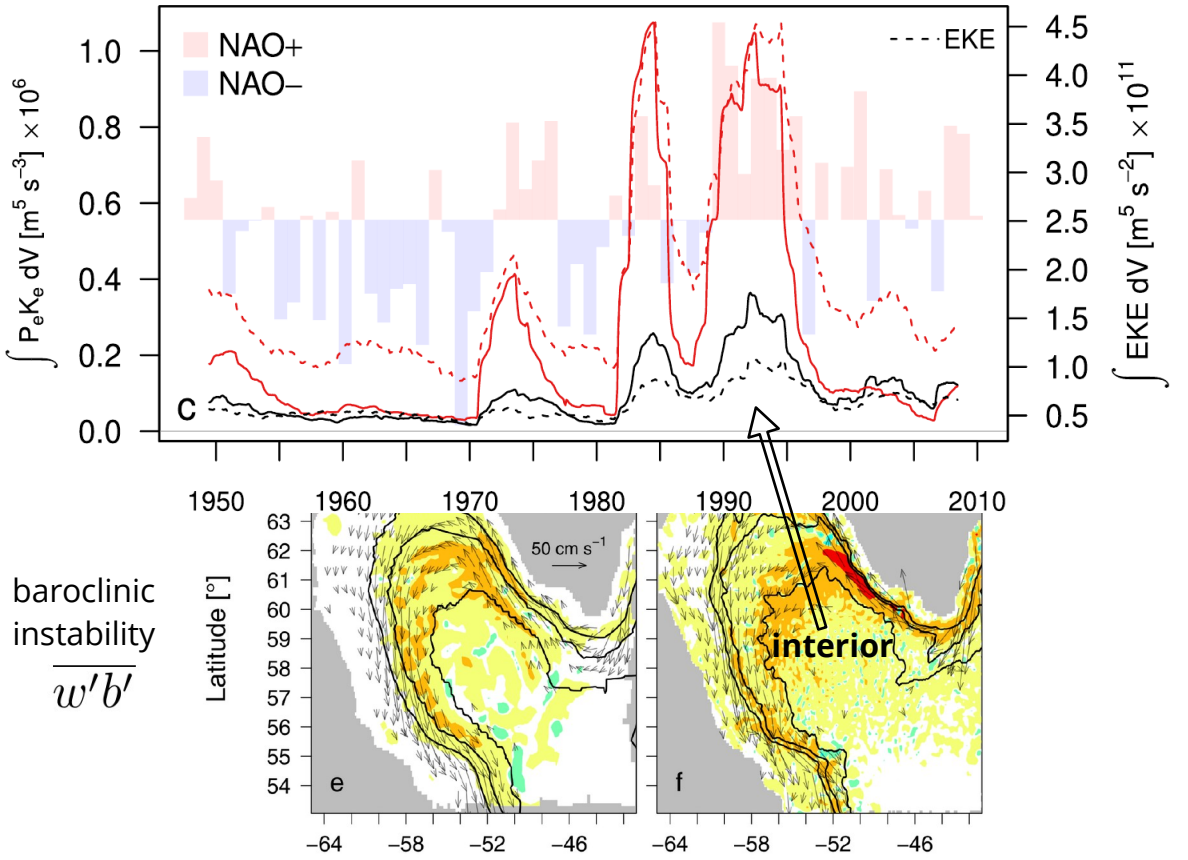


Lorenz Energy Cycle (Section 12.2 in Olbers et al. 2012):



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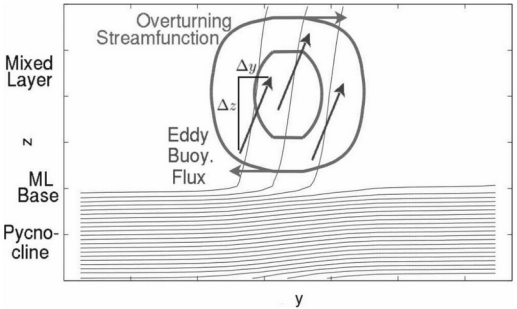
p5

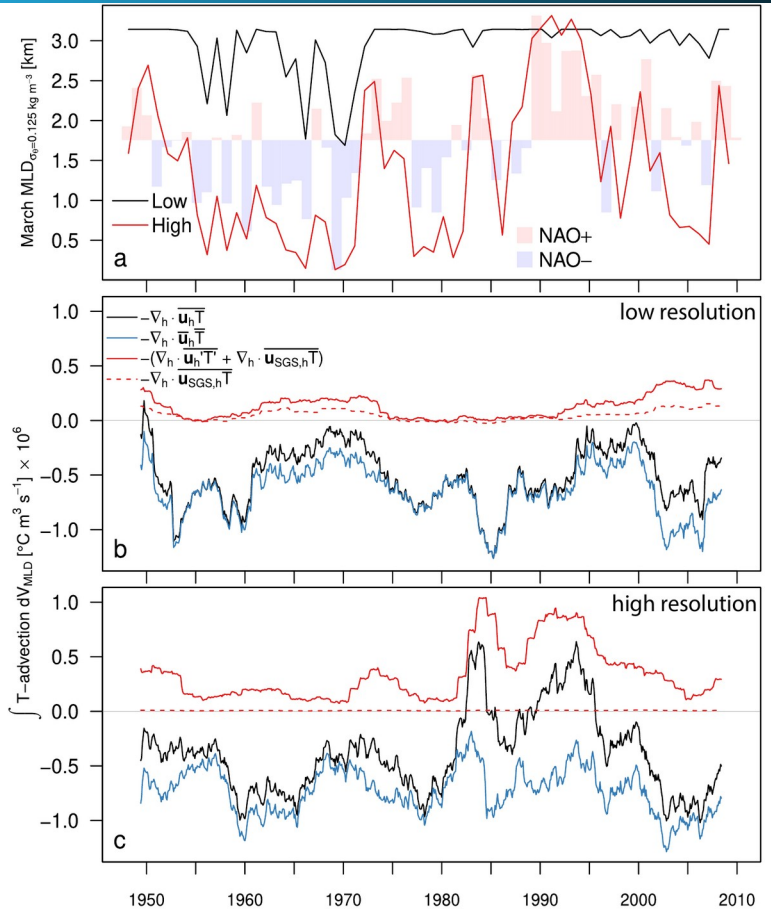
Summary

1) @5km: eddy temperature fluxes restratify deep MLD
   @20km: state-of-the-art SGS parameterization too weak
2) baroclinic instability $\overline{w'b'}$ main source of turbulence;
   upward eddy buoyancy flux flattens isopycnals:



Fox-Kemper et al. 2008

   → large decadal variability related to forcing not shown earlier
3) temporal "eddy" definition not clear in literature, e.g.:
   - $\overline{\text{2day}}$ minus $\overline{\text{10year}}$ includes seasonal & interannual signals
   - $\overline{\mathbf{u}'T'} = \overline{\mathbf{u}T} - \overline{\mathbf{u}}\,\overline{T}$ includes signals from dt_{model} to 1 month
   - see additional slides or Danek et al. 2023 (Ocean Modelling)



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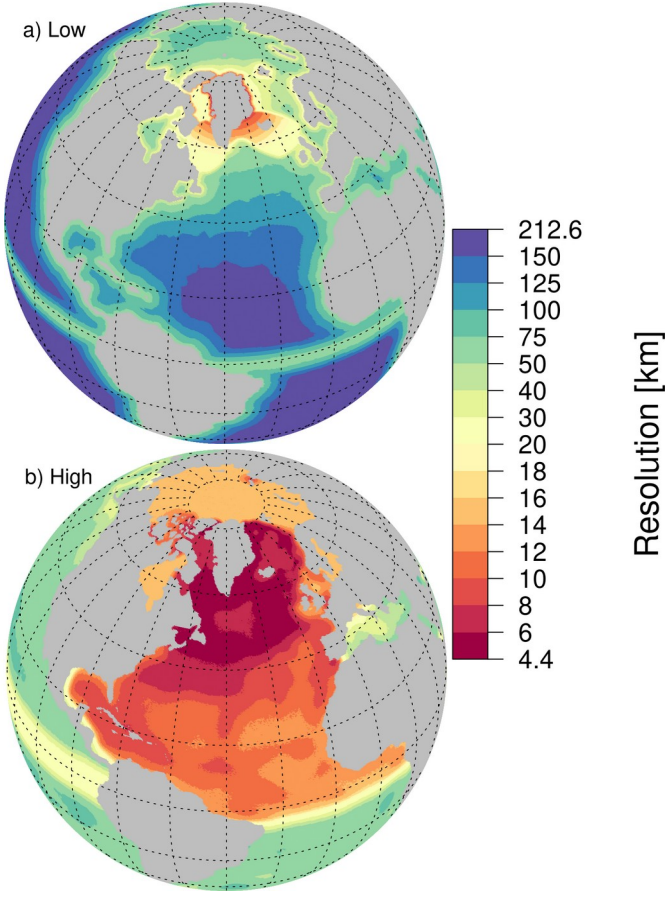
Model setup

- Hindcast simulations with ocean-sea ice model FESOM1.4 (Danilov et al. 2004, Wang et al. 2014)
- Two meshes to investigate eddy effects:
  1) Low res: ~53e3 surface nodes, 39 vertical levels → ~20 km in Labrador Sea and ~100 km in NA
  2) High res: ~800e3 61 → ~5 km ~10 km
- Resolution refinement:
  1) coastline/equator: Kelvin waves, upwelling
  2) North Atlantic + subpolar gyre: deep water formation
  3) High res scaled by observed
     a) SSH variability (satellite)
     b) temperature gradients @200m (WOA13)
     c) steep slopes (ETOPO1)
- 5 cycles of 62-year forcing CORE-II from 1948-2009 (Large and Yeager 2009) → 310 model years
- Further info: Scholz et al. 2013, 2014; Danek et al. 2019, 2023

Eddy definition

1) spatial: High res mesh
2) temporal: Reynolds averaging: $\overline{\mathbf{u}'T'} = \overline{\mathbf{u}T} - \overline{\mathbf{u}}\,\overline{T}$
   following von Storch et al. 2012
   → eddy = from model time step (30, 10 min) to month



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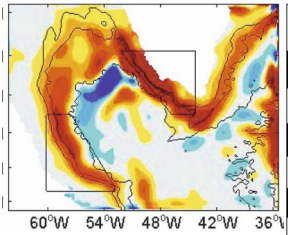
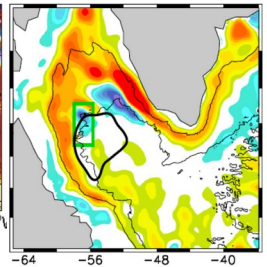
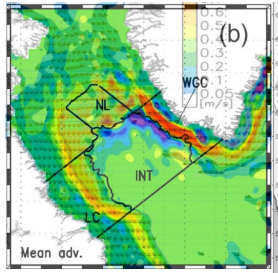
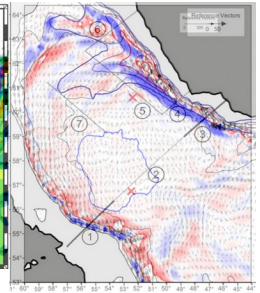
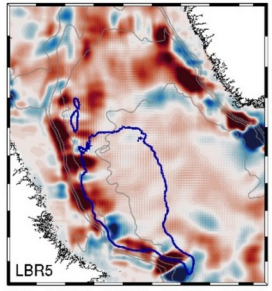
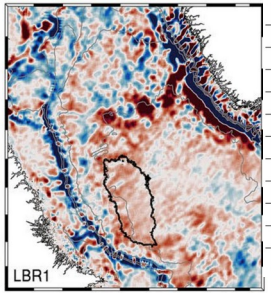
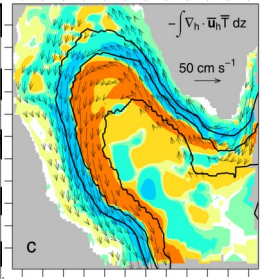
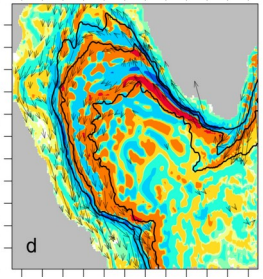
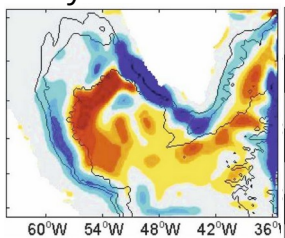
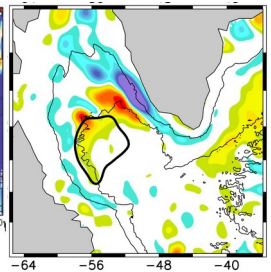
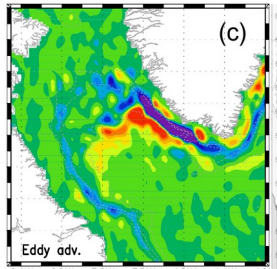
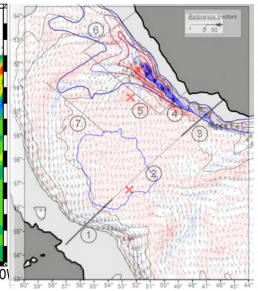
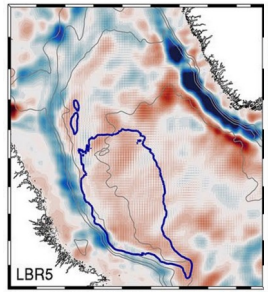
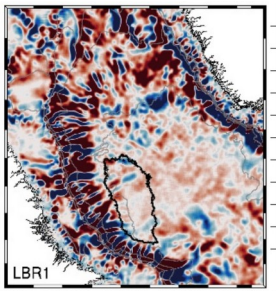
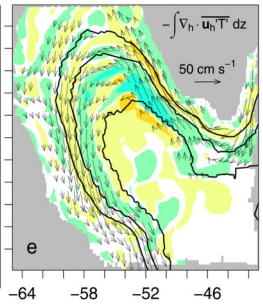
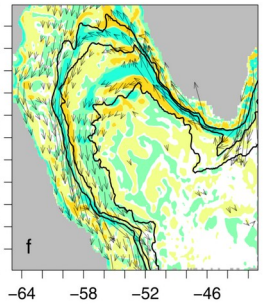
	Chanut et al. 2008	Saenko et al. 2014	Kawasaki & Hasumi 2014	de Jong et al. 2016	Tagklis et al. 2020 (includes vertical adv)		this study	
					5km	1km	20 km	5 km
mean								
eddy								
eddy:	2d-5a (snapshot)	2d-5a	dt-1mo	?-14a	?-7a		dt-1mo	
forcing:	annual	3hr	daily climatology 1979 to 1993	monthly anomalies	daily		6hr	

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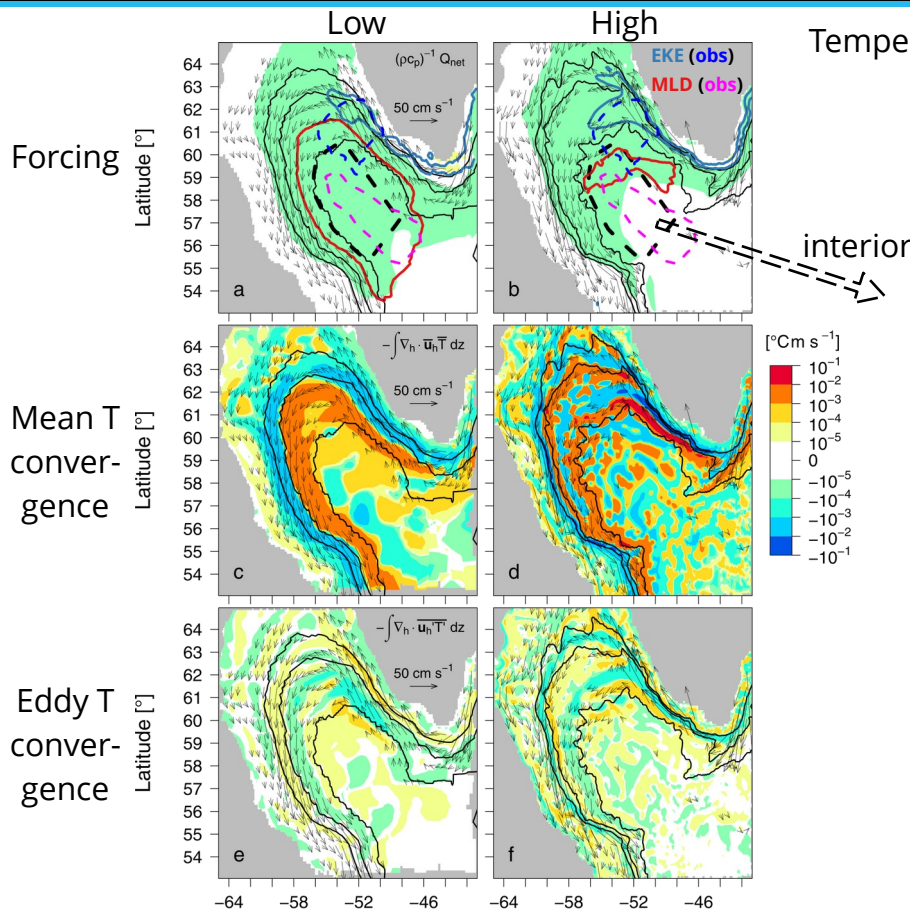
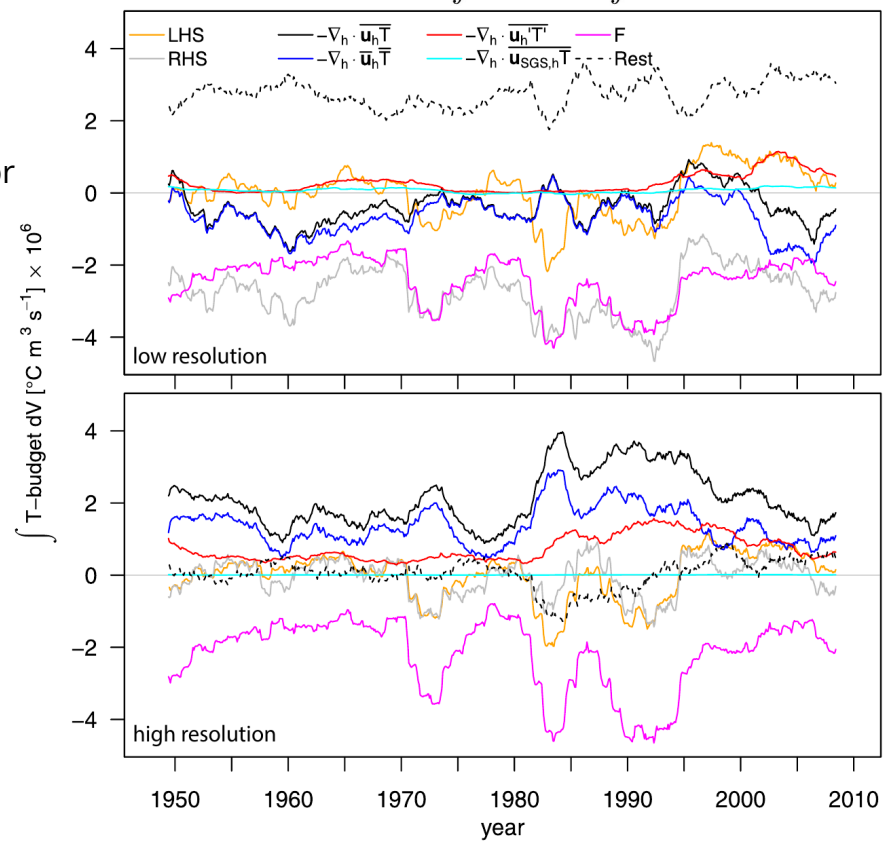
Temperature budget in flux form: $\partial_t \int T\,\mathrm{d}z = -\int \nabla\cdot(\mathbf{u}+\mathbf{u}_{\mathrm{SGS}})T\,\mathrm{d}z + F + \mathrm{Rest}$





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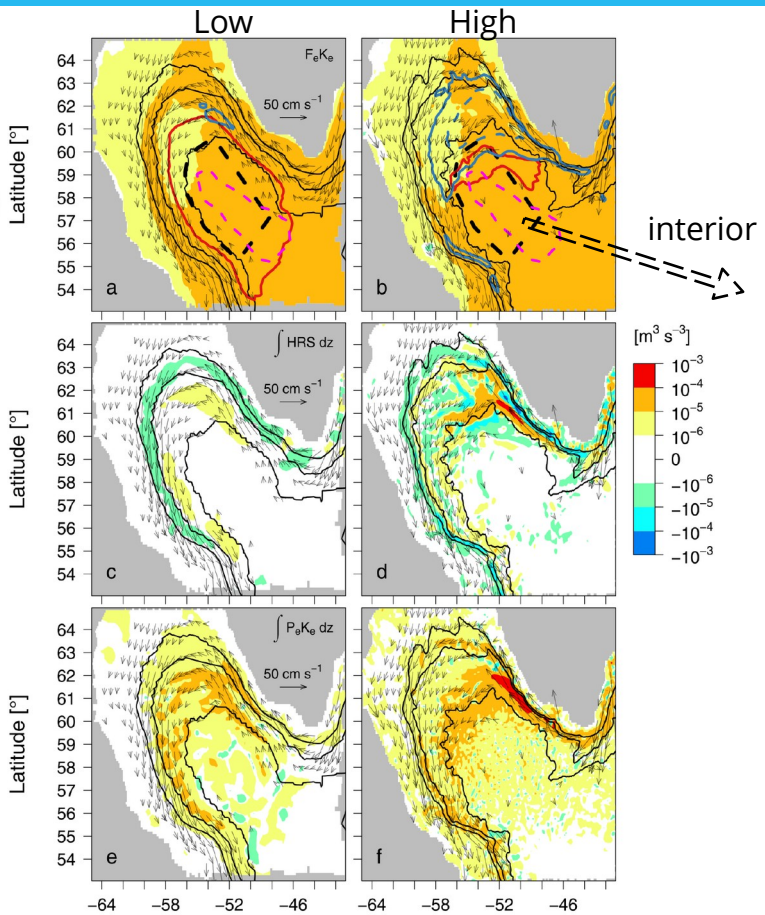
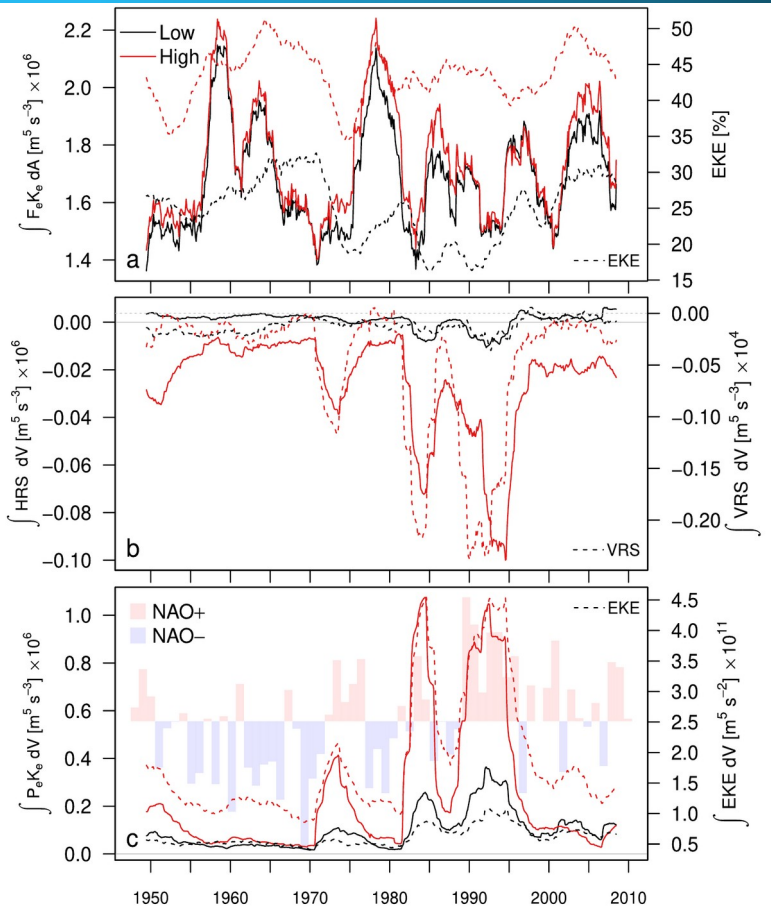
Forcing
$\rho_0^{-1}(\overline{\mathbf{u}_h' \cdot \boldsymbol{\tau}'})$

barotopic instability
HRS

baroclinic instability
$\overline{w'b'}$





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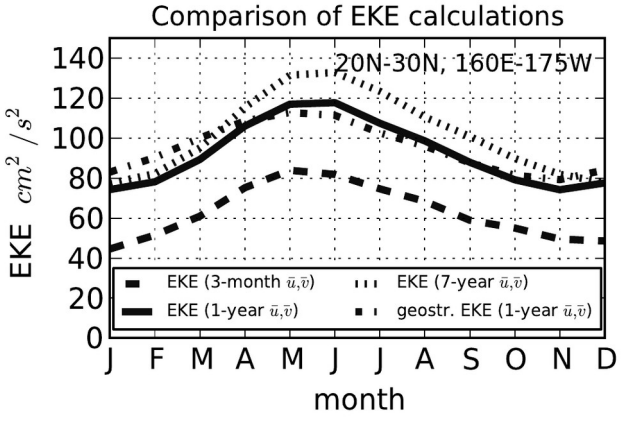
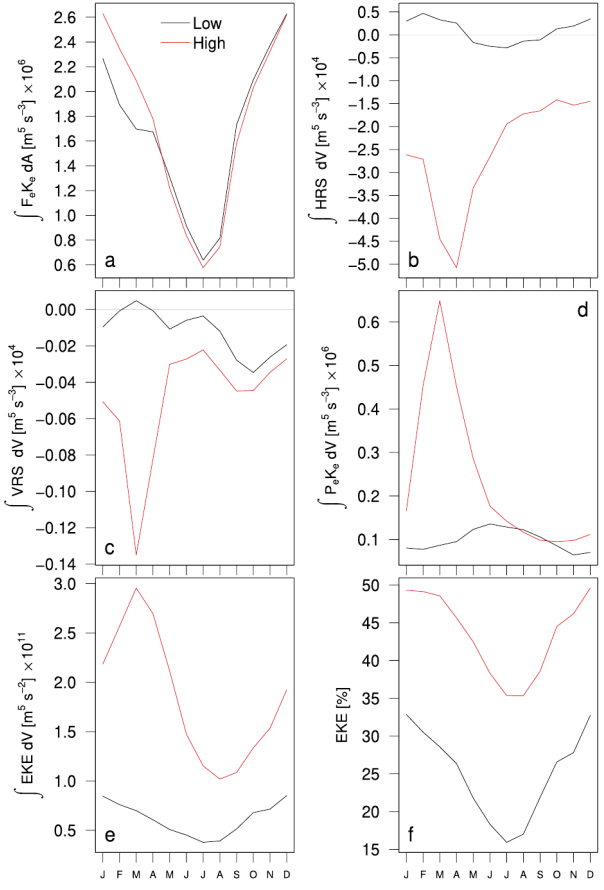
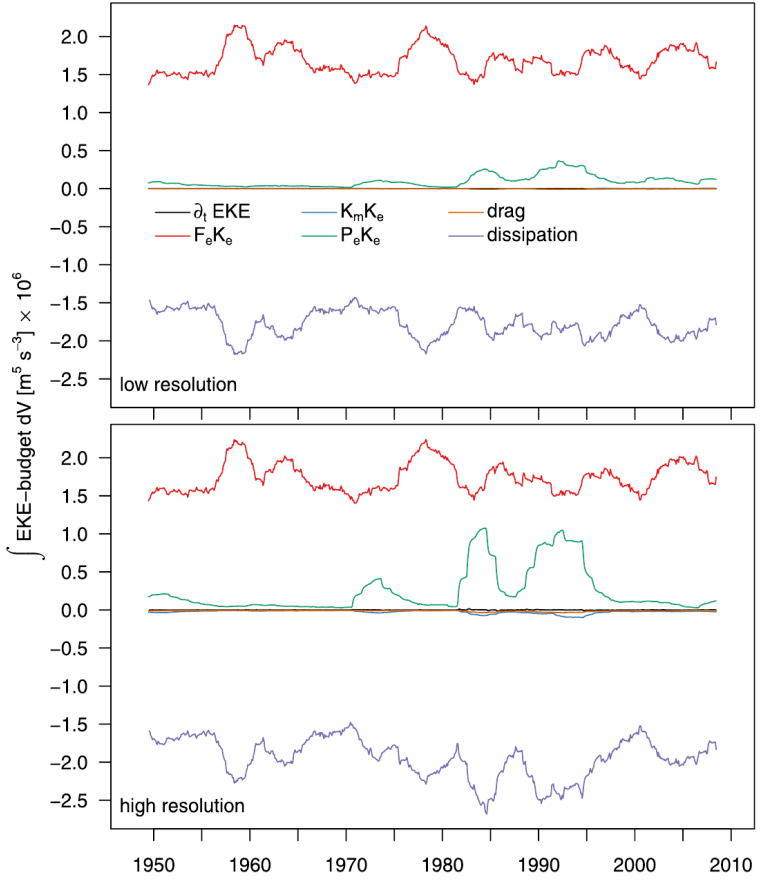


Rieck et al. 2015





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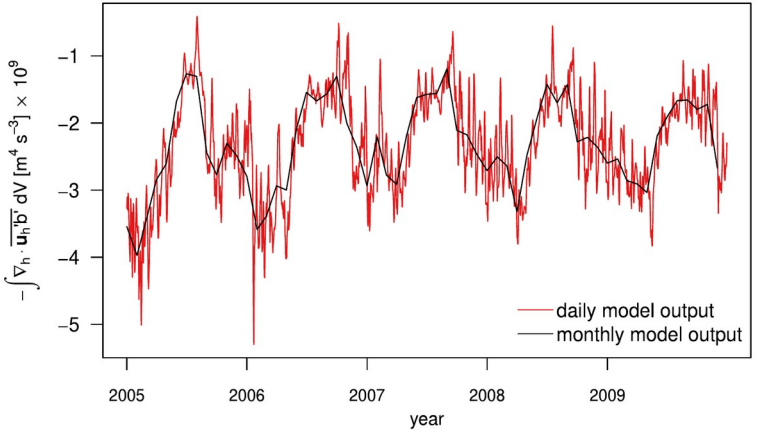

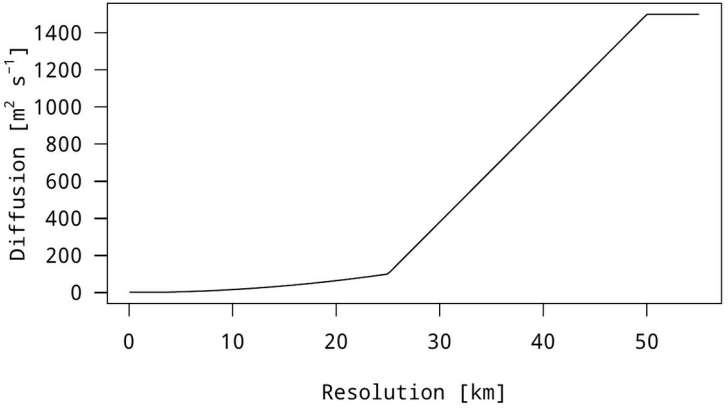

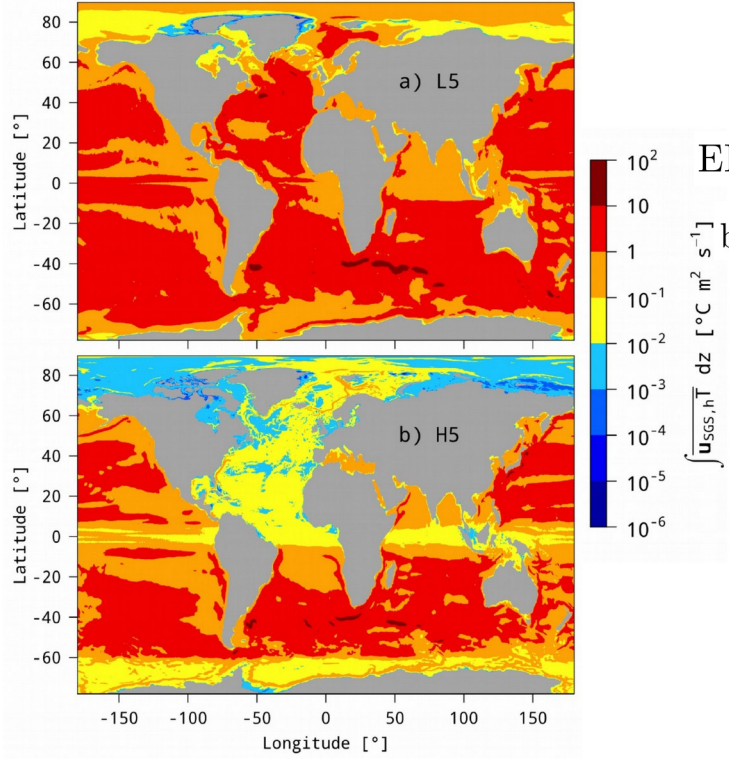

$$-\nabla_h \cdot \overline{(\mathbf{u}_h + \mathbf{u}_{SGS,h})T} = -\nabla_h \cdot (\overline{\mathbf{u}}_h \overline{T} + \overline{\mathbf{u}'_h T'} + \overline{\mathbf{u}_{SGS,h} T})$$

$$F = (\rho\, c_p)^{-1} Q_{net}$$

$$\mathrm{EKE} = \mathbf{u}'^{\,2}_h / 2$$

$$\text{EKE dissipation} = -A_v \overline{|\partial_z \mathbf{u}'_h|^2}$$

$$\text{bottom drag} = -C_d \overline{|\mathbf{u}'_h|}\, \overline{\mathbf{u}'_h \cdot \mathbf{u}'_h}$$