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The effects of representing unresolved ocean variability using an energy backscatter approach on climate-relevant oceanic metrics

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Background, Motivation, and Goal

- Global-scale coarse-resolution ocean models have systematically weak kinetic energy (KE) when compared to eddy-resolving simulations.
- Relatively large eddy viscosity in coarse-resolution models is needed to maintain numerical stability. This leads to 1) too much dissipation of KE, and 2) stabilization of the resolved baroclinic modes.
- Commonly used mesoscale parameterizations (e.g., Gent and McWilliams, 1990; hereafter GM) reduce the available potential energy, but this energy subsequently disappears from the model instead of being converted into KE.
- New parameterizations have been developed recently with the goal of re-injecting the missing KE into the system via a backscatter approach (Jansen et al., 2014; Bachman, 2019;).
- **Our goal** is to evaluate how the parameterization proposed by Bachman (2019), referred to as GM+E, affects climate-relevant oceanic metrics in coupled ocean/sea-ice simulations.

The GM+E parameterization

In a nutshell, this scheme exploits the energy transfer implied by GM to inform the backscatter approach. Full details in Bachman (2019).

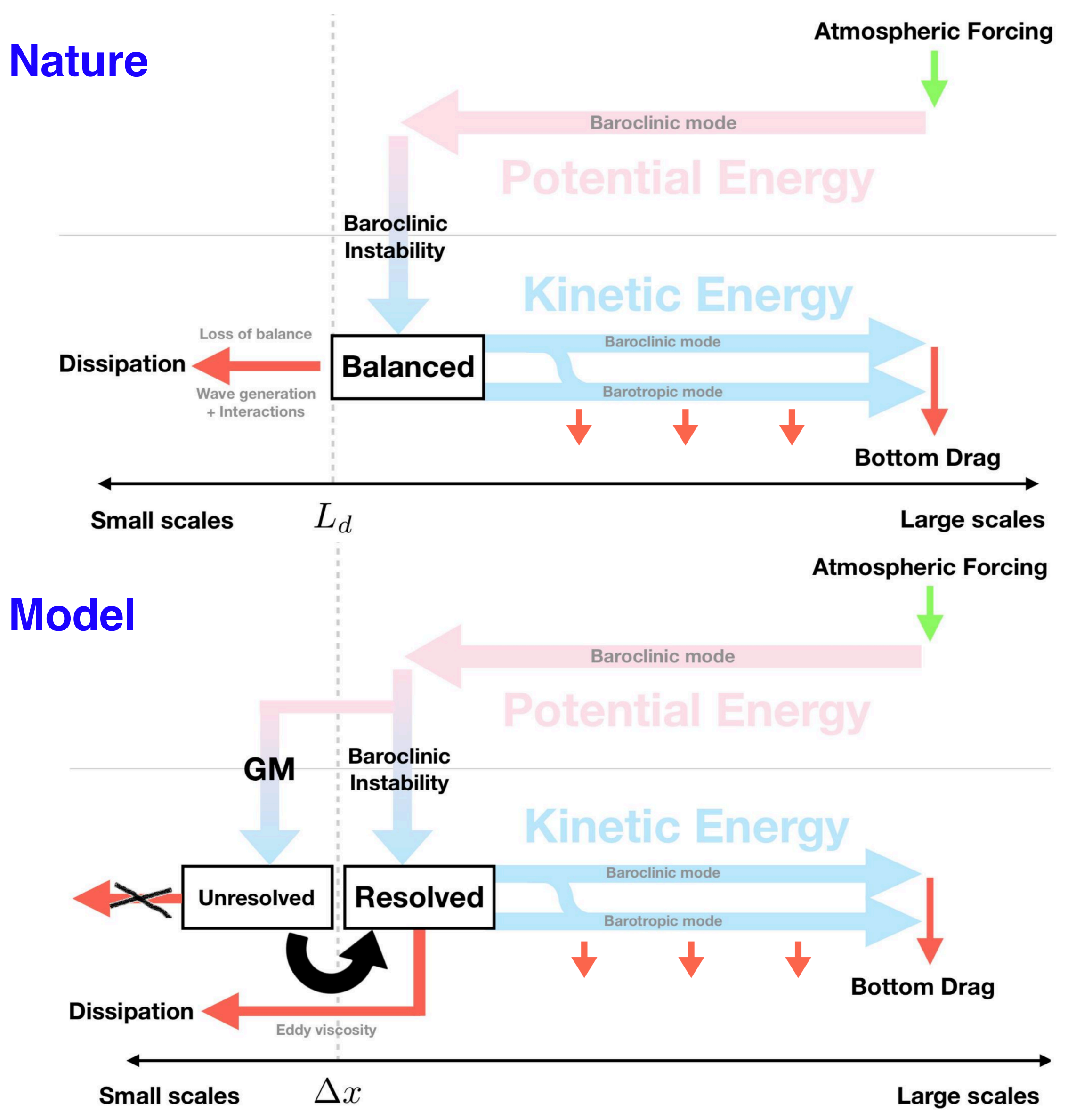

Fig. 1: Schematic of the energy cycle in nature, following theoretical studies, and in a coarse-resolution ocean general circulation model. From Bachman (2019).

Vector invariant momentum equations

energy re-injection

$$\frac{\partial \vec{u}}{\partial t} + (f + \nabla \times \vec{u}) \times \vec{u} = -\nabla B + b\vec{k} + \nabla \cdot \nu \nabla \vec{u} + \underline{\nabla \cdot \kappa_Q \nabla \vec{U}} \quad (1)$$

Original κ_Q (Bachman, 2019)

$$\kappa_Q = -\kappa_{GM} \frac{|\nabla_h b|^2}{N^2\left[(\partial_x \overline{U})^2 + (\partial_x \overline{V})^2 + (\partial_y \overline{U})^2 + (\partial_y \overline{V})^2\right]} \quad (2)$$

Simplified κ_Q , used in this study

$$\kappa_Q = -\kappa_{GM} \times C \quad (3)$$

Global ocean/sea ice experiments

Community Earth System Model (CESM)

- MOM6/CICE5
- Nominal 2/3° grid spacing, equatorial refinement
- Z* vertical coordinate, 63 layers
- K_{GM} = 800 $m^2 s^{-1}$
- Forcing, JRA-55 (58 years)

Table1: Summary of the numerical experiments conducted in this study.

Experiment	Description
Control	without backscatter
C1	with backscatter C=1 in eq(3)
C5	with backscatter C=5 in eq(3)
C10	with backscatter C=10 in eq(3)

Mean near-surface currents (m s^{-1})

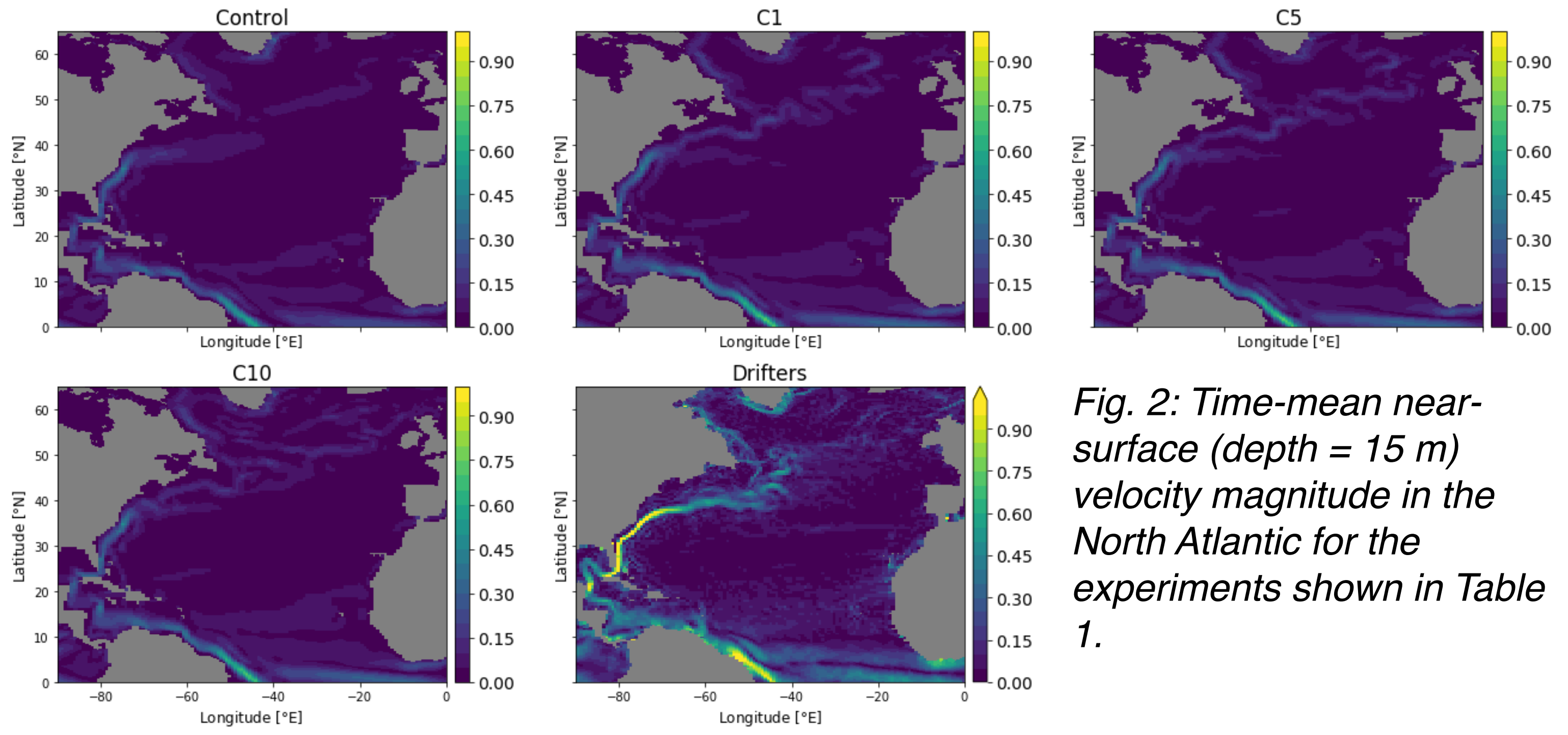

Fig. 2: Time-mean near-surface (depth = 15 m) velocity magnitude in the North Atlantic for the experiments shown in Table 1.

Also shown is the near-surface velocity magnitude drifter climatology from Laurindo et al., 2017.

Change in kinetic energy

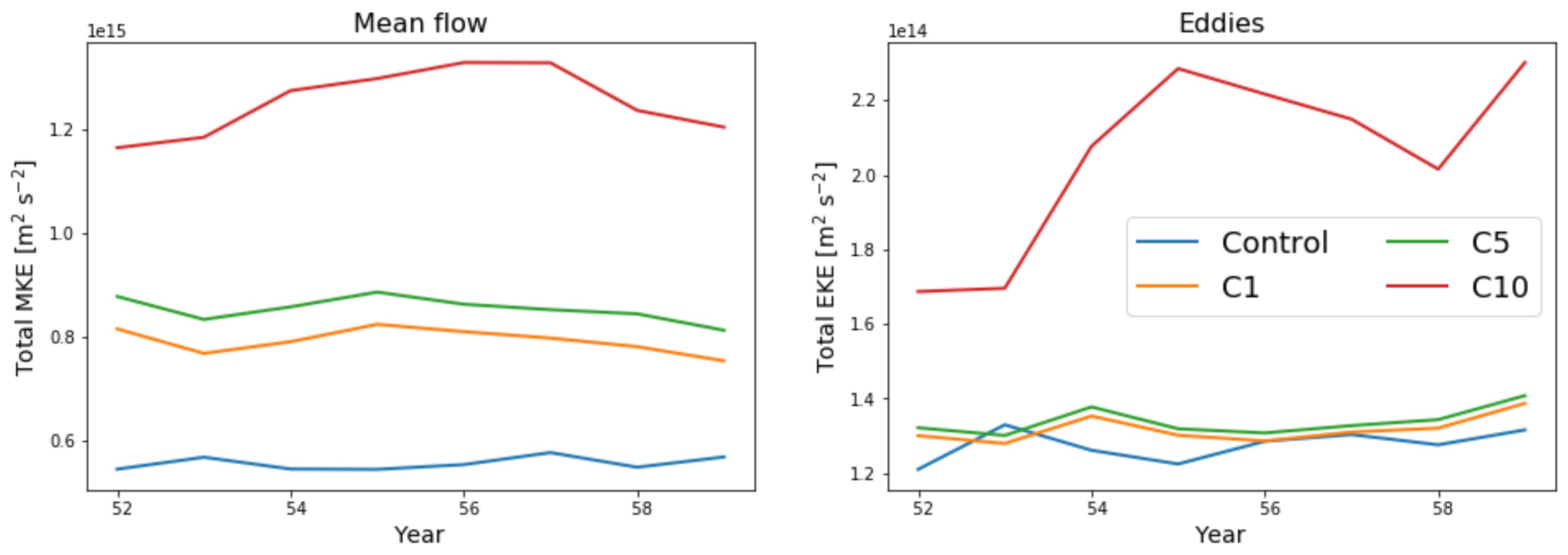

Fig. 3: Mean kinetic energy (MKE, $m^2 s^{-2}$) and eddy kinetic energy (EKE, $m^2 s^{-2}$) integrated over the entire domain as a function of time (last 8 years of simulations) and for experiments shown in Table 1. The mean is defined as a temporal average over one month.

Acknowledgements

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Mixed layer depth (m)

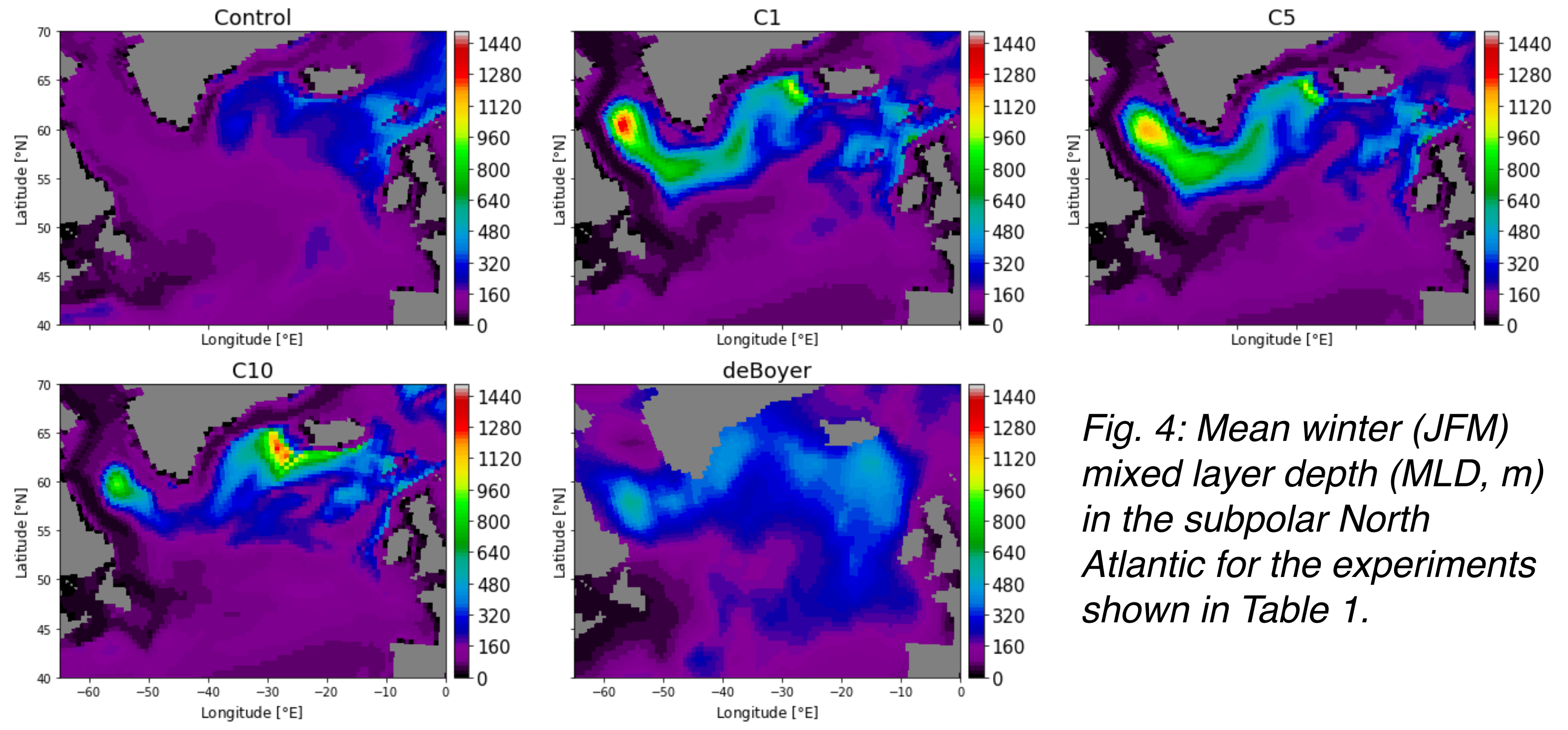

Fig. 4: Mean winter (JFM) mixed layer depth (MLD, m) in the subpolar North Atlantic for the experiments shown in Table 1.

Also shown is the winter MLD from the Boyer Montégut et al. (2004) climatology.

Drake passage transport and AMOC

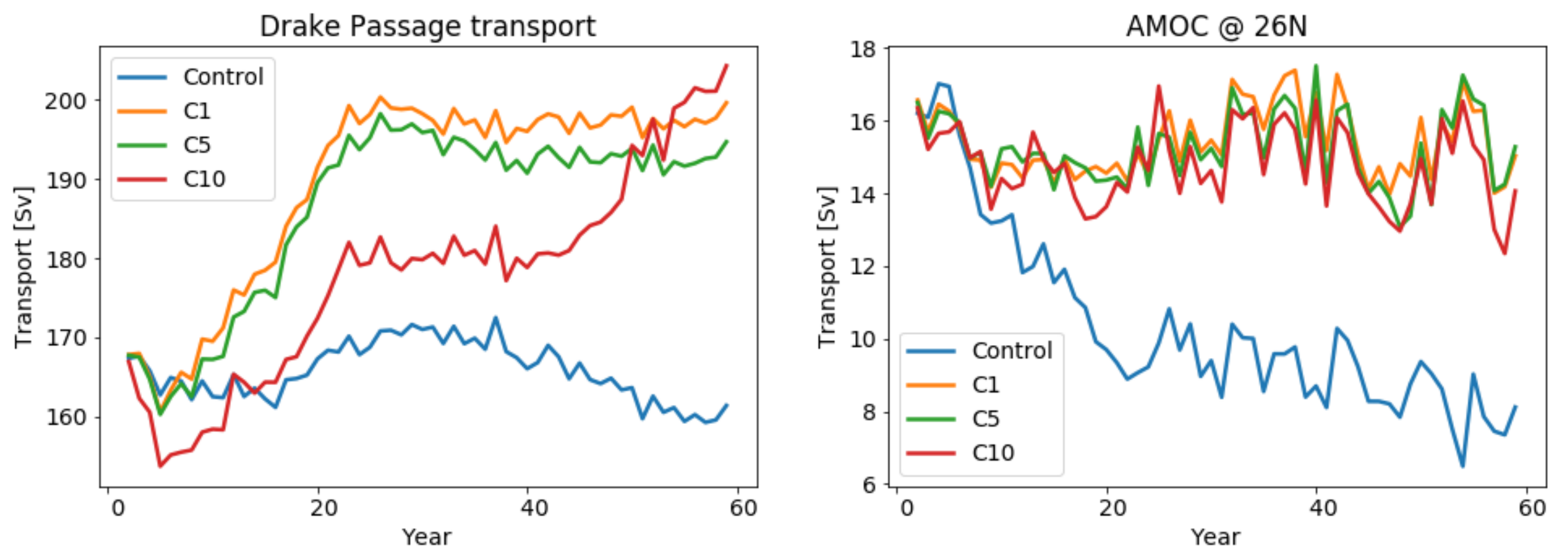

Fig. 5: Time-series of (left) Drake passage transport (Sv) and (right) maximum Atlantic meridional overturning (AMOC, Sv) at 26°N for all experiment shown in Table 1.

Summary

- Successfully implemented GM+E in an ocean model used for climate projections (MOM6) and performed a set of global forced simulations with different levels of energy re-injection (see Table 1).
- GM+E has a significant effect in many climate-relevant oceanic metrics and can be a powerful "knob" when tuning climate models.
- Empirically, there seems to be a threshold level of energy injection where the flow develops "new" features such as standing meanders and zonal jets rather than merely amplifying the existing flow patterns from the control simulation. This has potentially negative effects which we are still exploring.
- **Still a lot to be learned!**

References

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