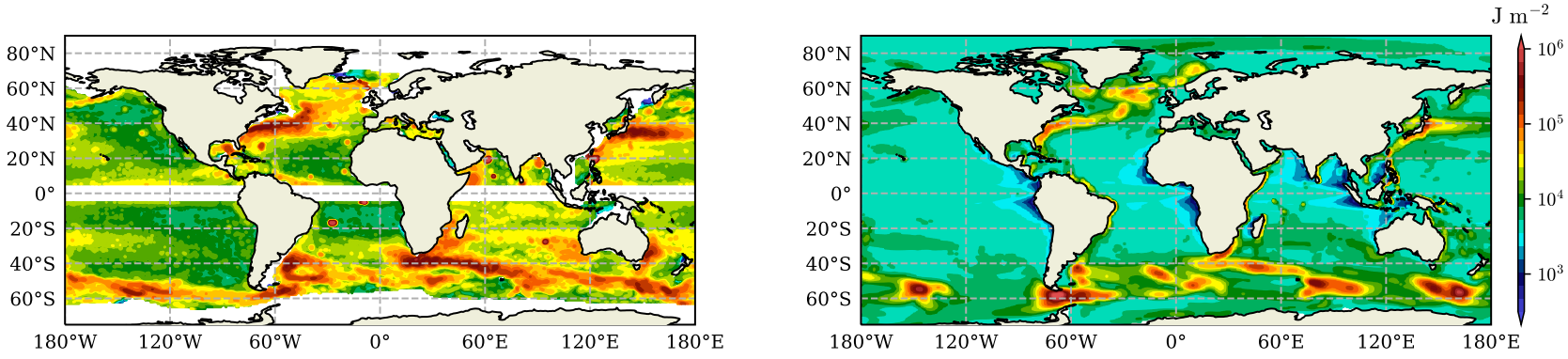
Implementation of the GEOMETRIC scheme in NEMO

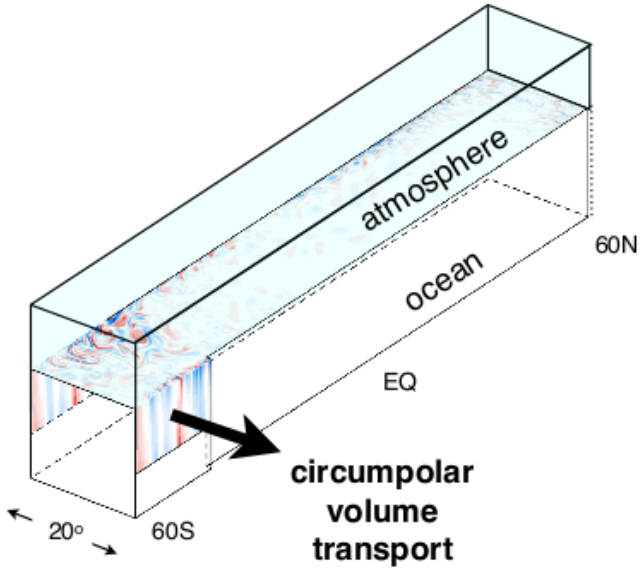


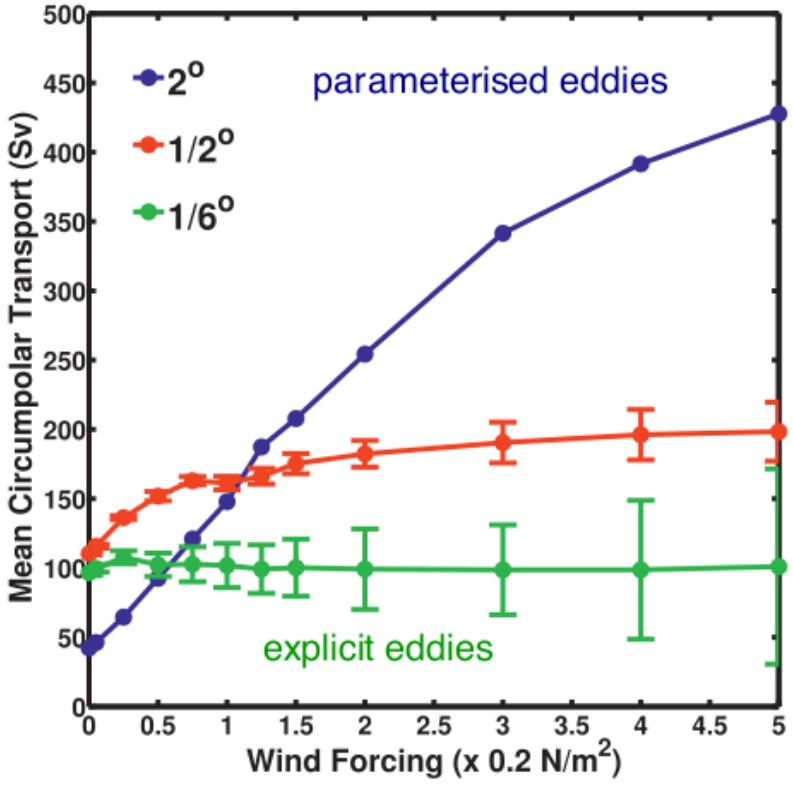
J. Mak, G. Madec, D. P. Marshall, J. R. Maddison & X. Zhai

NEMO users meeting, 12 Oct, 2018

Eddy saturation

Same ocean model at different resolutions:

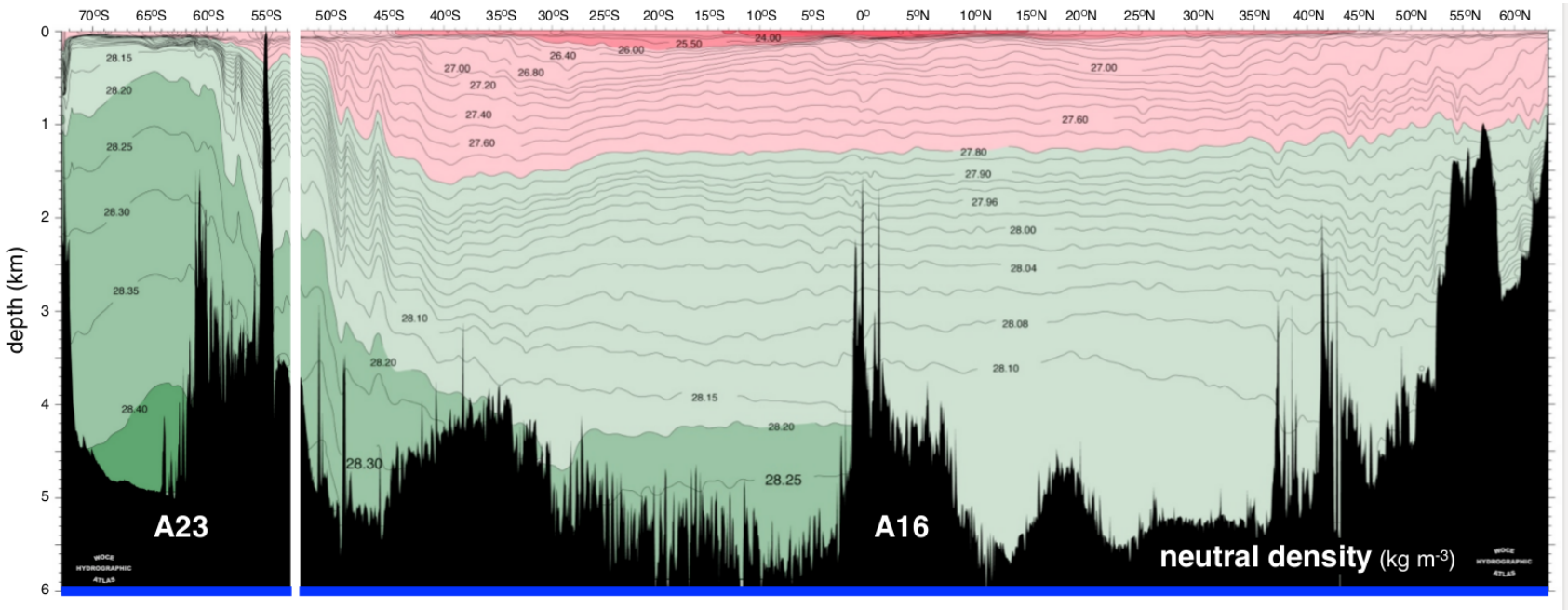




Munday, Johnson & Marshall (2013), *J. Phys. Oceanogr.*

Eddy saturation

Implications for global stratification and MOC?



Consequences for heat/carbon uptake

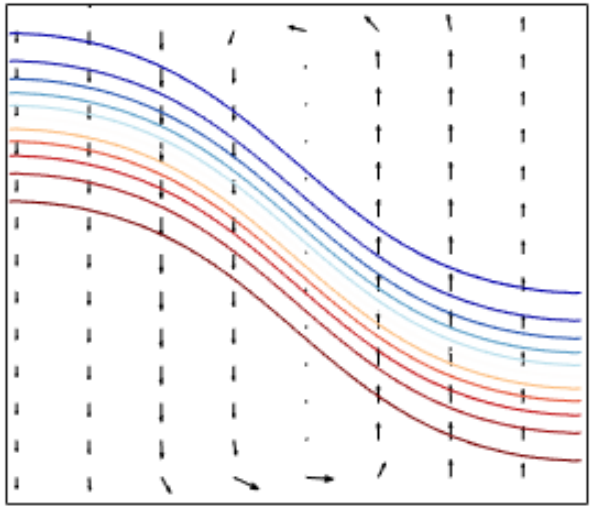
Koltermann *et al.* (2011), *WOCE*

Parameterisation

Gent–McWilliams (GM) scheme:

$$\overline{\boldsymbol{u}'b'} = -\kappa_{\mathrm{gm}} \nabla \bar{b}$$

- widely used in ocean GCMs, many good things about it
- $\kappa_{\mathrm{gm}} = \kappa_{\mathrm{gm}}(\ldots)$?



Eddy energy $E \leftrightarrow$ eddy activity, $\kappa_{\mathrm{gm}} = \kappa_{\mathrm{gm}}(f(E), \ldots)$?

(e.g., $\kappa_{\mathrm{gm}} \sim \sqrt{K}$)

Gent & McWilliams (1990), *J. Phys. Oceanogr.*

Eden & Greatbatch (2008), *Ocean Modell.*

GEOMETRIC framework

Mean equation may be written as

$$\frac{\partial \overline{\boldsymbol{u}}}{\partial t} + f(\overline{\boldsymbol{u}}) = \nabla \cdot \mathbf{T}, \qquad \mathbf{T} = \begin{pmatrix} -\mathsf{M} + \mathsf{P} & \mathsf{N} & 0 \\ \mathsf{N} & \mathsf{M} + \mathsf{P} & 0 \\ -\mathsf{S} & \mathsf{R} & 0 \end{pmatrix}$$

- rank 2 tensor $\mathbf{T}$ encodes all fluctuation quantities
- parametrise such that symmetries preserved

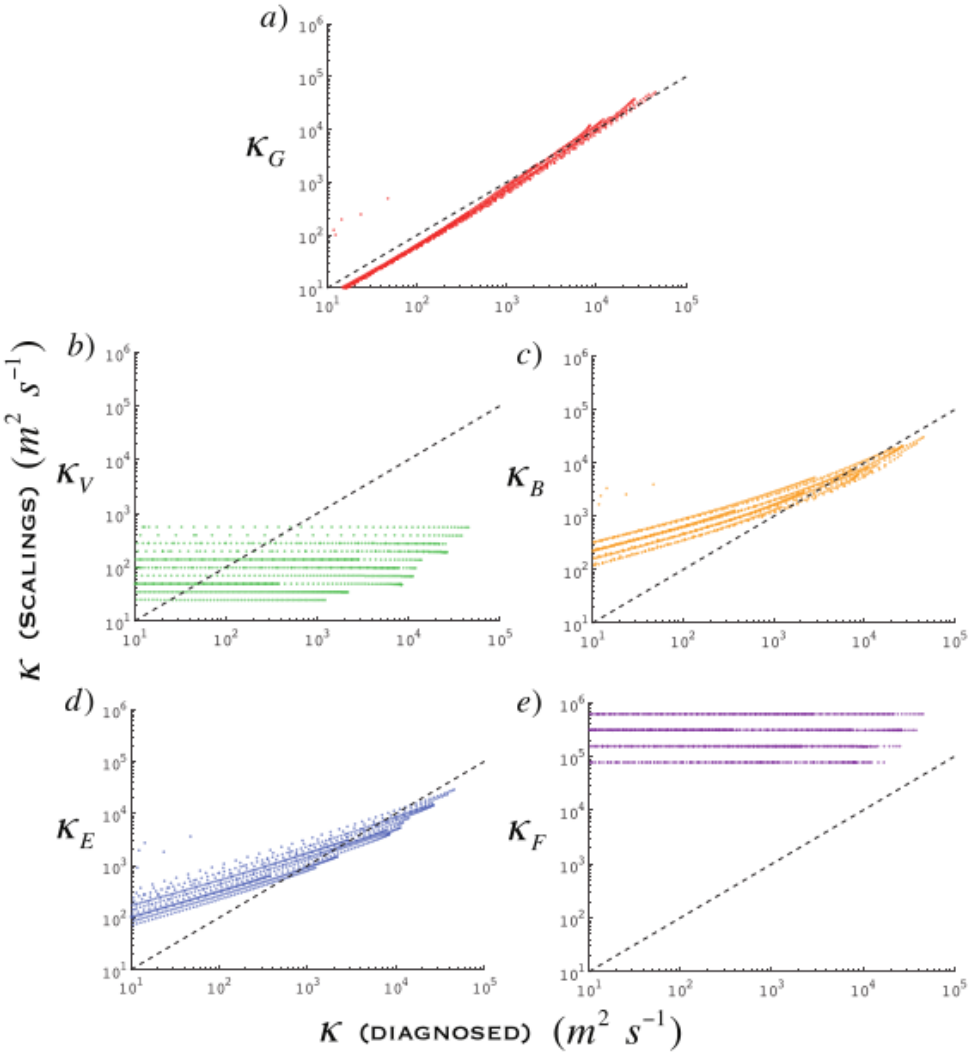
  $\rightarrow$ GM is one such (close for buoyancy fluxes R and S)
- $\|\mathbf{T}\|^2 \leq E$, tensor may be bounded in terms of eddy energy
- fluctuations in terms of geometric parameters implies

$$\kappa_{\mathrm{gm}} = \alpha E \frac{(\partial \bar{b}/\partial z)^{1/2}}{|\nabla \bar{b}|^2}, \qquad |\alpha| \leq 1$$

Marshall, Maddison & Berloff (2012) *J. Phys. Oceanogr.*

Maddison & Marshall (2013) *J. Fluid. Mech.*

GEOMETRIC: diagnoses



Bachman, Marshall, Maddison & Mak (2017) *Ocean Modell.*

GEOMETRIC scheme

$$\kappa_{\mathrm{gm}} = \alpha E \frac{N}{M^2}, \quad |\alpha| \leq 1$$

GEOMETRIC scaling needs information about:

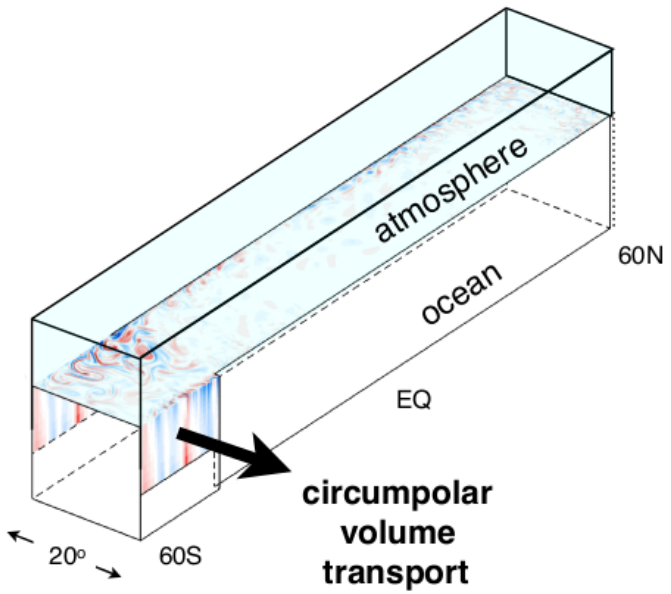
- $|\alpha| \leq 1$, non-dimensional eddy efficiency parameter

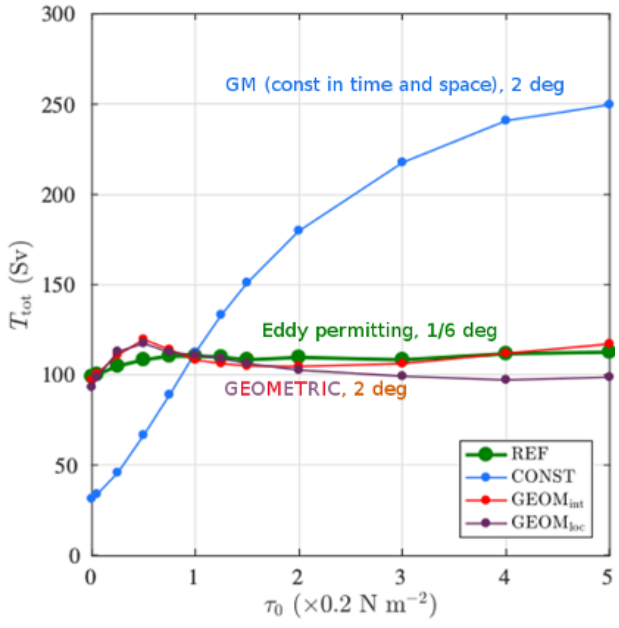
  $\rightarrow \alpha = 0.04$ here

- E, the **total** eddy energy

  $\rightarrow$ given by a prognostic eddy energy budget

GEOMETRIC scheme: 3d sector model





$$\kappa_{\rm gm} = \alpha \frac{\int E \, {\rm d}z}{\int \Gamma(z)(M^2/N) \, {\rm d}z} \Gamma(z)$$

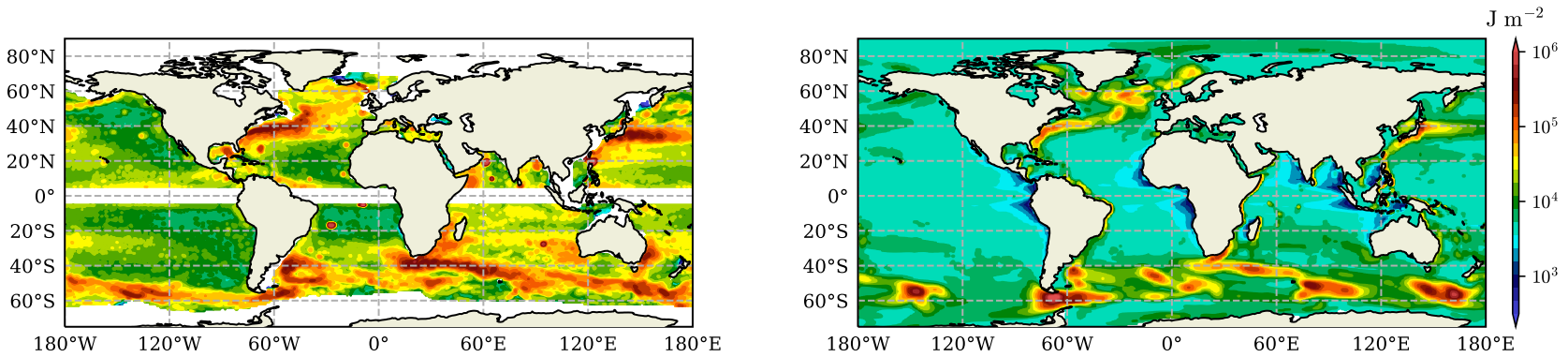
$$\frac{\partial}{\partial t} \int E \, {\rm d}z + \nabla_H \cdot \left((\widetilde{u}^z - 0 e_x) \int E \, {\rm d}z \right) = \int \kappa_{\rm gm} \frac{M^4}{N^2} \, {\rm d}z - \lambda \int E \, {\rm d}z + \kappa_E \nabla_H^2 \int E \, {\rm d}z,$$

Mak, Maddison, Marshall & Munday (2018), *J. Phys. Oceanogr.*

GEOMETRIC scheme: 3d global model

$$\kappa_{\mathrm{gm}} = \alpha \frac{\int E \, \mathrm{d}z}{\int \Gamma(z)(M^2/N) \, \mathrm{d}z} \Gamma(z)$$

$$\frac{\partial}{\partial t} \int E \, \mathrm{d}z + \nabla_H \cdot \left((\widetilde{u}^z - c e_x) \int E \, \mathrm{d}z \right) = \int \kappa_{\mathrm{gm}} \frac{M^4}{N^2} \, \mathrm{d}z - \lambda \int E \, \mathrm{d}z + \kappa_E \nabla_H^2 \int E \, \mathrm{d}z,$$



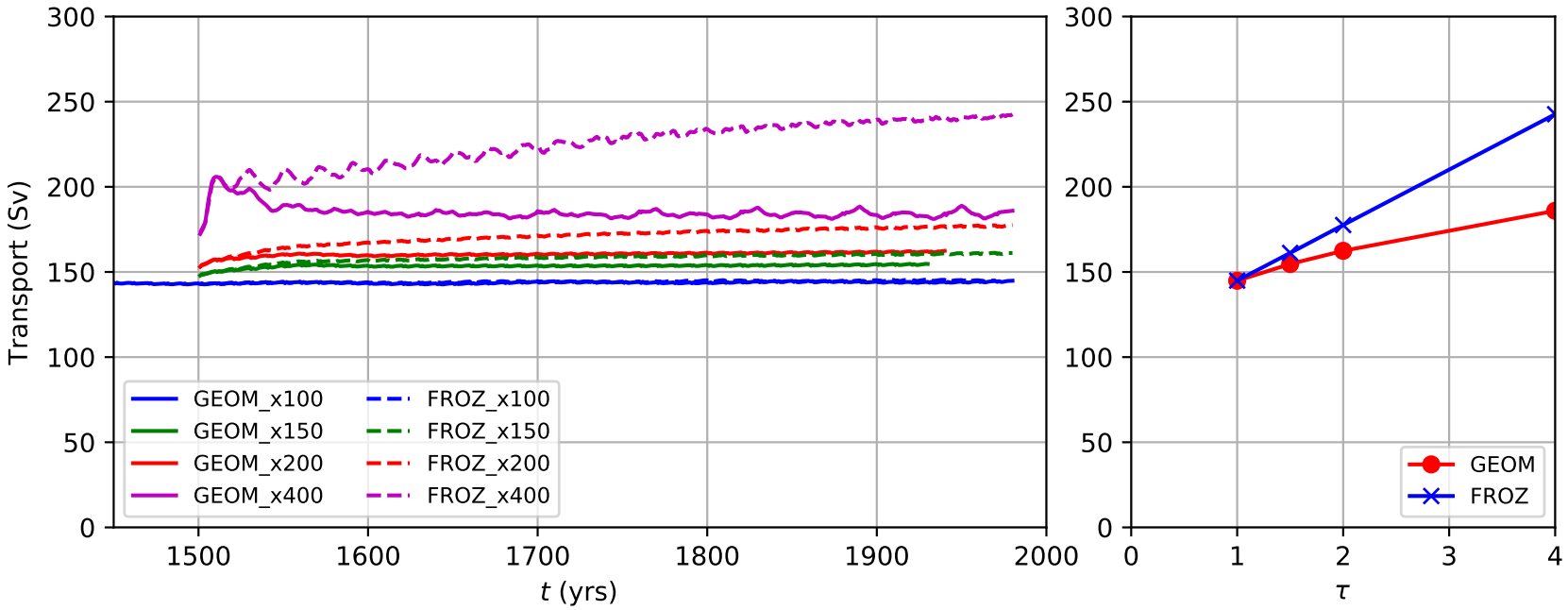
(NEMO v8666 [v4.0dev], eORCA1-L46 + LIM3 + GEOMETRIC with normal year forcing)

(With thanks to Jeff Polton, Andrew Coward and Simona Flavoni for NEMO code guidance)

- implemented in NEMO as extra option in `ldftra`

  → developed in NEMO v8666, extra file `ldfeke.F90`

GEOMETRIC scheme: 3d global model



Sample results from ORCA2 with normal year forcing

- NCAR bulk formulae
- GEOM = fully dynamic
- GM = κ_{gm} at end of spin up, frozen in time
- wind stress perturbation experiments

Story so far...

- GEOMETRIC appears to improve ocean sensitivities

  → eddy saturation, potential for eddy compensation

  → calculations with NEMO ORCA1 ongoing
- consequences for heat content / carbon uptake / others

- GEOMETRIC extra option in `ldftra`

  → extra file `ldfeke.F90` and some inputs for λ

  → updated and will compile and run in NEMO v9925

$$\frac{\partial}{\partial t}\int E\,\mathrm{d}z + \nabla_H \cdot \left((\widetilde{\boldsymbol{u}}^z - c\boldsymbol{e}_x) \int E\,\mathrm{d}z \right) = \int \kappa_{\mathrm{gm}} \frac{M^4}{N^2}\,\mathrm{d}z - \lambda \int E\,\mathrm{d}z + \kappa_E \nabla_H^2 \int E\,\mathrm{d}z,$$

Story so far...

GEOMETRIC supplements GM with an eddy energy budget:

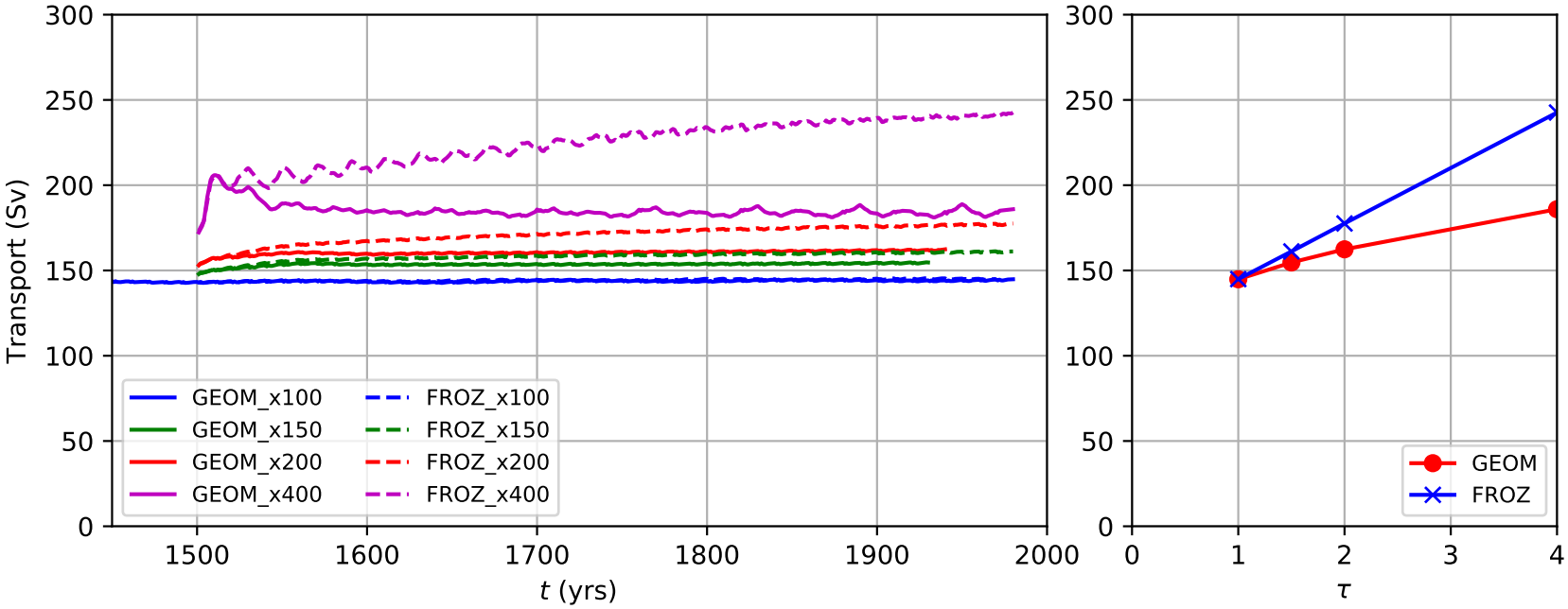
$$\kappa_{\mathrm{gm}} = \alpha \frac{\int E \, \mathrm{d}z}{\int \Gamma(z)(M^2/N) \, \mathrm{d}z} \Gamma(z)$$

$$\frac{\partial}{\partial t} \int E \, \mathrm{d}z + \nabla_H \cdot \left((\widetilde{\boldsymbol{u}}^z - c\boldsymbol{e}_x) \int E \, \mathrm{d}z \right) = \int \kappa_{\mathrm{gm}} \frac{M^4}{N^2} \, \mathrm{d}z - \lambda \int E \, \mathrm{d}z + \kappa_E \nabla_H^2 \int E \, \mathrm{d}z,$$

Ongoing + planned experiments:

- wind perturbation experiments (GEOM vs. GM, ongoing)
- CMIP style CO_2 experiments (UKESM, starting now)
- ...

Story so far...



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