Backscatter in CESM MOM6

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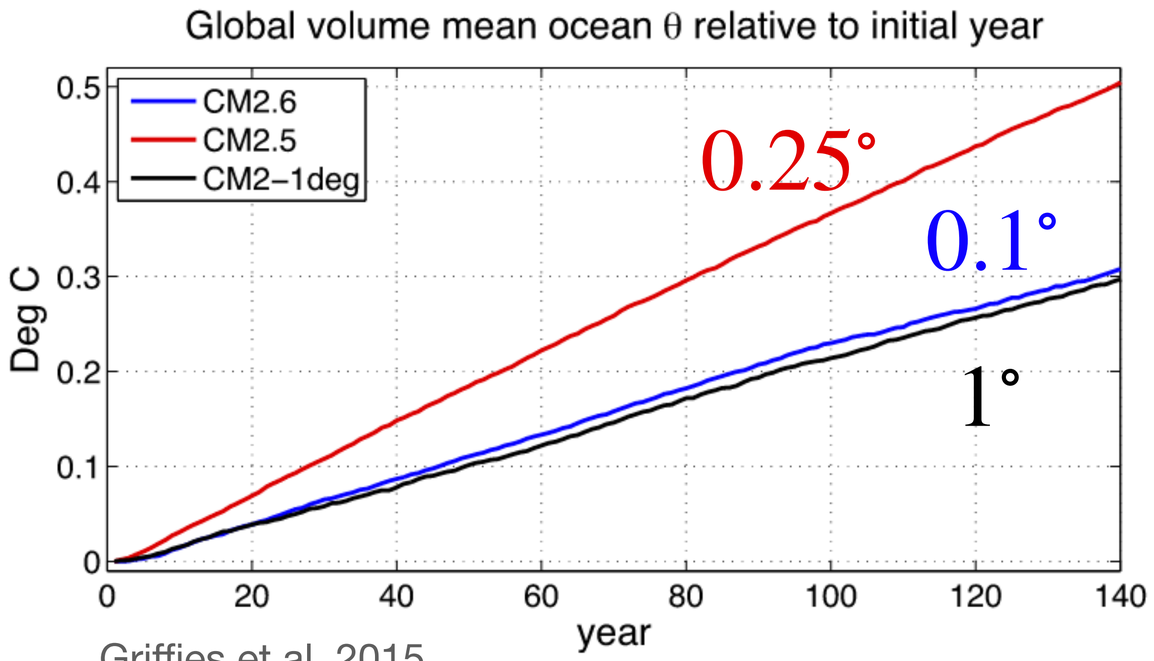
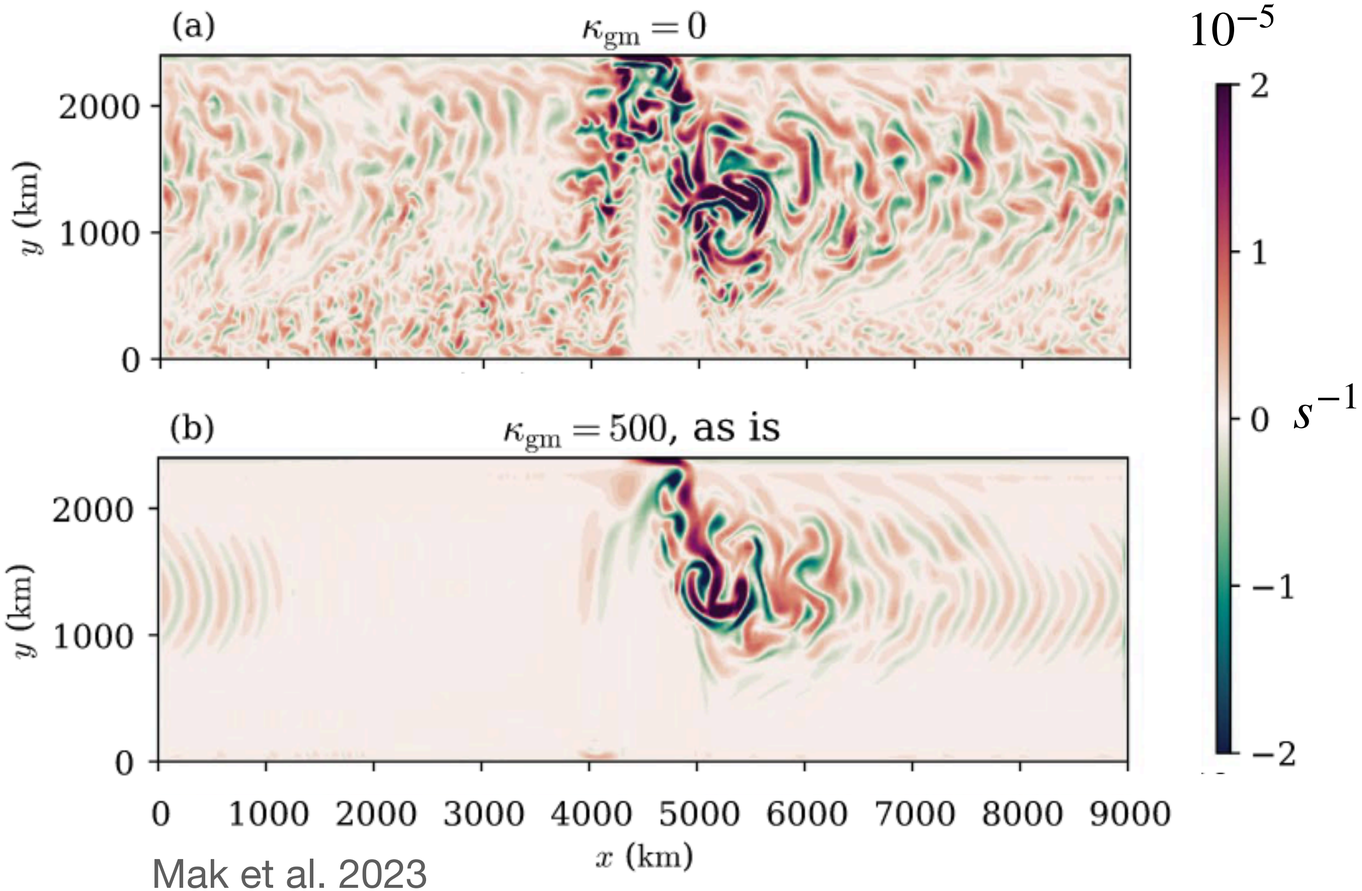
How can we parameterize eddies in $1/4°$ CESM MOM6?

Isopycnal height diffusion and eddies



Griffies et al. 2015

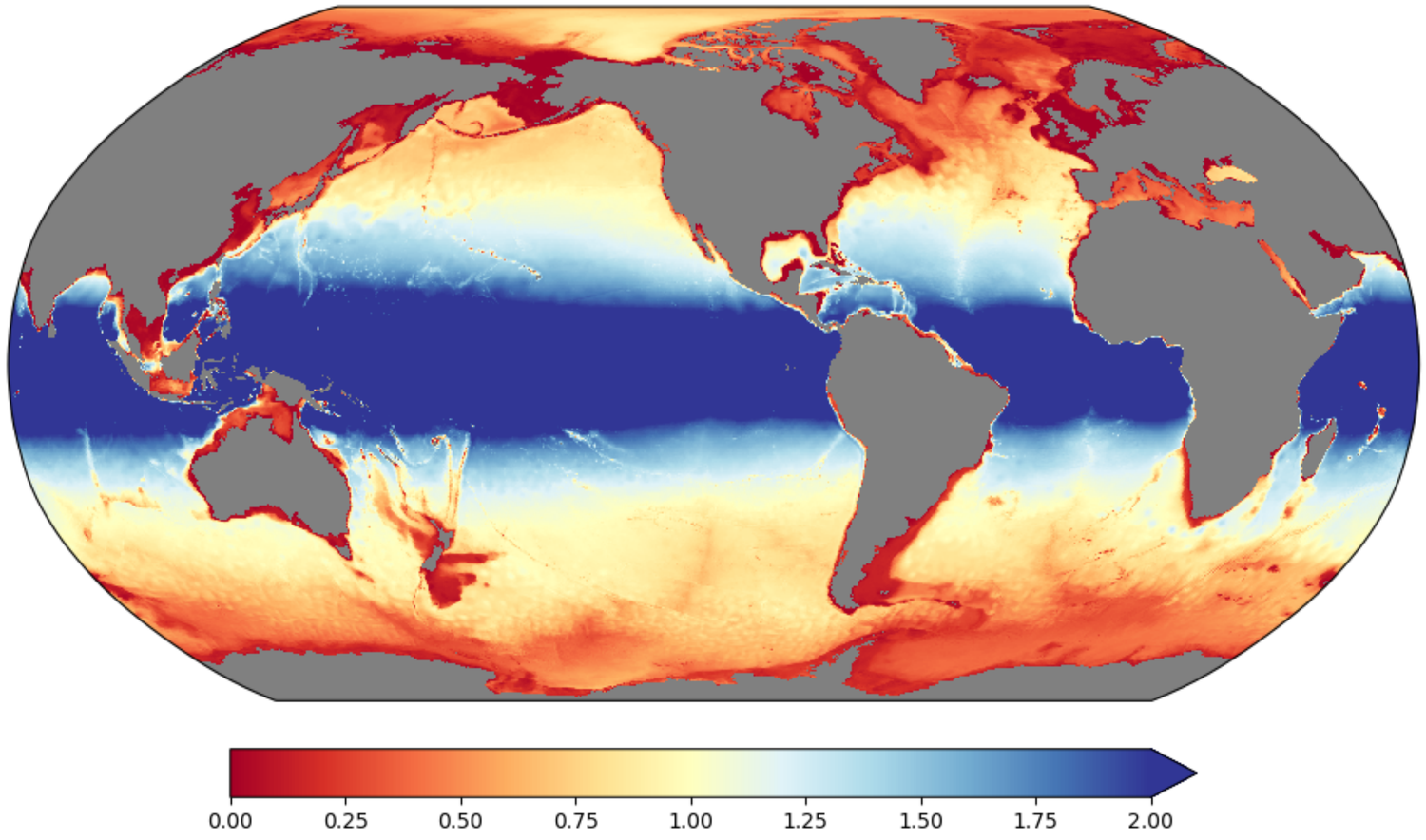
Re-entrant channel with 25 km grid spacing



Mak et al. 2023

Hyperviscosity and eddies

$R = L_d/\Delta$



$\max(R) \approx 6.5$ near the equator

QG: Six-layer, double gyre

$R = L_d/\Delta$	KE fraction
8	1
4.5	$0.8 - 0.92$
2.6	$0.55 - 0.8$
1.9	$0.35 - 0.7$
1.3	$0.2 - 0.6$

Grooms (Submitted to Ocean Modelling)

Challenges in modeling eddies in the gray zone

1) Isopycnal diffusion eliminates most eddies

2) Eddies are excessively dissipated by hyperviscosity

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Possible solutions:

Turn off isopycnal diffusion when L_d is resolved. Hallberg (2013)

Re-inject APE dissipated by isopycnal diffusion as KE e.g., Bachman (2019) Jansen et al. (2019)

Re-inject KE dissipated by hyperviscosity e.g., Jansen et al. (2014,2015) Grooms (Submitted)

Momentum equation:

$$\partial_t \boldsymbol{u} + \ldots = -\underbrace{\nabla\left[\nu_4 \nabla\left(\nabla^2 \boldsymbol{u}\right)\right]}_{\text{hyperviscosity}} + \underbrace{\nu_2 \nabla^2 \boldsymbol{u}}_{\text{anti-viscosity}}$$

How do you choose ν_2?

Scheme	Prognostic equation?	Energy source	Vertical structure	Reference
MEKE BS	2D	Biharmonic viscosity	*No*	Jansen et al. (2015)
MEKE GM+BS	2D	Biharmonic viscosity & GM	*No*	Jansen et al. (2019)
Dynamic BS	3D	Biharmonic viscosity	Yes	Juricke et al. (2019)
Kinematic BS	*None*	Biharmonic viscosity	Yes	Juricke et al. (2020)
GM+E	*None*	GM	*No*	Bachman (2019)
Leith BS	*None*	Leith biharmonic viscosity	Yes	Grooms (Submitted)

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Leith BS	Yes	Grooms (Submitted)

Vertical structure of ν_2

Surface intensified $\Longrightarrow$ more APE

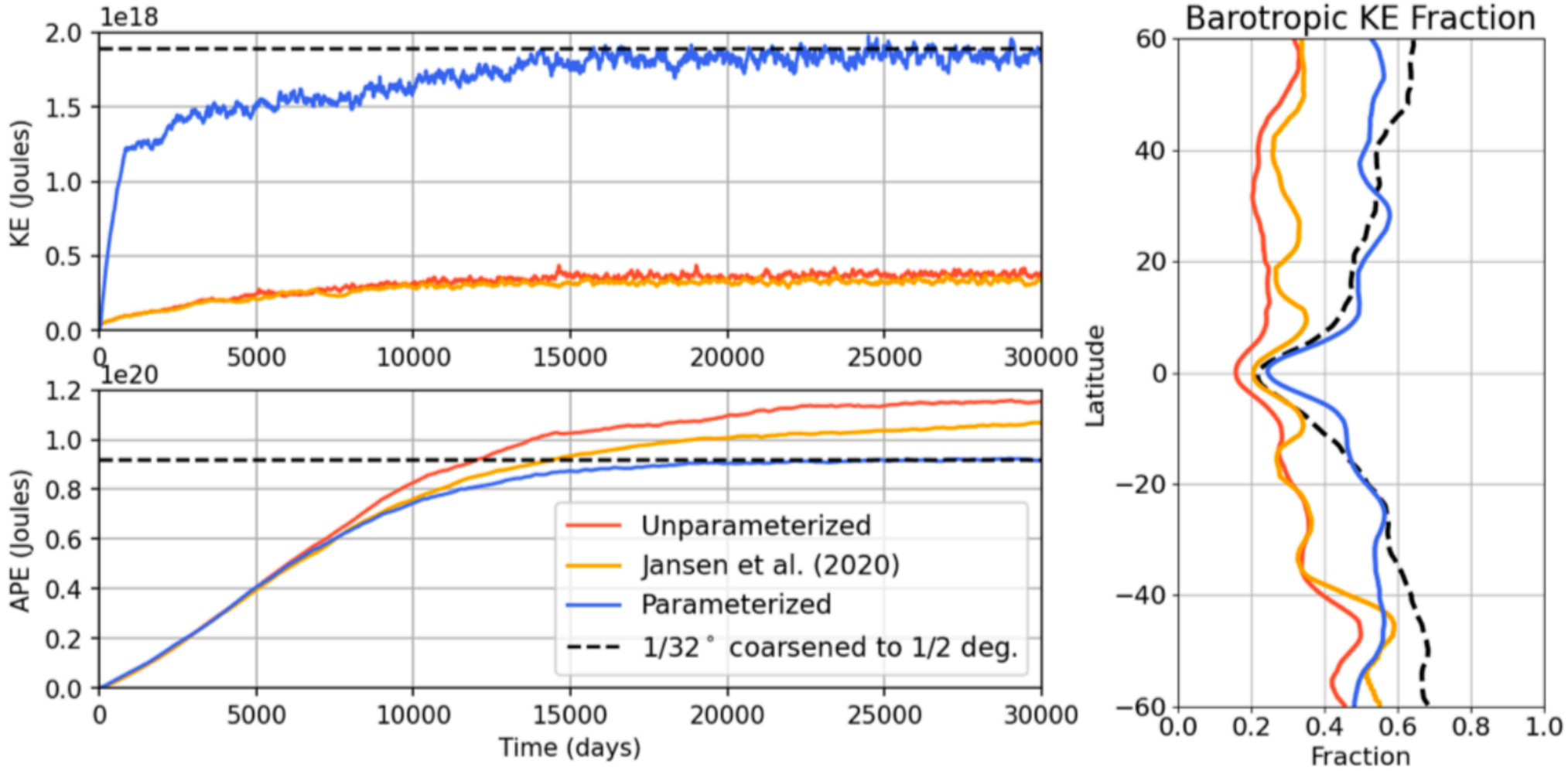
Depth-independent $\Longrightarrow$ less APE

Yankovsky et al. (Submitted)

Choices:

- EBT^{α} Yankovsky et al. (Submitted)
- SQG-like Wenda Zhang et al. (Submitted)

Backscatter alone or with GM?



Yankovsky et al. (Submitted)

What scheme is best for $1/4^\circ$ CESM-MOM6?

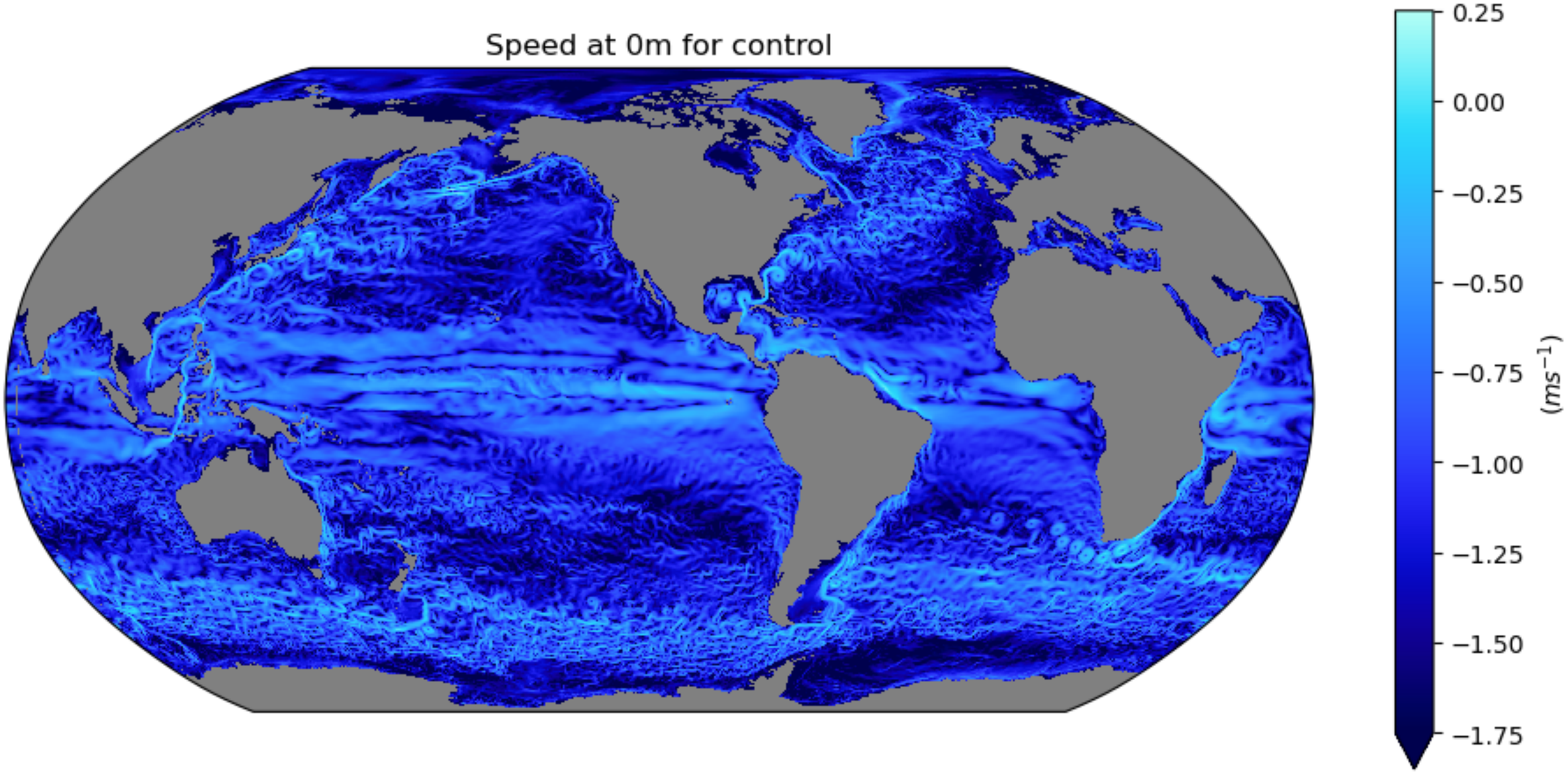
Scheme	Prognostic equation?	Vertical structure	Reference
MEKE BS with EBT	2D	EBT^2	Jansen et al. (2015) Yankovsky et al. (Submitted)
Leith BS	*None*	Determined from ν_4 and vorticity	Grooms (Submitted)

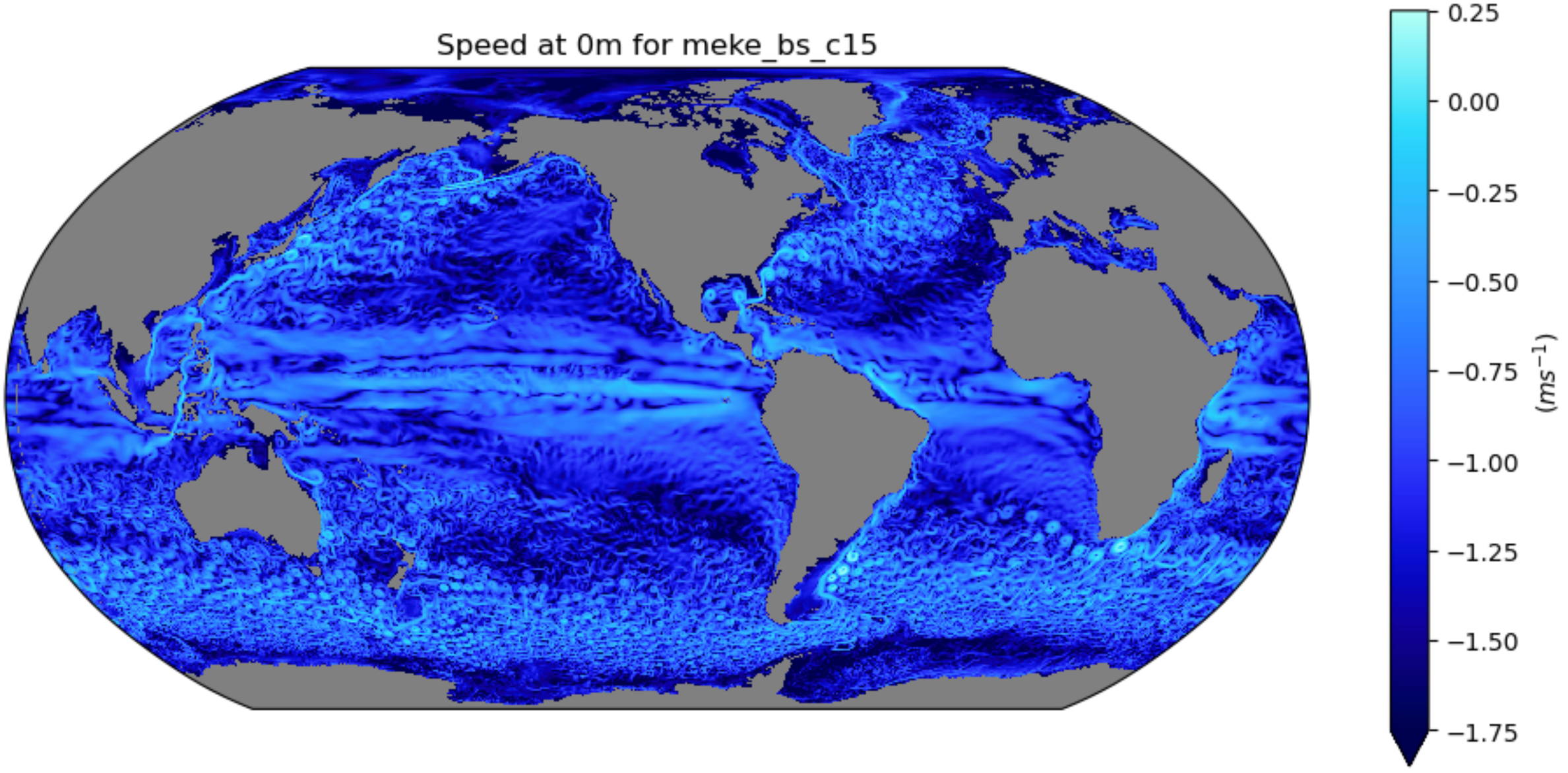
For each scheme: 1) Apply scheme everywhere

2) Apply if L_d is resolved, otherwise apply GM.

Question: Can backscatter replace GM even if L_d is unresolved?

Backscatter alone


Speed at 0m for control
0.25
0.00
−0.25
−0.50
−0.75
−1.00
−1.25
−1.50
−1.75
(ms^{-1})


Speed at 0m for meke_bs_c15
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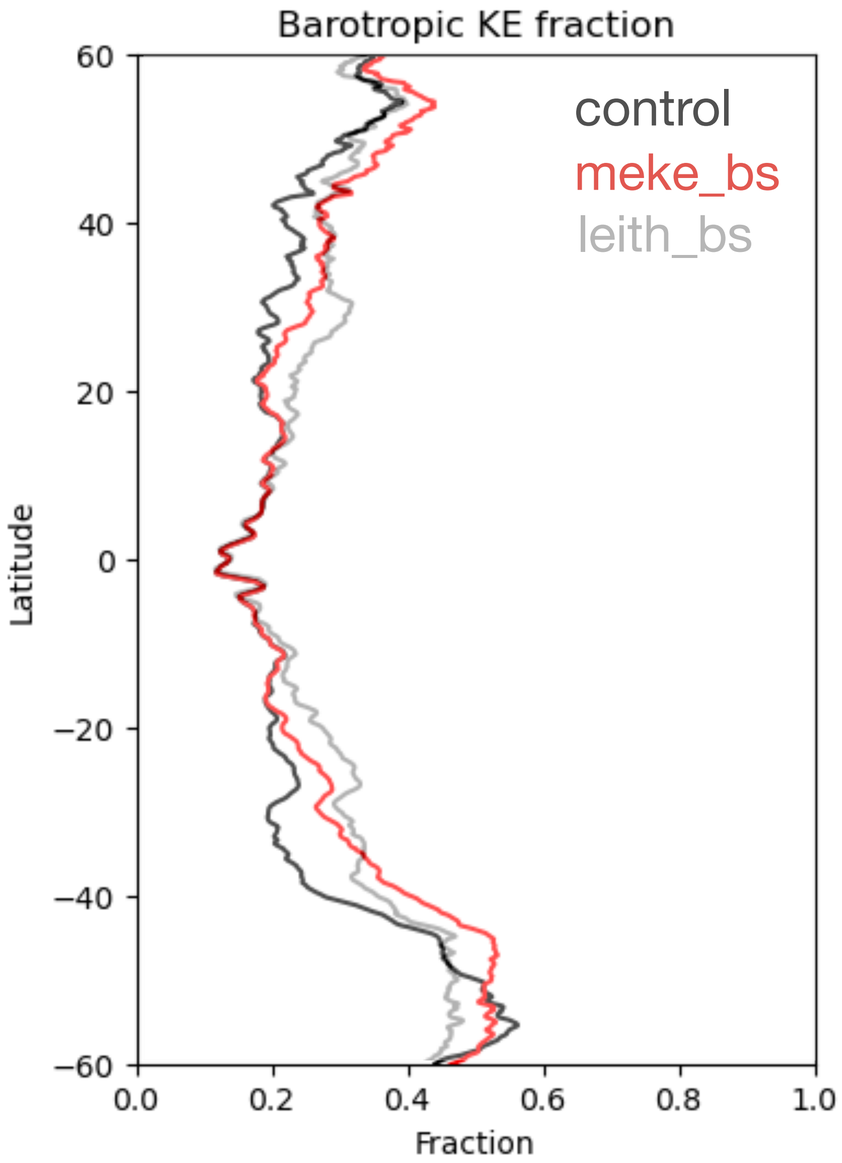
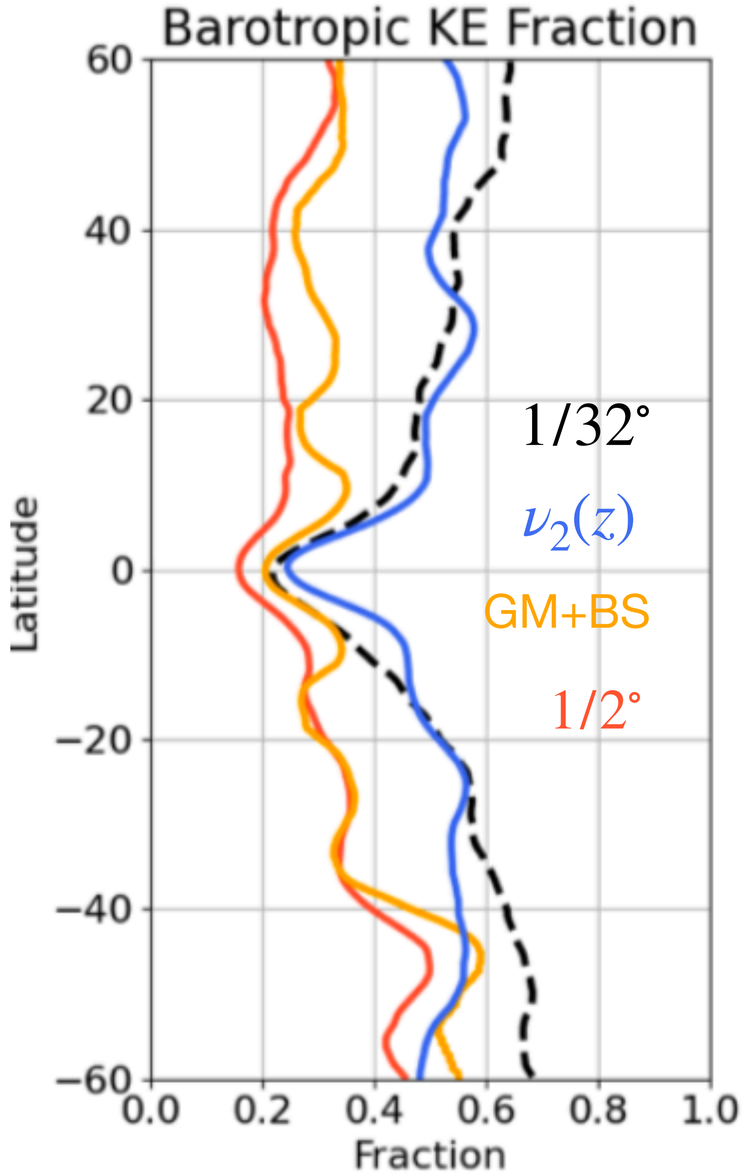
0.00
−0.25
−0.50
−0.75
−1.00
−1.25
−1.50
−1.75
(ms^{-1})

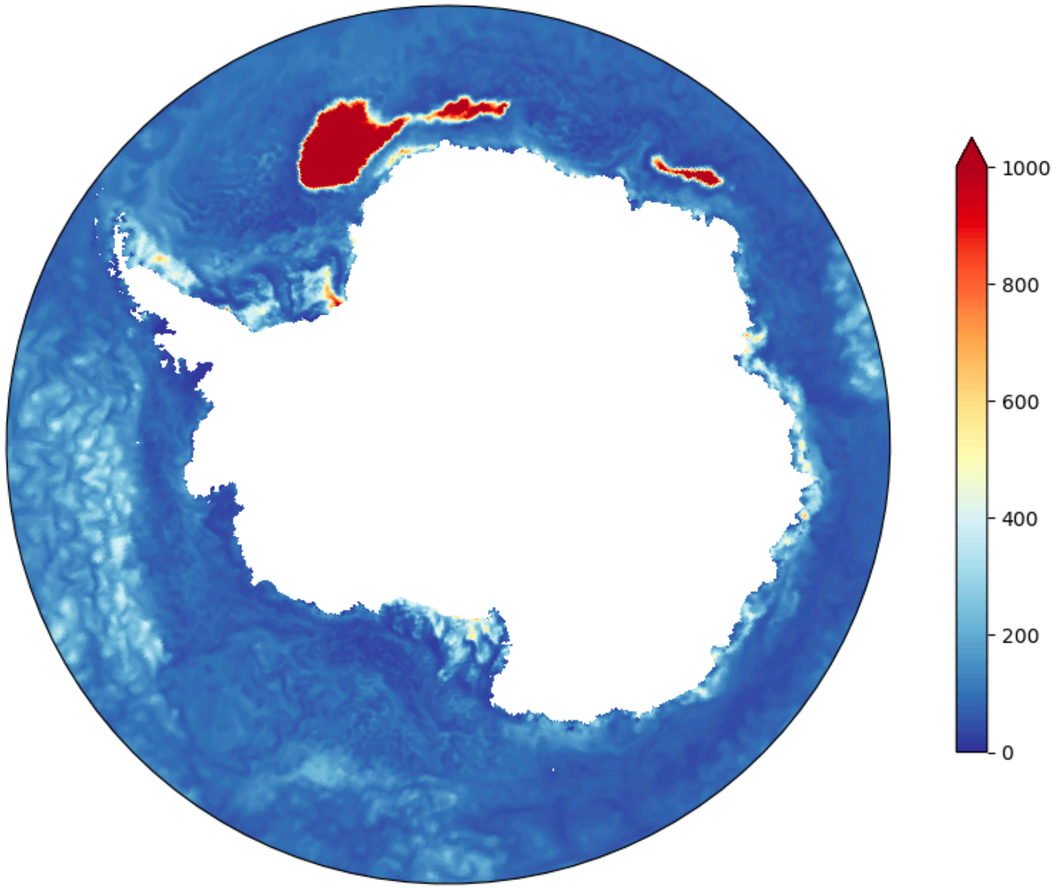




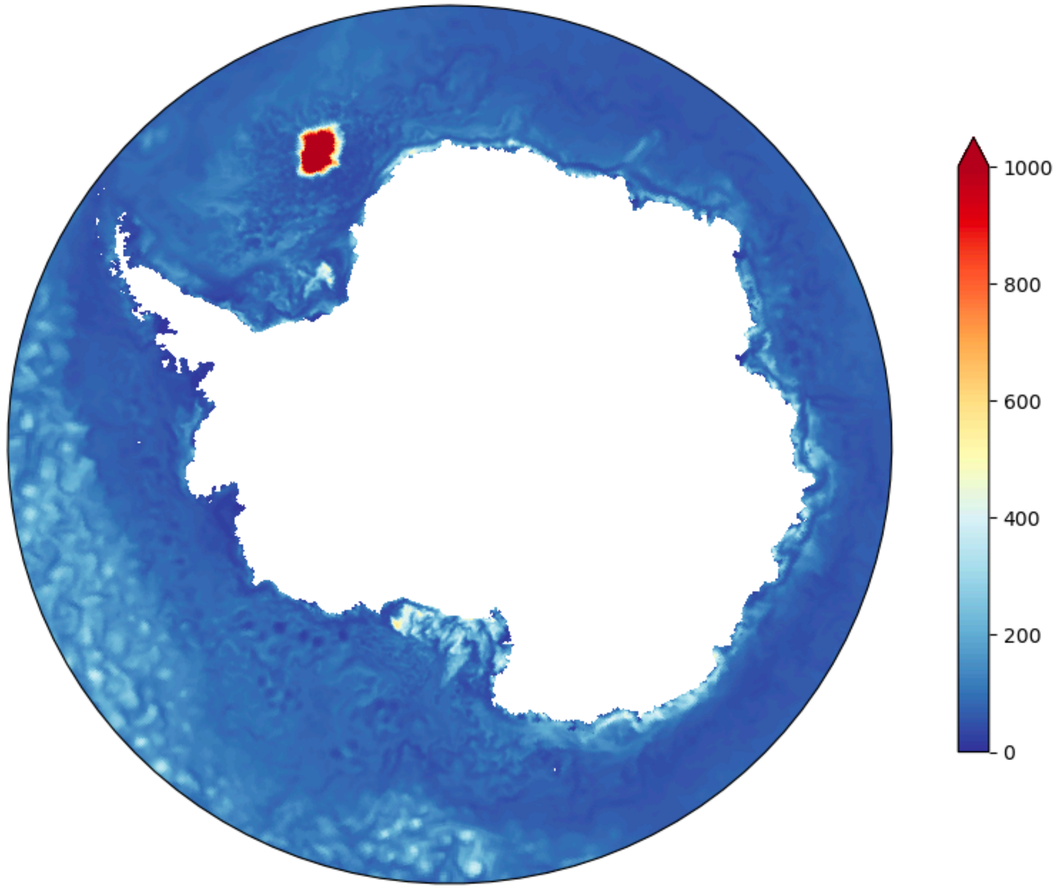
Yankovsky et al. (Submitted)

Backscatter in Southern Ocean leads to polynyas

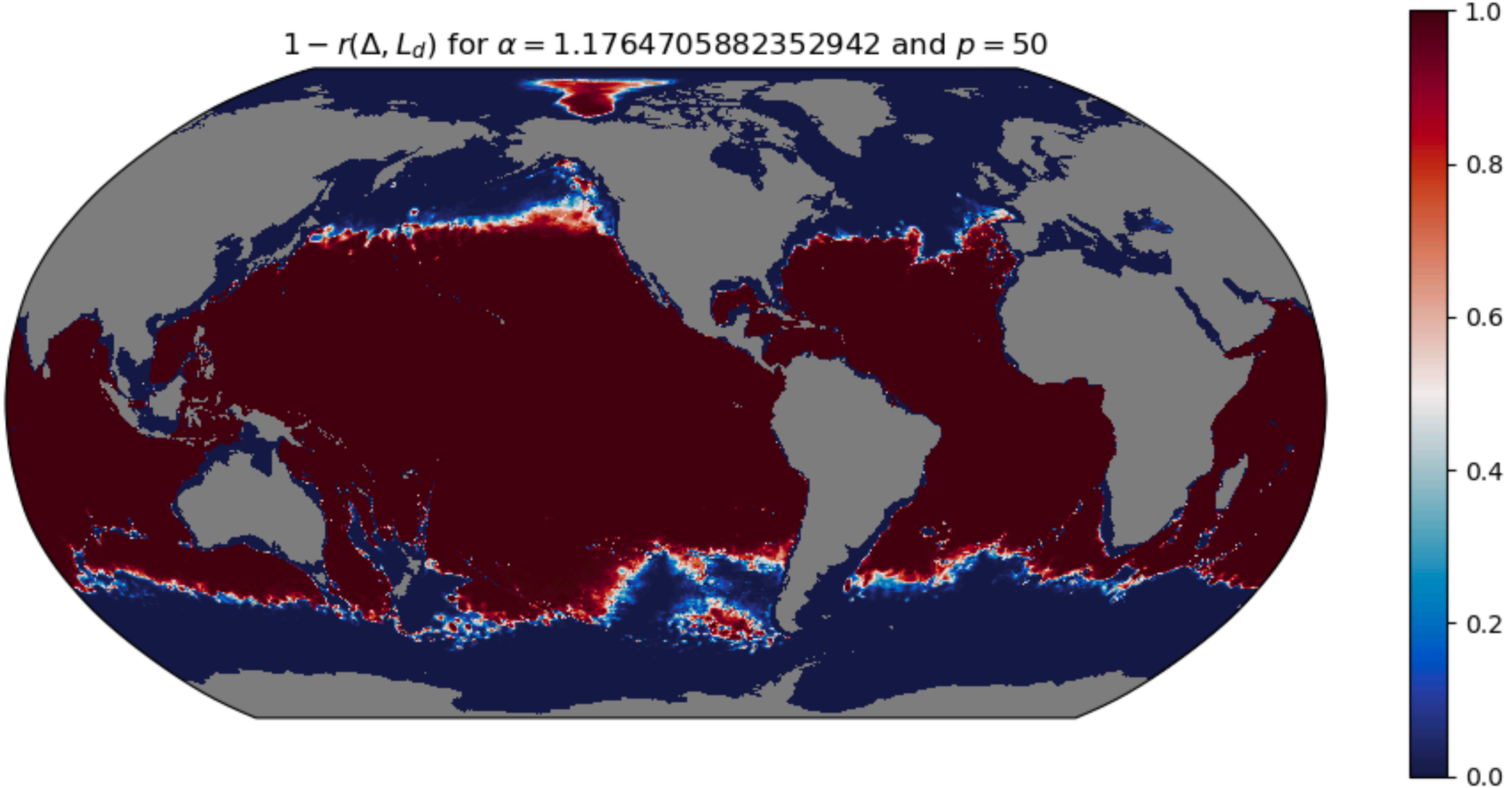
leith_bs



meke_bs

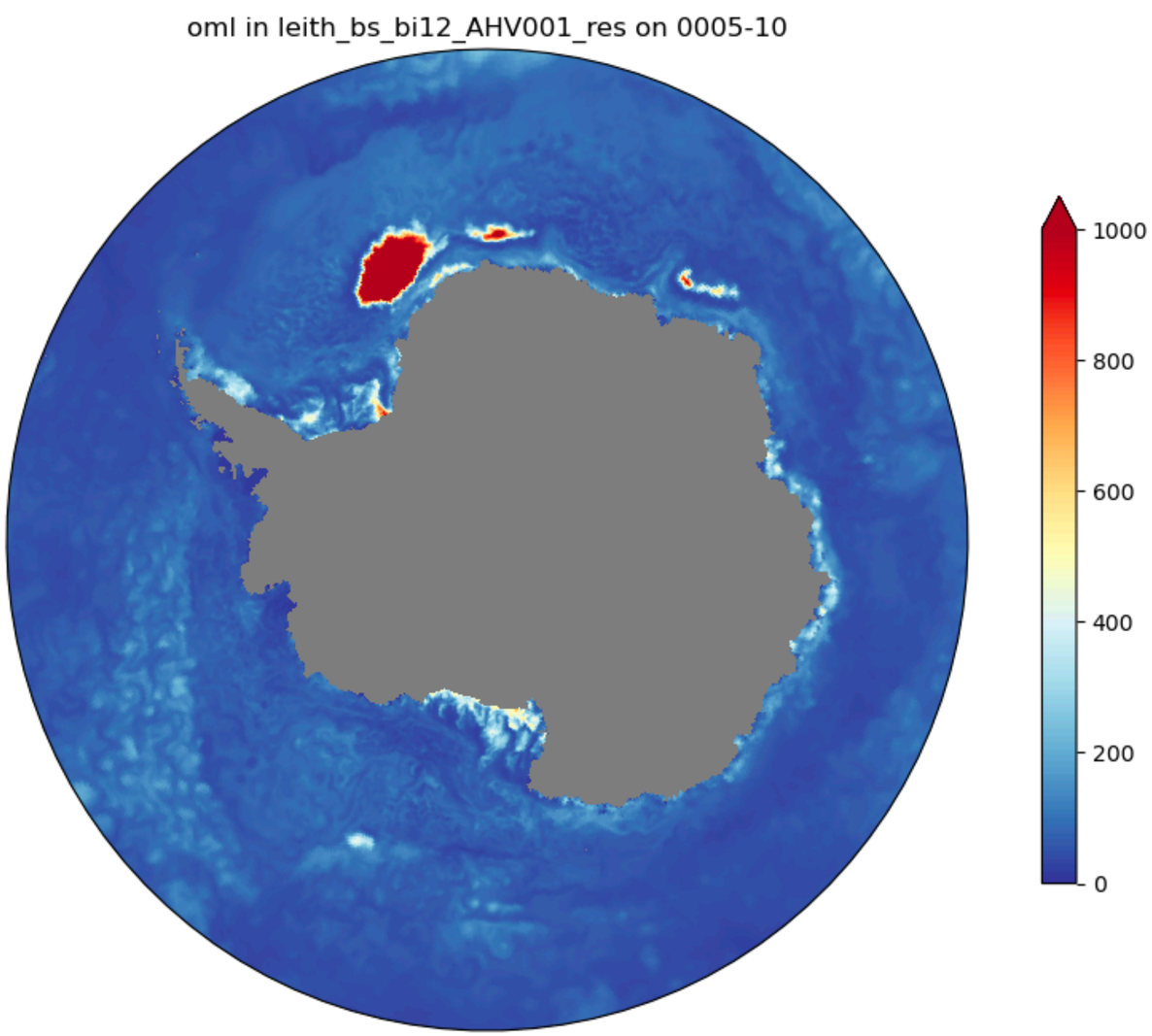


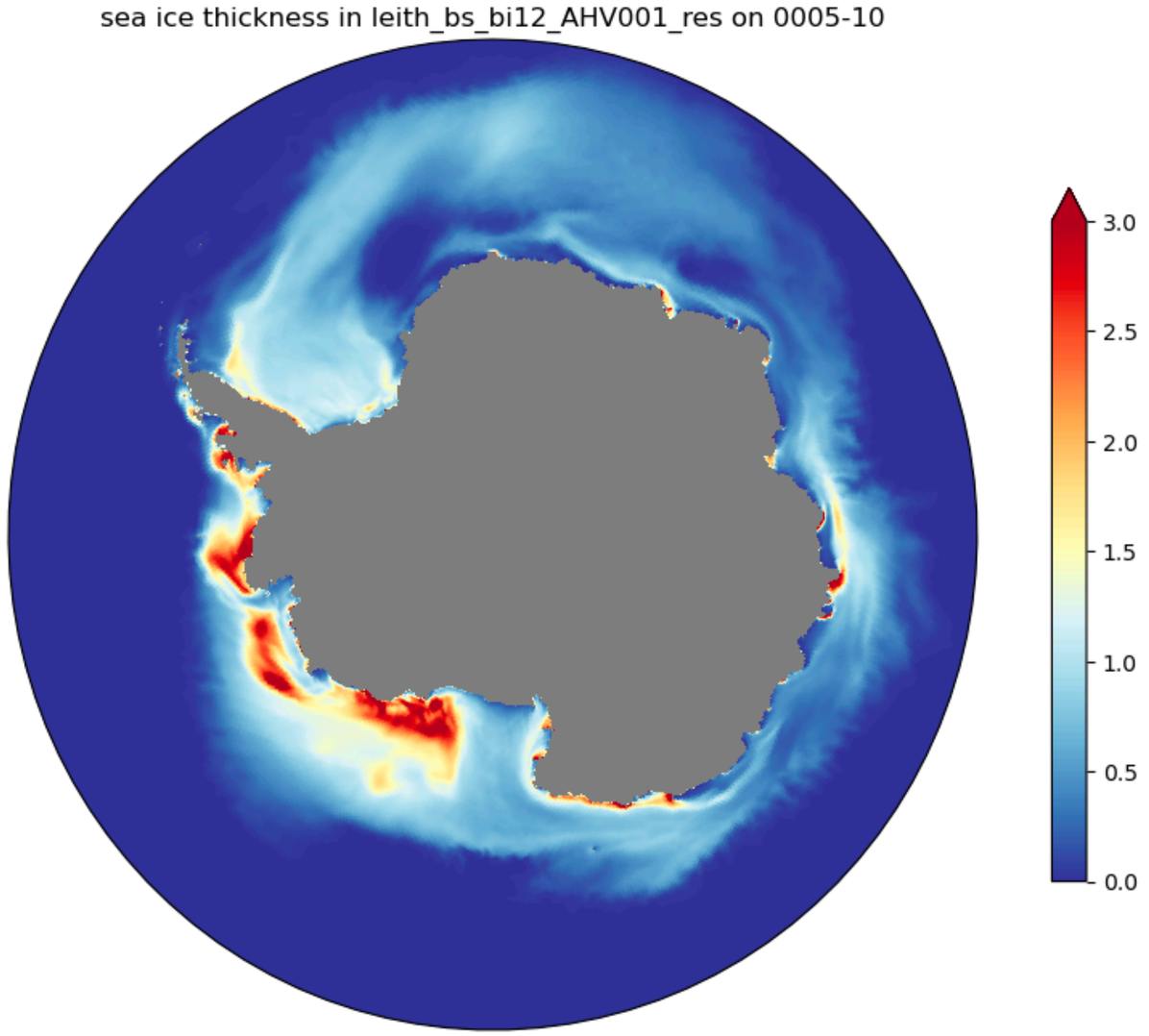
Try turning off backscatter at high latitudes



(Approximate step function with $R_0 = 0.85$)

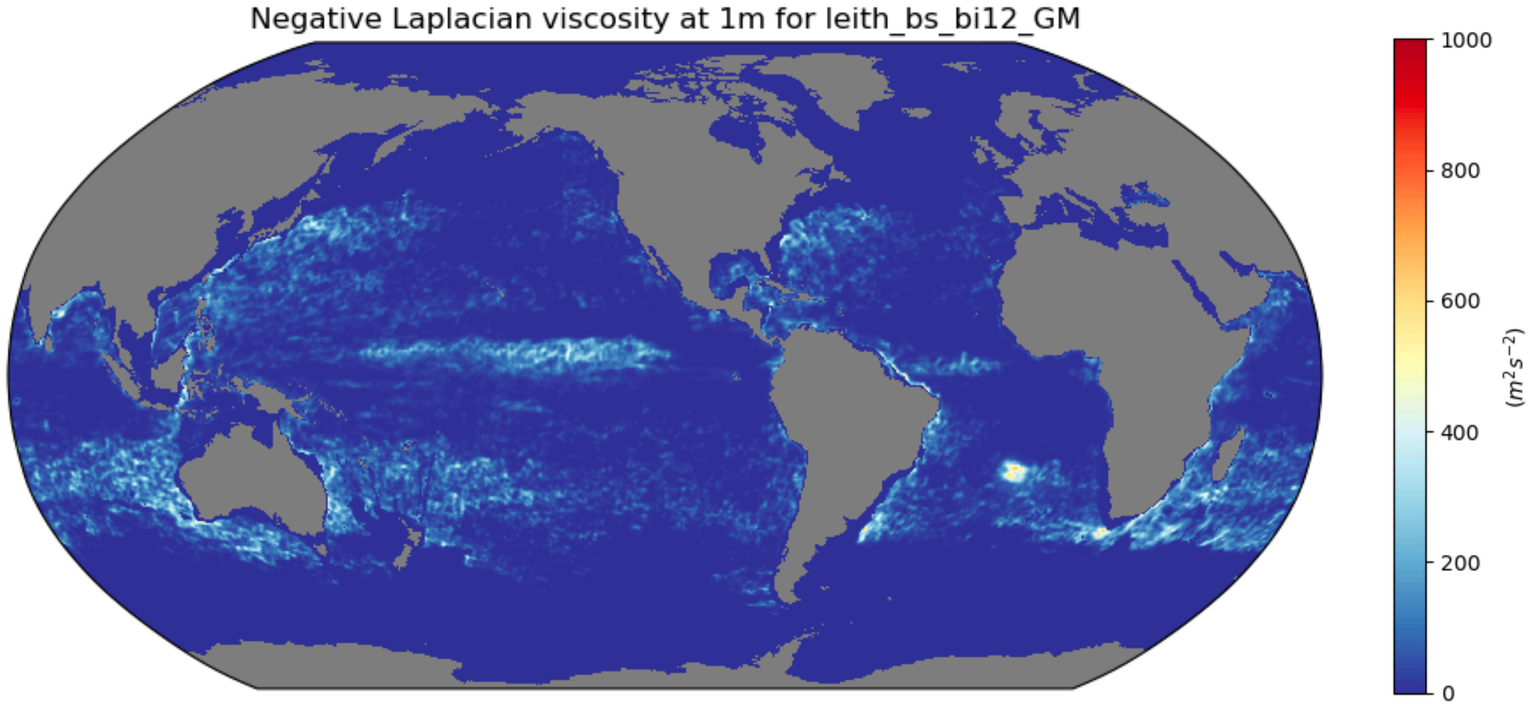
Try turning off backscatter at high latitudes



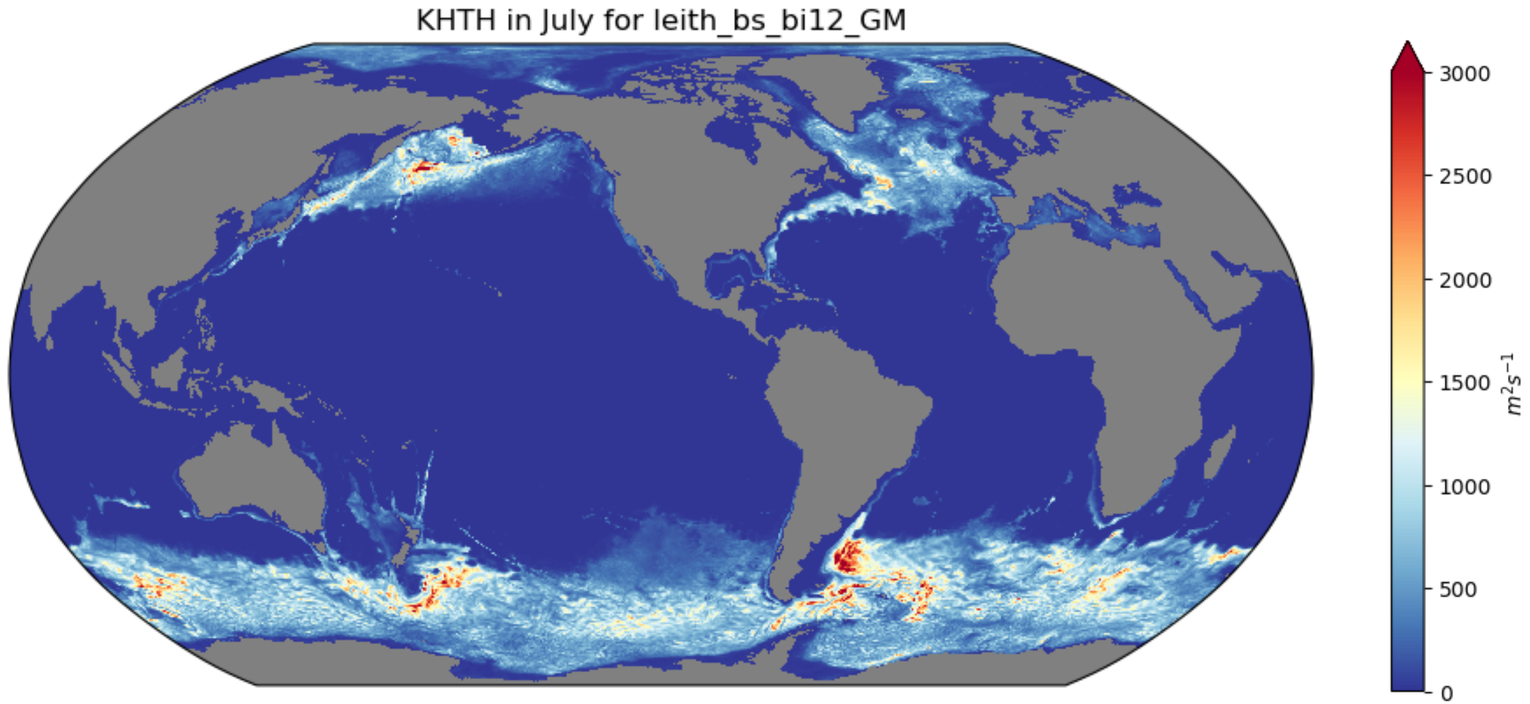


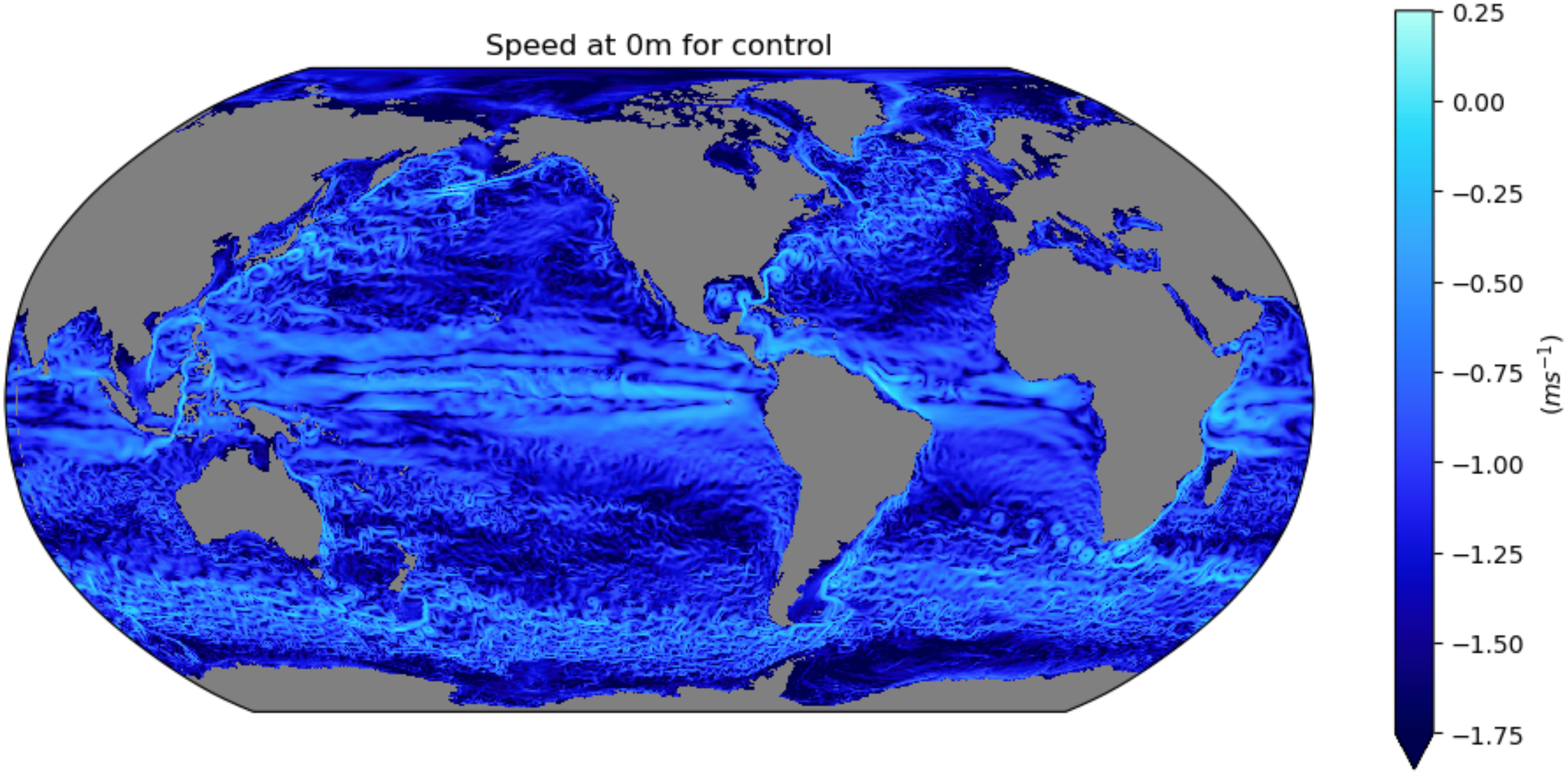
Backscatter and GM

Anti-viscosity ν_2:



Isopycnal height diffusion κ_{GM}:

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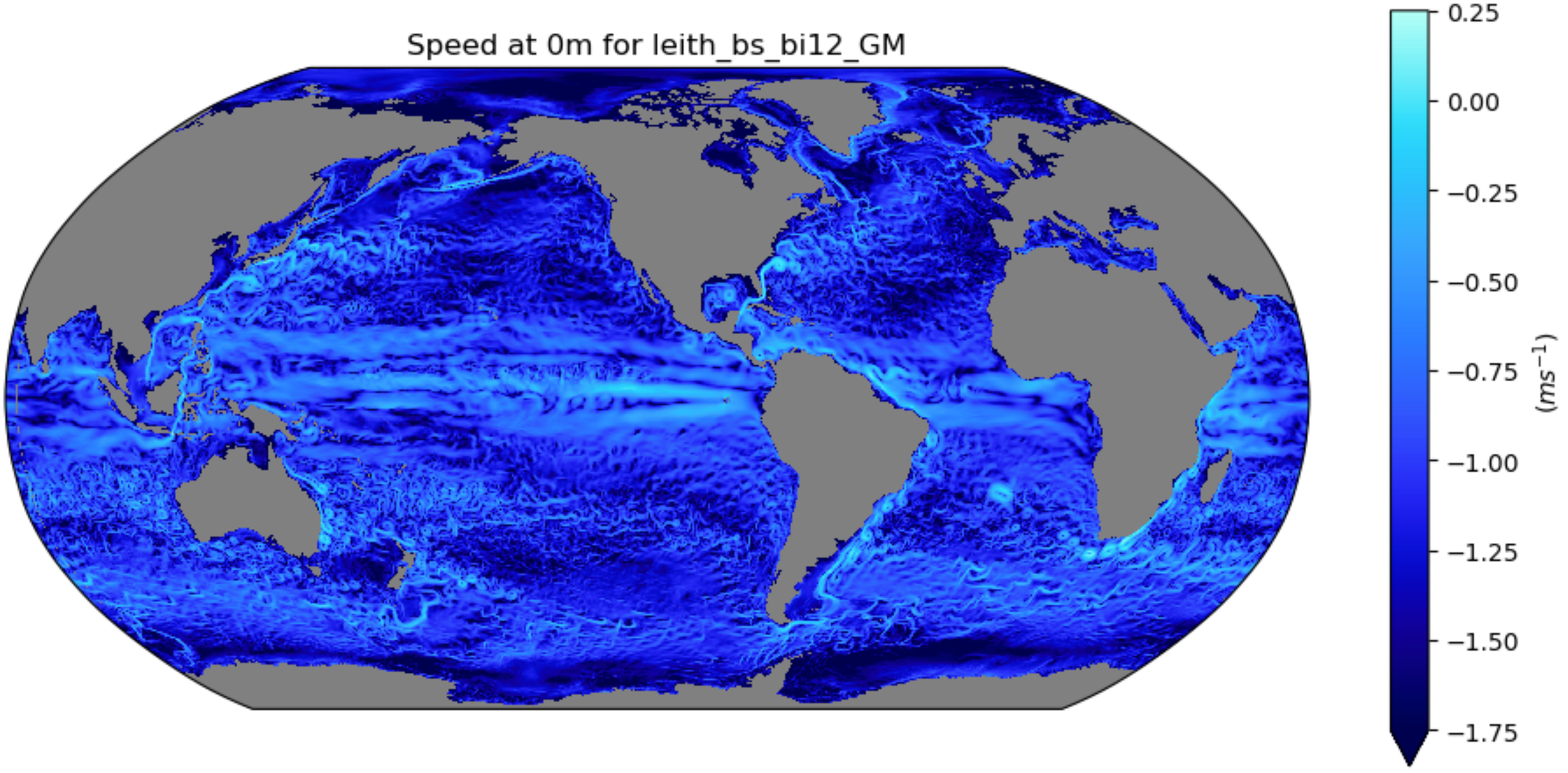
(ms^{-1})

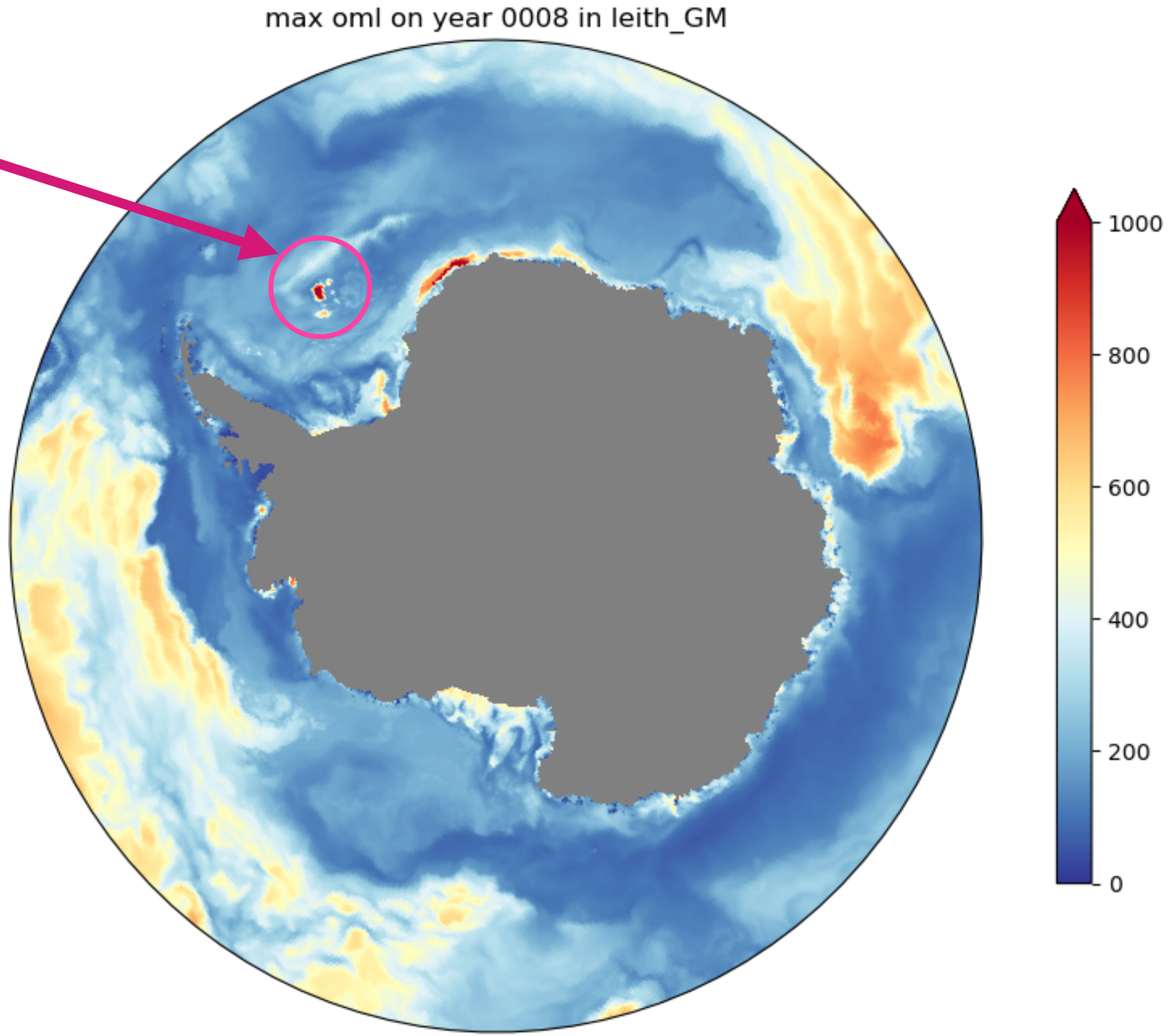

Speed at 0m for leith_bs_bi12_GM
0.25
0.00
−0.25
−0.50
−0.75
−1.00
−1.25
−1.50
−1.75
(ms^{-1})

Polynya?

Mixed-layer deepens to 1000m

Lasts one day

Recurs once or twice annually



Next steps

Proceeding to test the schemes with backscatter and GM

Work in progress…