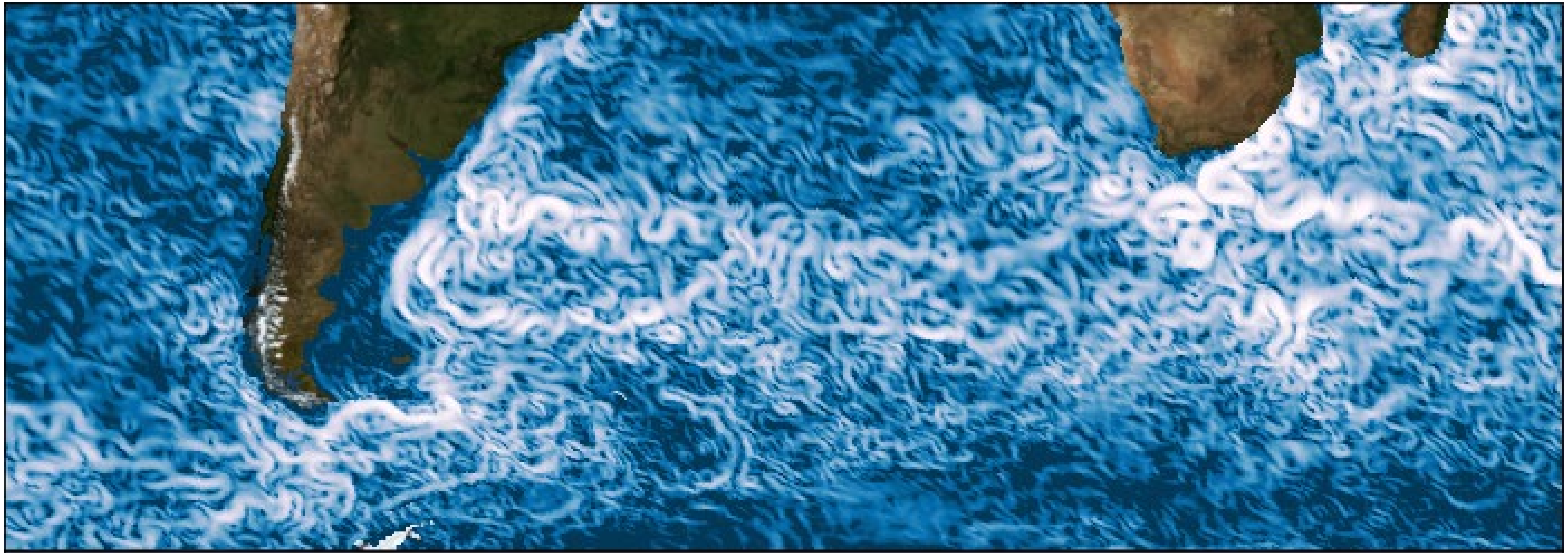
Parameterizing ocean turbulence: Bias reduction via advanced representation of mesoscale eddies

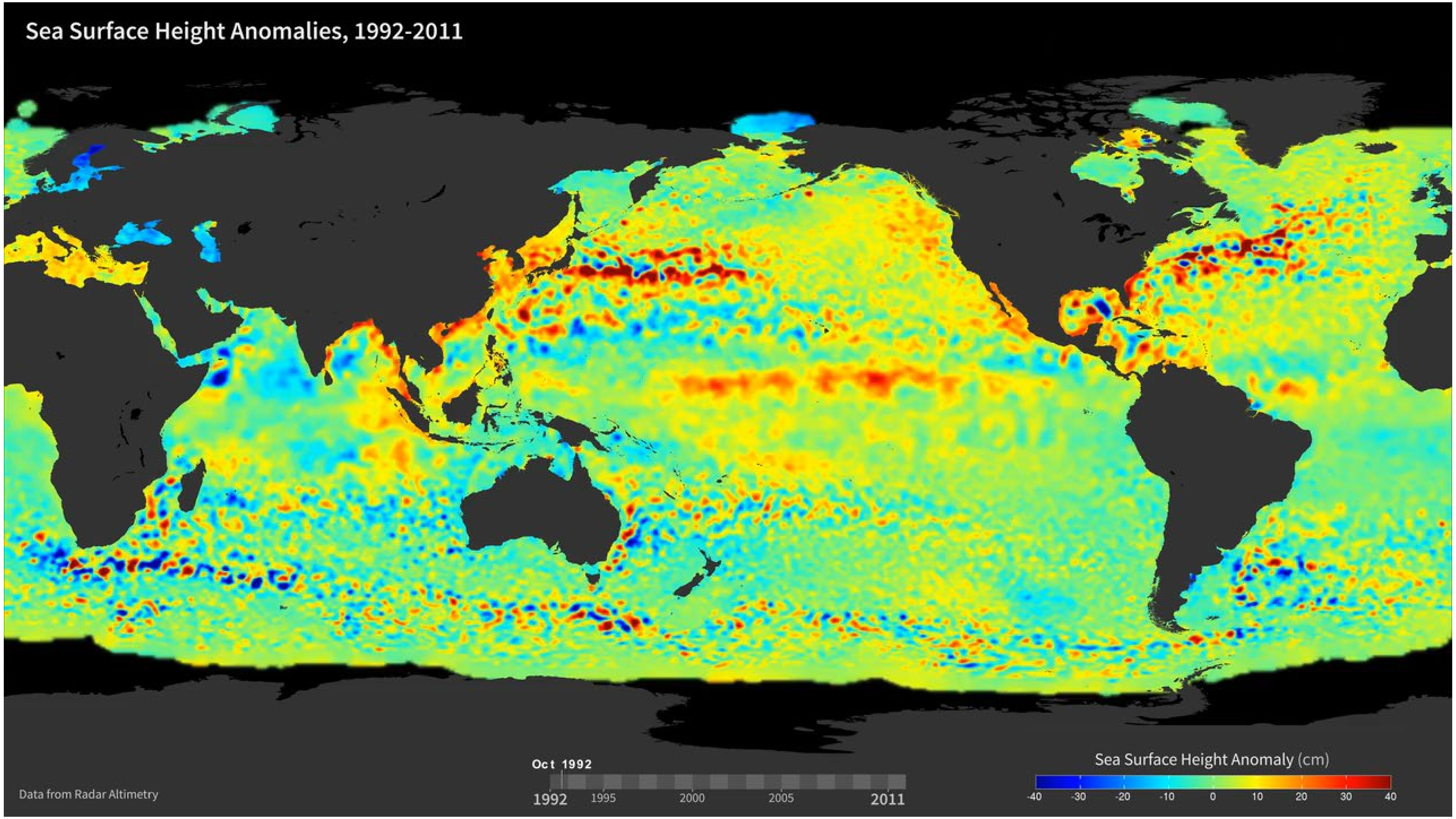
6th WGNE workshop on systematic errors

S. Juricke , E. Bagaeva, K. Bellinghausen, S. Danilov,
N. Koldunov, A. Kutsenko, M. Oliver, D. Sein, D. Sidorenko

01.11.2022

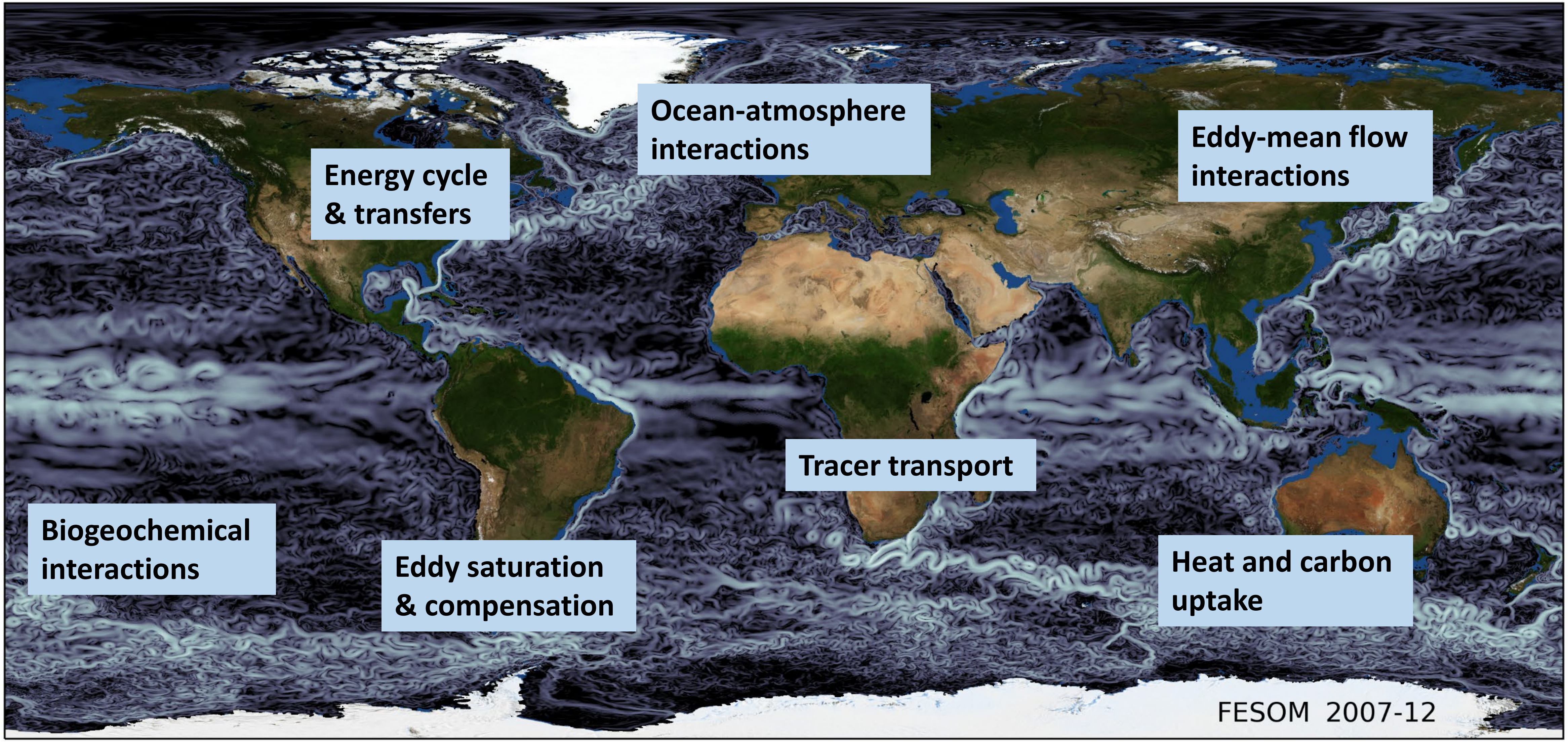


Introduction



AVISO SSH anomalies

Introduction



https://fesom.de

Ocean modelling

We need different parameterizations of ocean eddies at different resolutions:

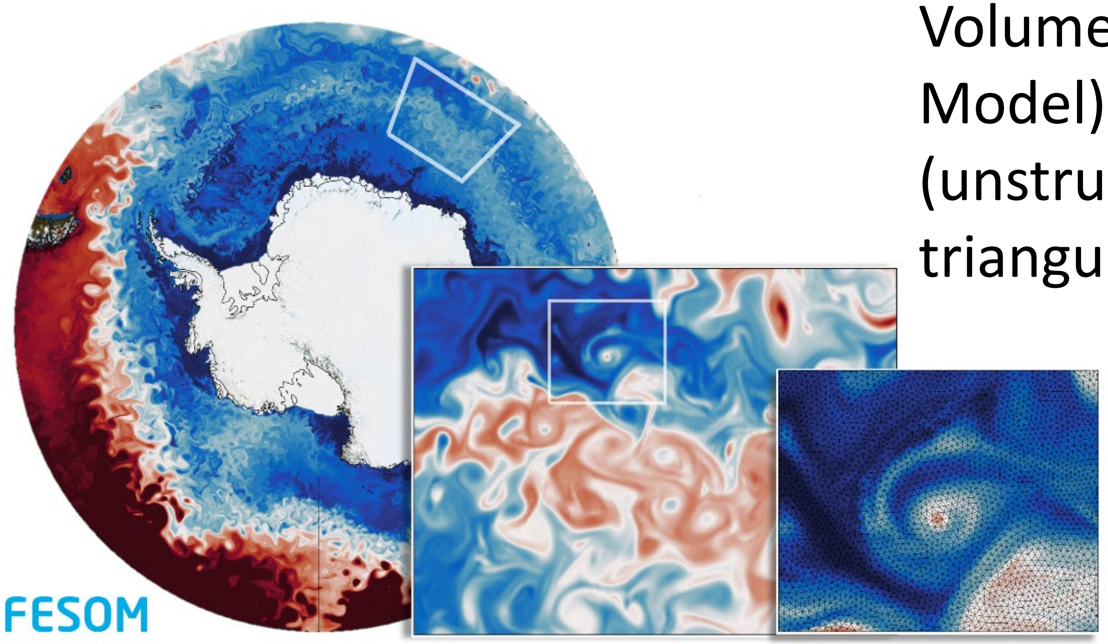
- **Non-eddy resolving** (1° and coarser) → Gent-McWilliams + eddy (Redi) diffusion + eddy viscosity

- **Eddy permitting** (between 1° and 0.1°) → eddy (Redi) diffusion + eddy viscosity (+ partial Gent-McWilliams?)

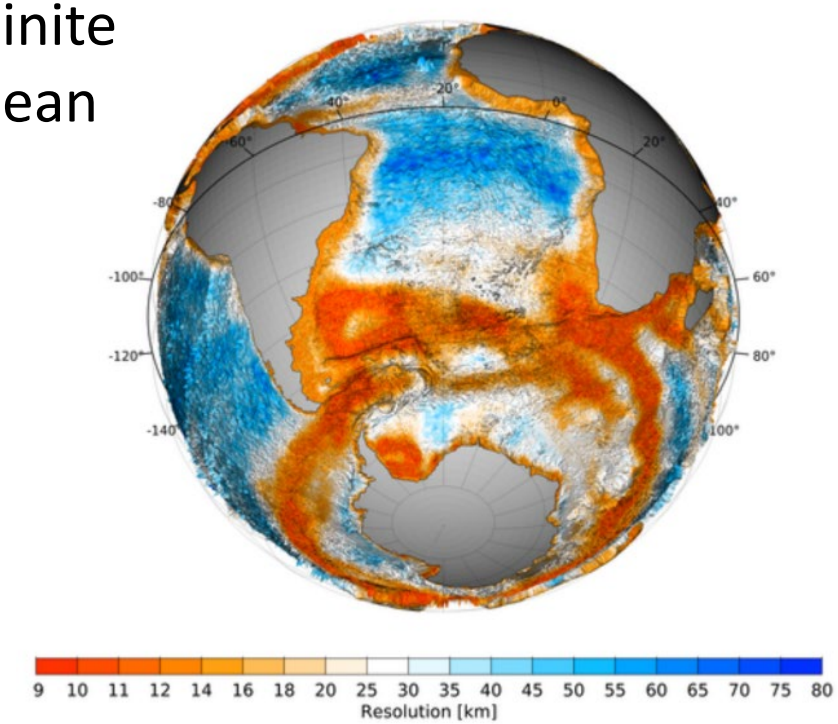
- **Eddy resolving** (0.1° and finer) → viscosity

Ocean modelling

Seeking a momentum closure that dissipates minimal amount of energy and at the smallest possible scales, i.e. around the grid scale, but keeps the model stable



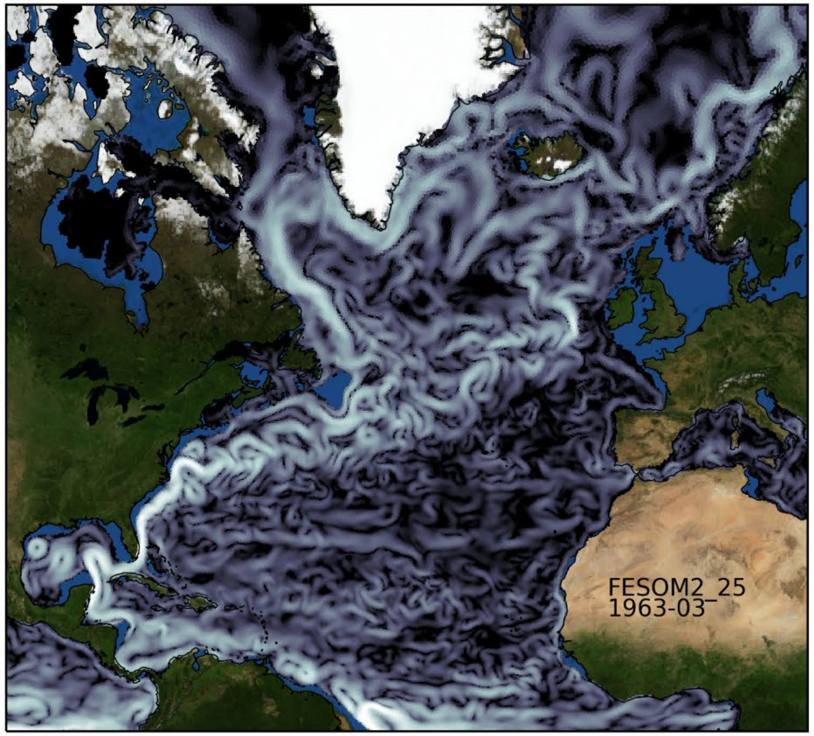
Model: FESOM2 (Finite Volume Sea ice-Ocean Model) based on (unstructured) triangular grids



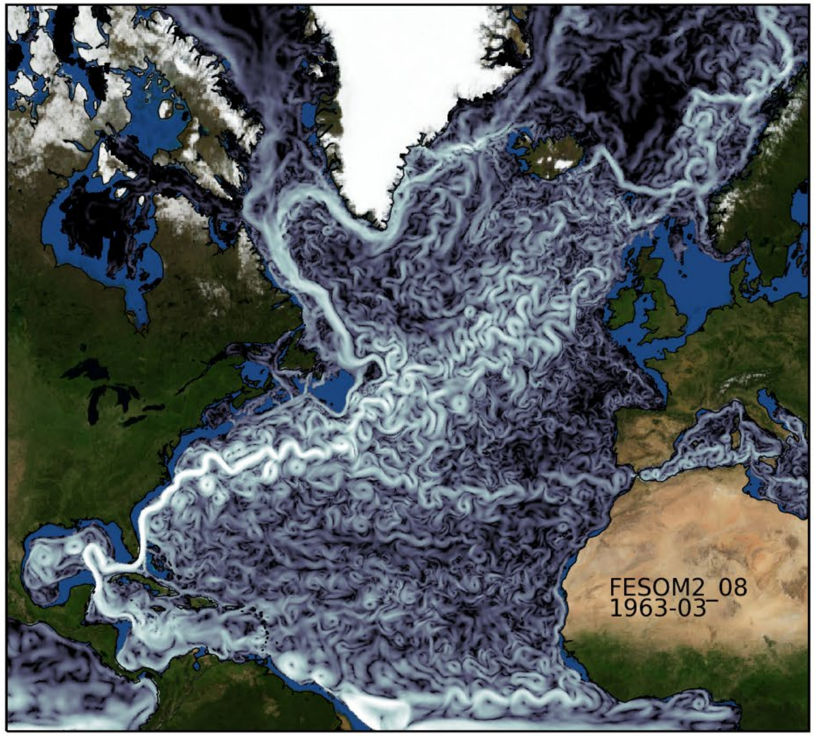
https://fesom.de

Ocean modelling

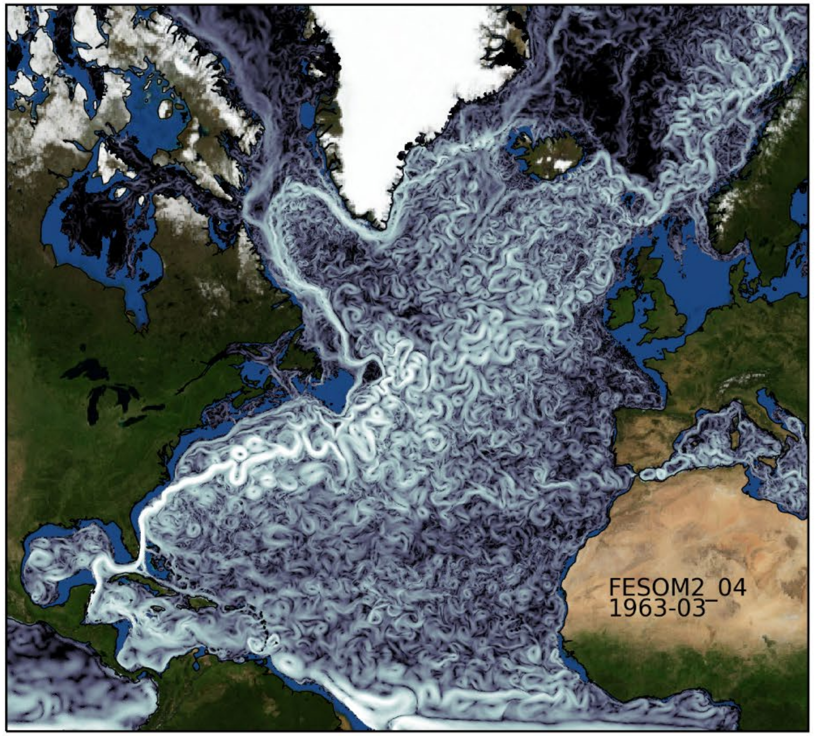
Effect of ocean model resolutions



25km



8km

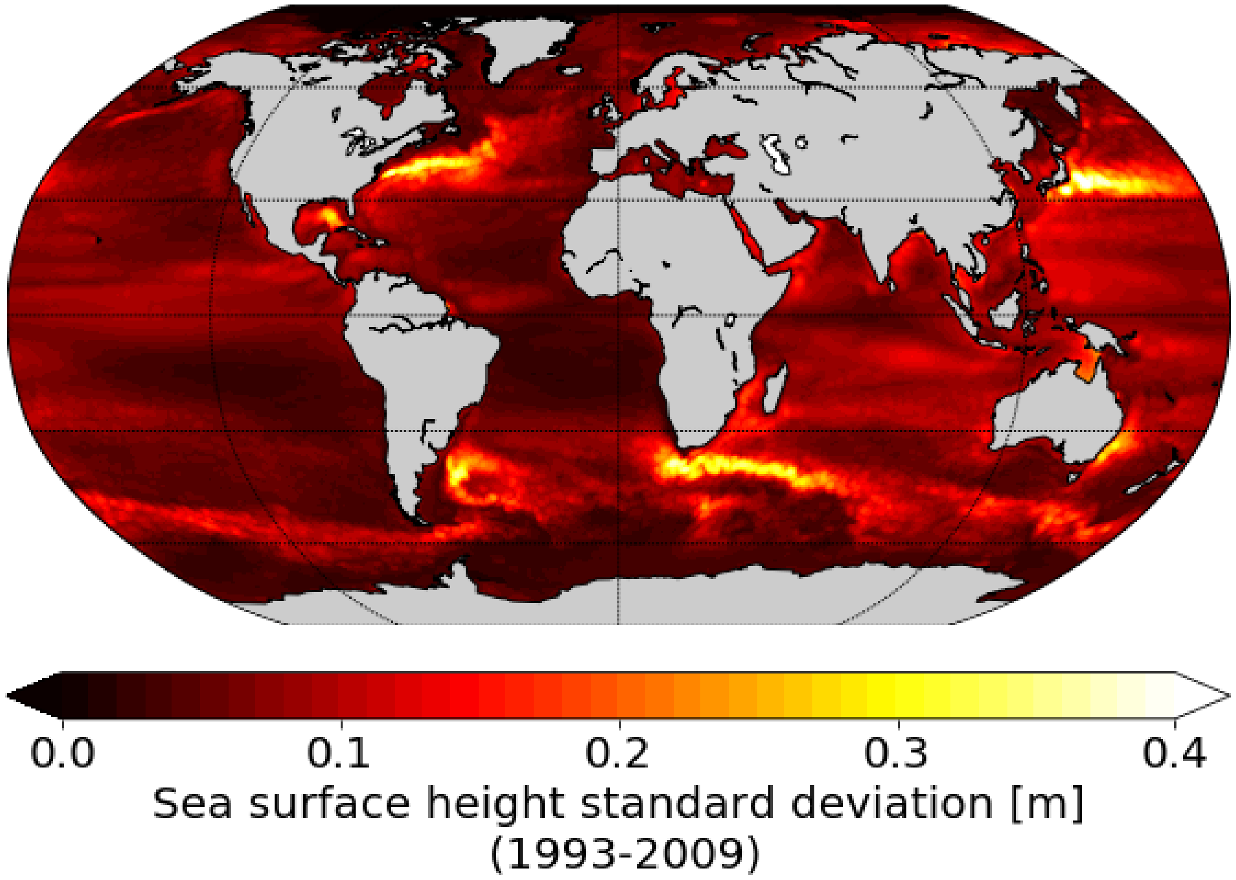


4km

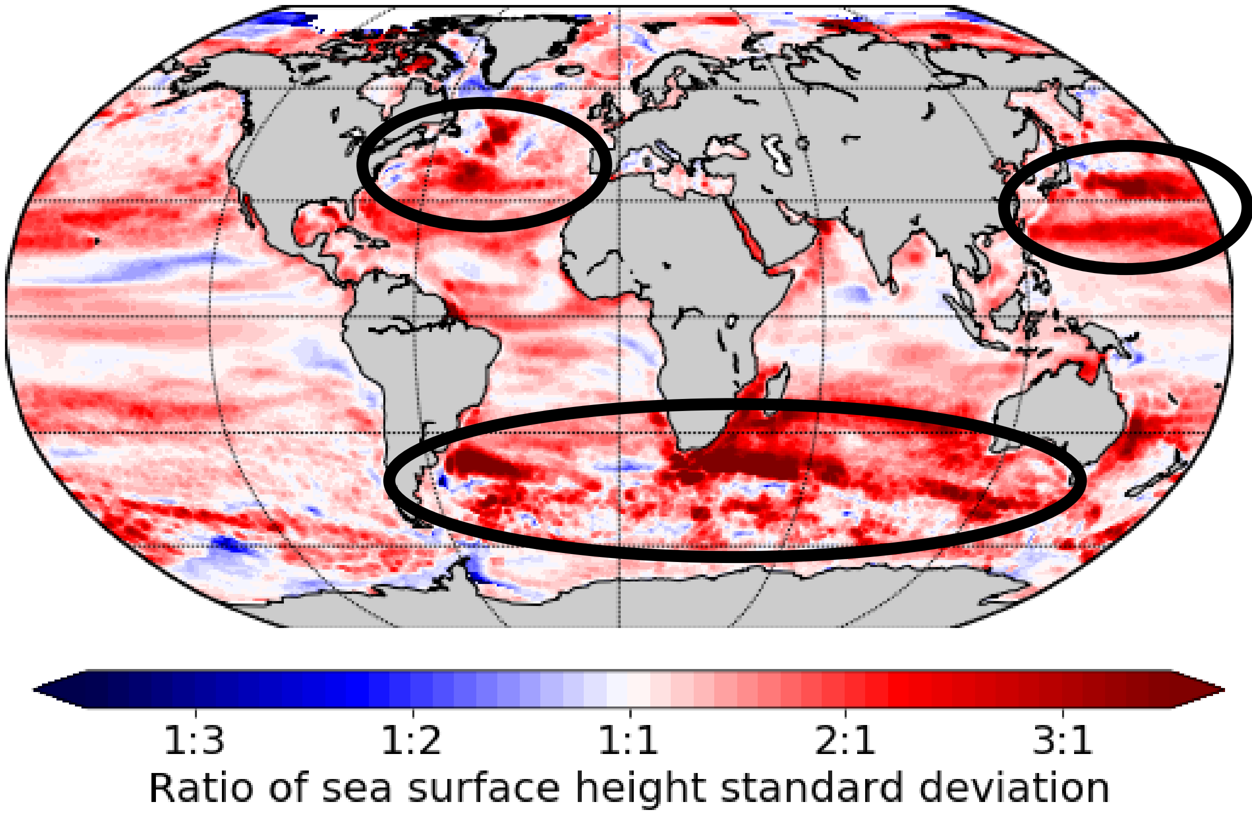
https://fesom.de

Ocean modelling

AVISO



OBS/REFERENCE (¼°)



Sea surface height variability (1993-2009)

Juricke et al. (2020)

Kinetic energy backscatter parameterization

$$\vec{u}_t + \vec{u} \cdot \nabla \vec{u} + w \partial_z \vec{u} + f \vec{k} \times \vec{u} + \frac{1}{\rho_o} \nabla P = V(\vec{u}) \qquad + \partial_z (A_v \partial_z \vec{u})$$

Dynamic Backscatter (DB)

$$\vec{u}_t + \vec{u}\cdot\nabla\vec{u} + w\partial_z\vec{u} + f\vec{k}\times\vec{u} + \frac{1}{\rho_o}\nabla P = V(\vec{u}) + B(\vec{u}) + \partial_z(A_v\partial_z\vec{u})$$

$(1 - c_{dis})\dot{E}_{dis}$

physical dissipation

Dissipation rate

Backscatter rate

$$\partial_t e = -c_{dis}\dot{E}_{dis} - \dot{E}_{back} + Diffusion$$

sub-grid kinetic energy $e(x, y, z, t)$

(Jansen et al., 2015; Klöwer et al., 2018, Juricke et al., 2019)

Backscatter coefficient $\nu_b = -c_0 A\sqrt{\max(2e, 0)}$

with scaling c_0, grid spacing A

Juricke et al. (2020a)

Kinematic Backscatter (KB)

$$\vec{u}_t + \vec{u} \cdot \nabla \vec{u} + w\partial_z \vec{u} + f\vec{k} \times \vec{u} + \frac{1}{\rho_o}\nabla P = V(\vec{u}) + \alpha F(V(\vec{u})) + \partial_z(A_v \partial_z \vec{u})$$

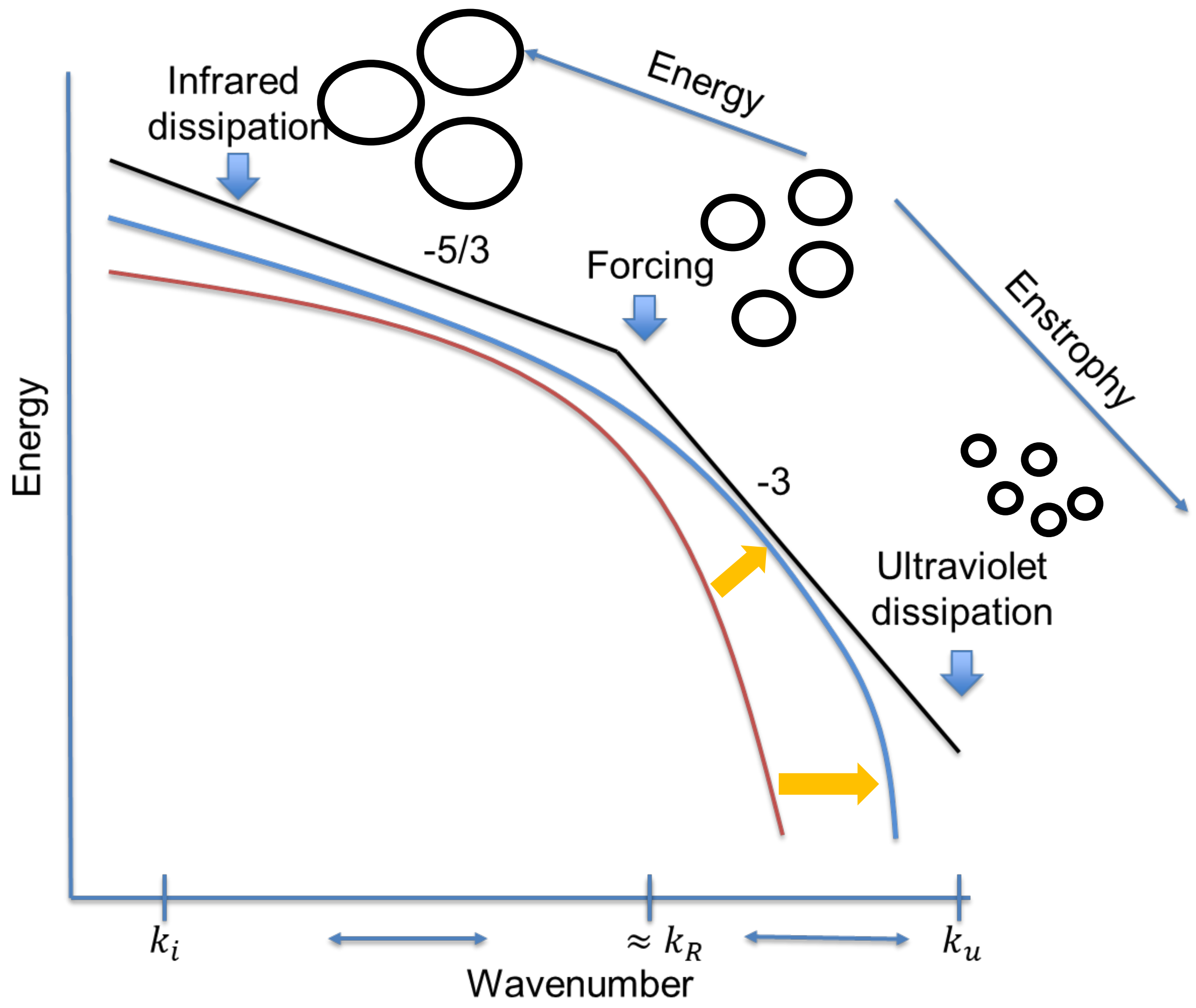
where F is a filter to smooth the viscous term and α is a term smaller than -1 to achieve backscatter, but not too smaller to achieve overall dissipation with

$$V(\vec{u}) + \alpha F(V(\vec{u}))$$

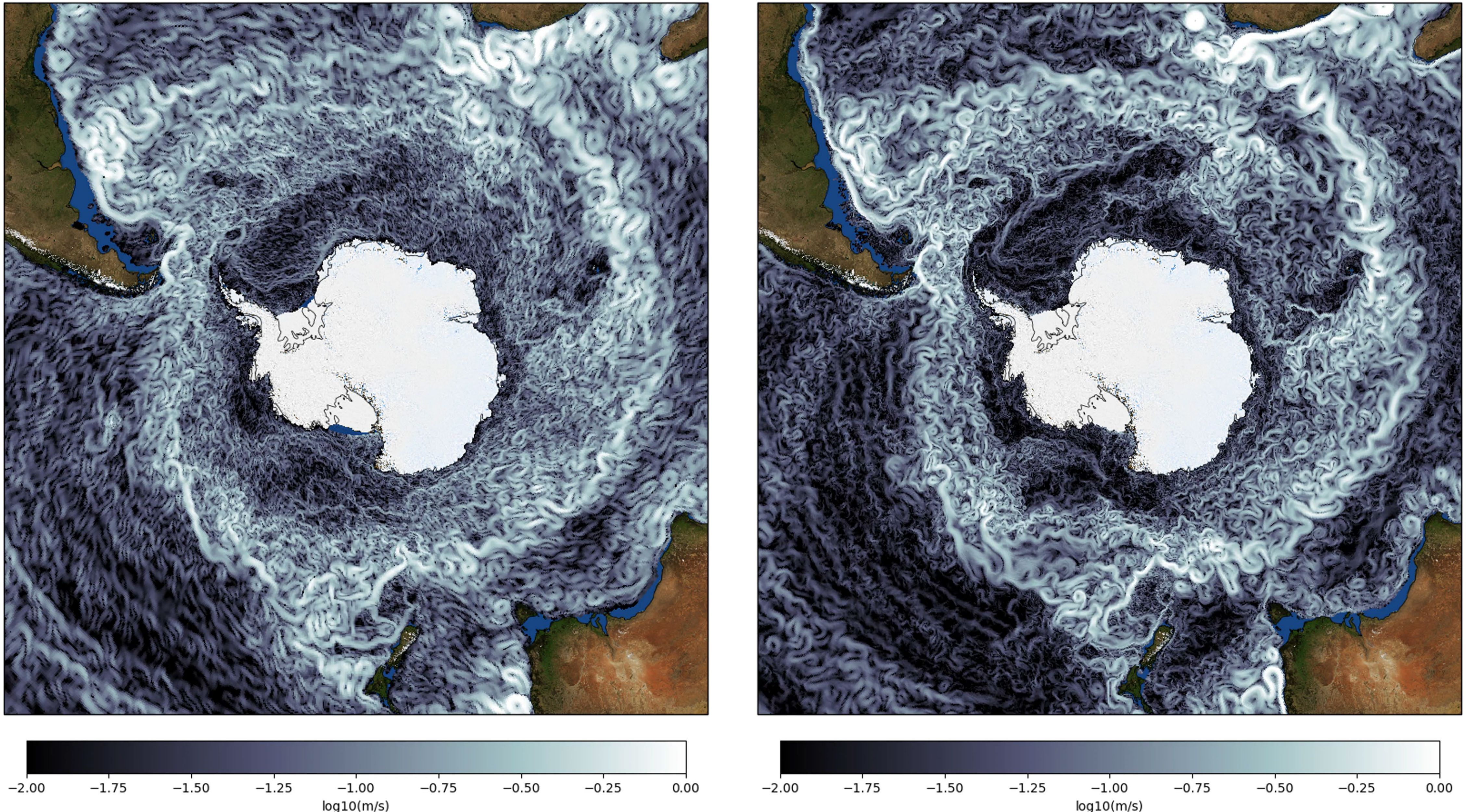
e.g. $\alpha = -1.5$

Juricke et al. (2020b)

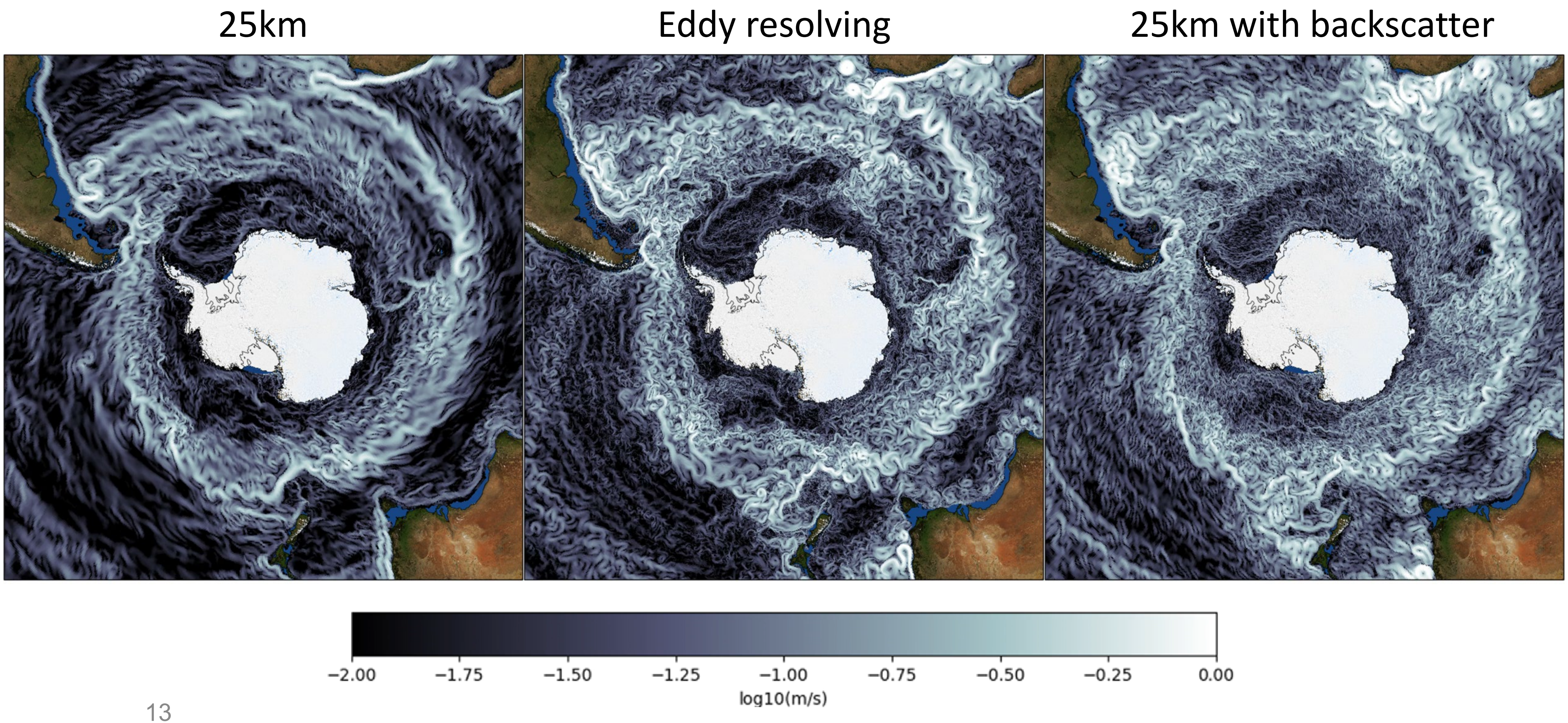
Kinetic energy backscatter



Kinetic energy backscatter: Global results



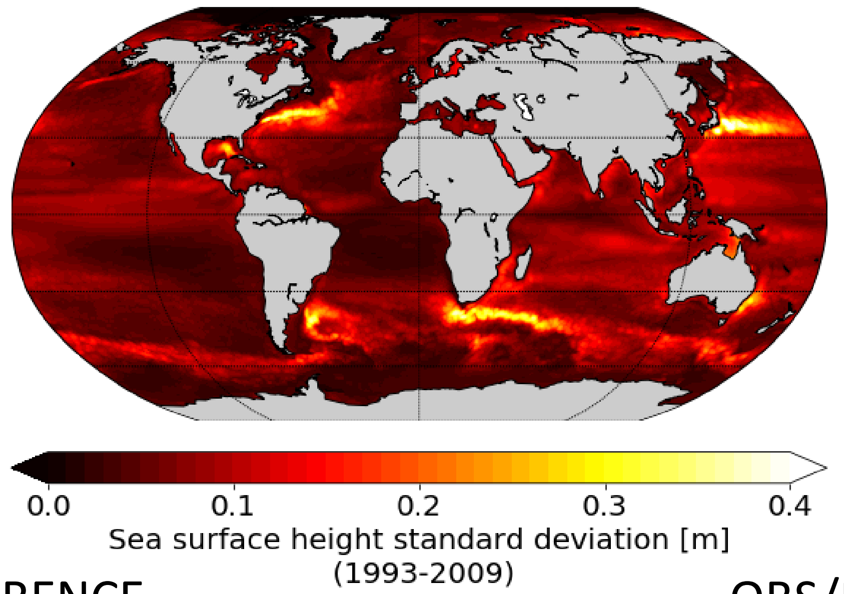
Kinetic energy backscatter: Global results



Kinetic energy backscatter: Global results (DB)

Sea surface height variability (1993-2009)

AVISO

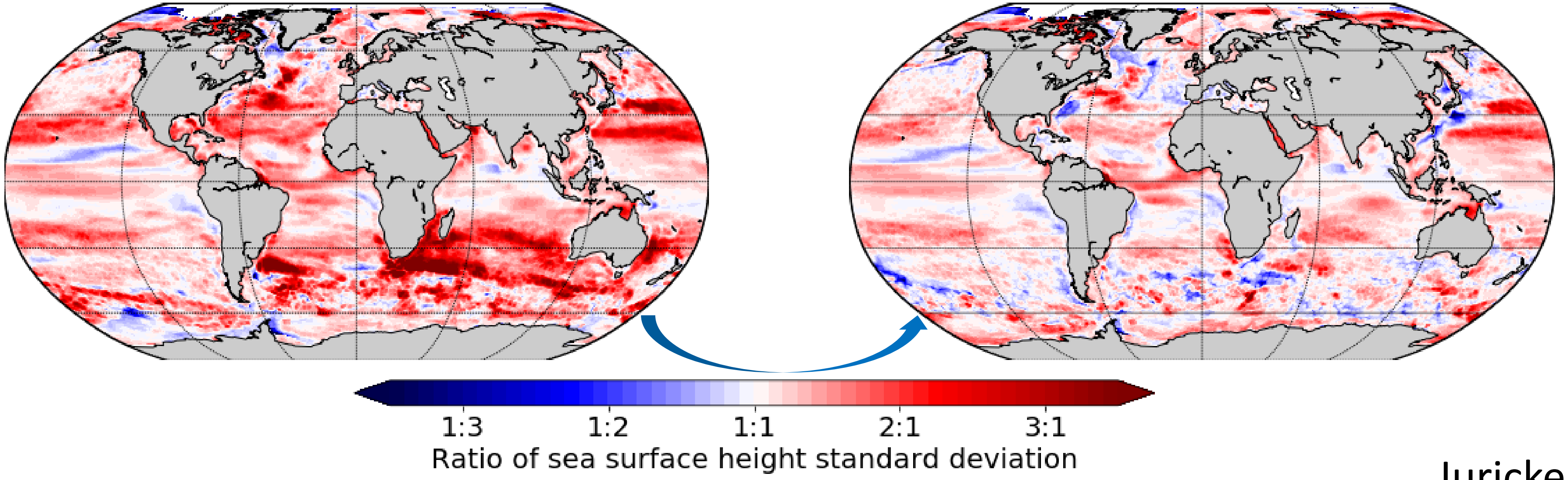


Reduced underestimation of SSH variability with backscatter

Globally around **10%** bias reduction
Locally (Agulhas, Malvinas) **>40%**

OBS/REFERENCE

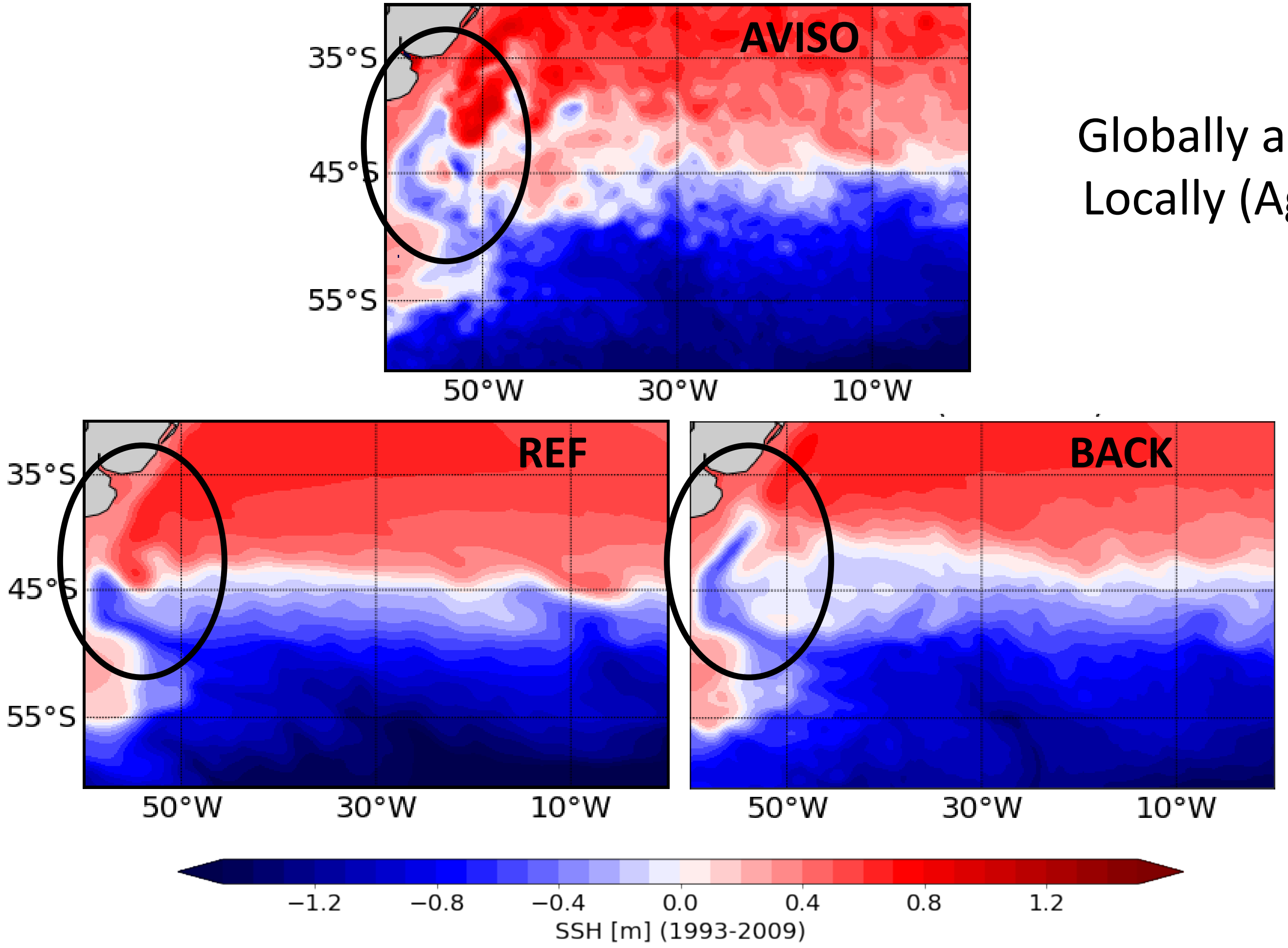
OBS/DBACKSCATTER



Juricke et al. (2020a)

Kinetic energy backscatter: Global results (DB)

Improved representation of mean currents with backscatter
Changes in mean SSH, Malvinas Current

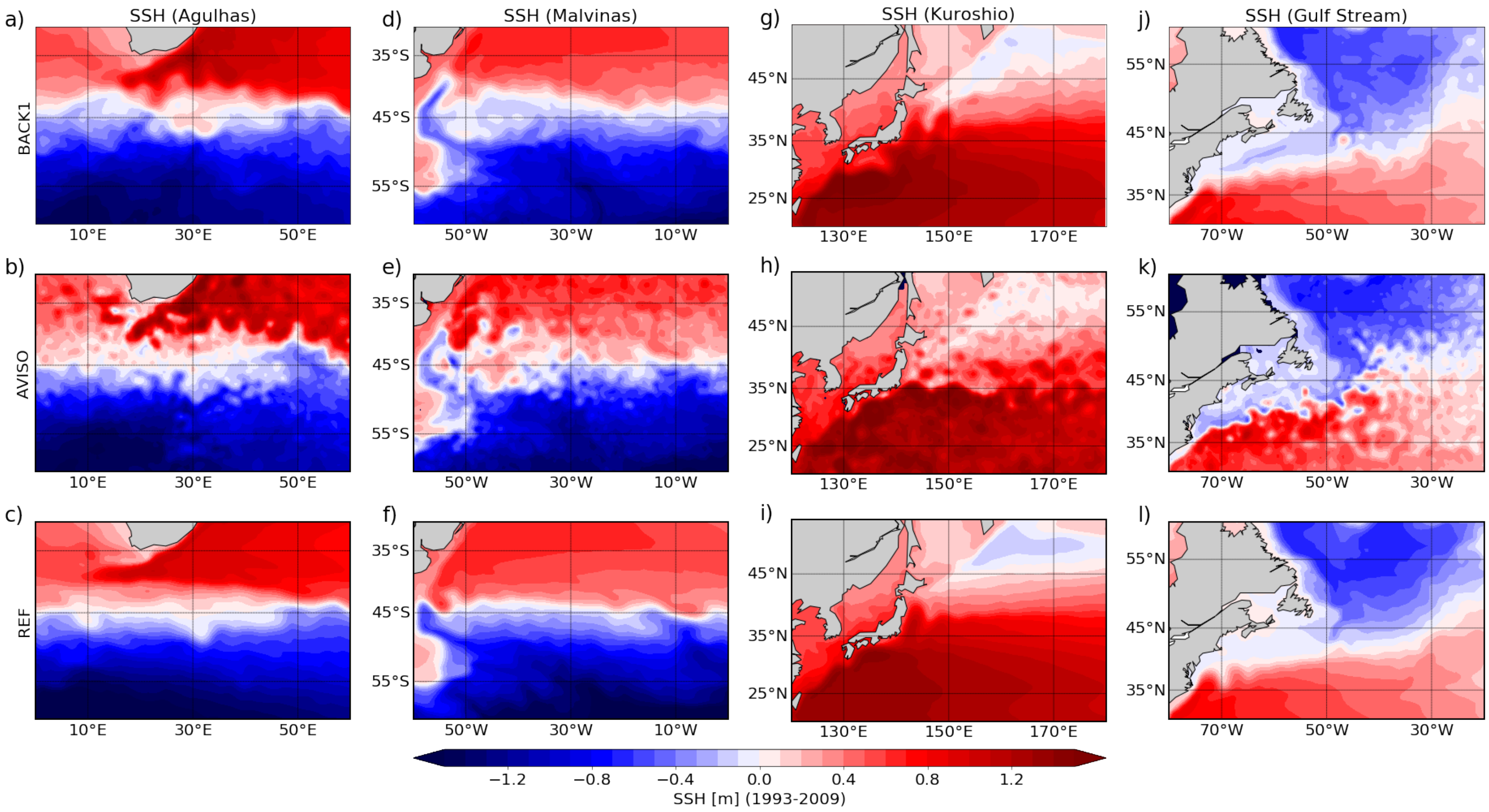


Globally around **10%** bias reduction
Locally (Agulhas, Malvinas) **15-20%**

Juricke et al. (2020a)

Kinetic energy backscatter: Global results (DB)

Improved representation of mean currents with backscatter

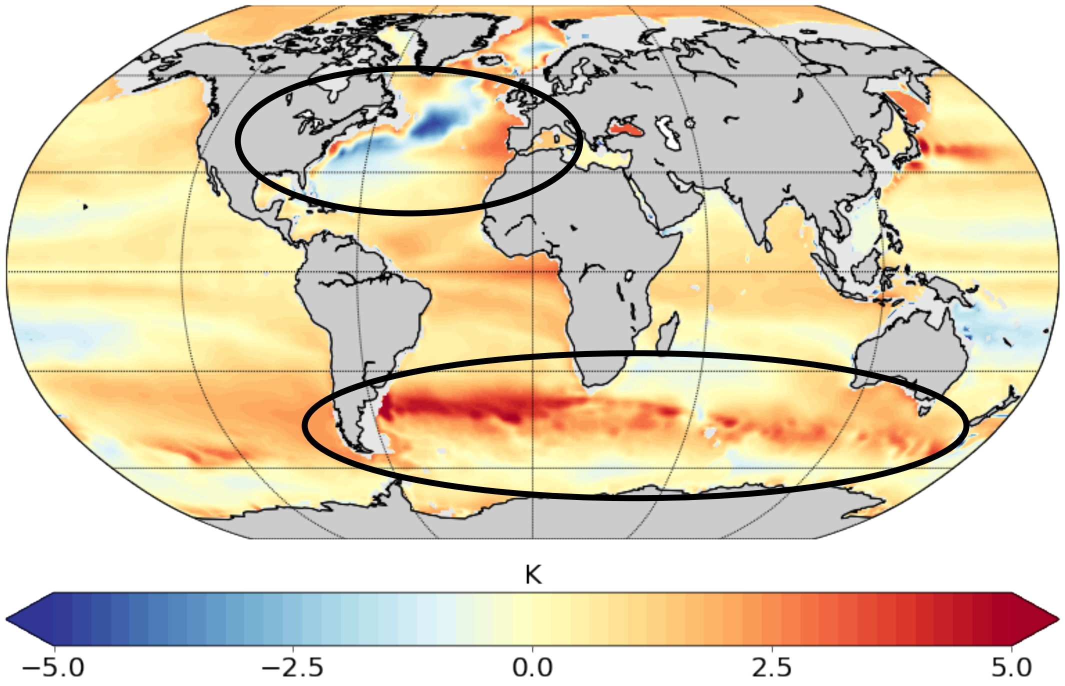


Juricke et al. (2020a)

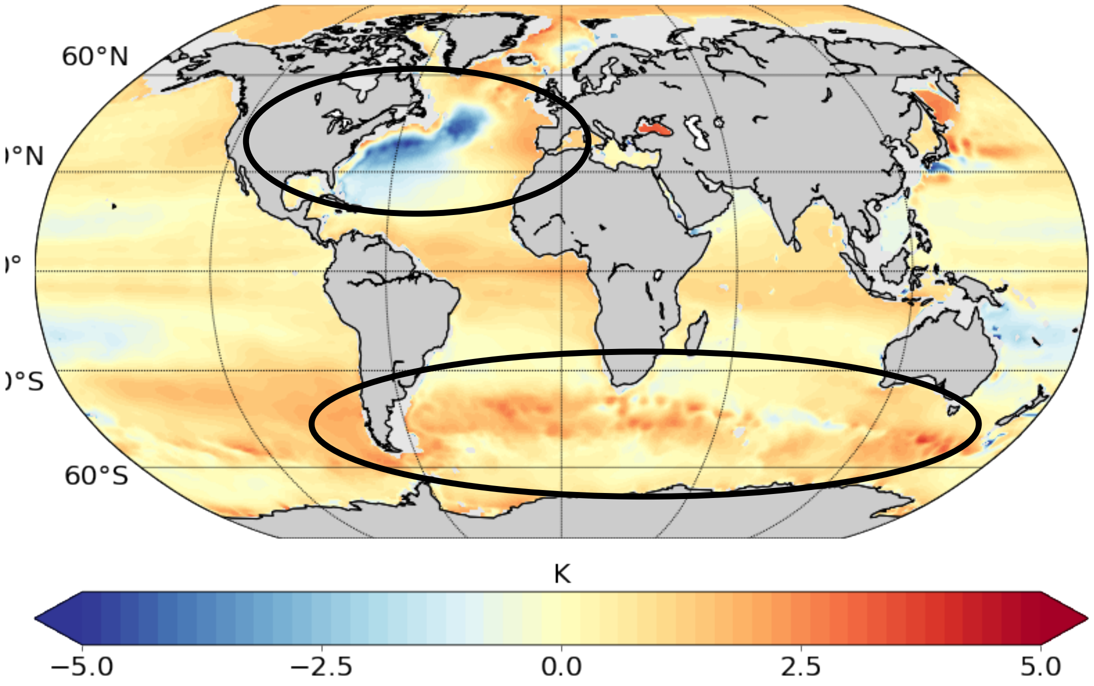
Kinetic energy backscatter: Global results (KB)

Temperature biases are reduced at various vertical levels, especially in the Southern Ocean and part of North Atlantic

Reference 500m



Backscatter 500m



Globally around **10%** T and S bias reduction at surface
Locally (Indian Ocean transect) around **30%**
More or less neutral at depth

Juricke et al. (2020b)

Kinetic energy backscatter: Global results (DB)

Bias reduction due to dynamic backscatter

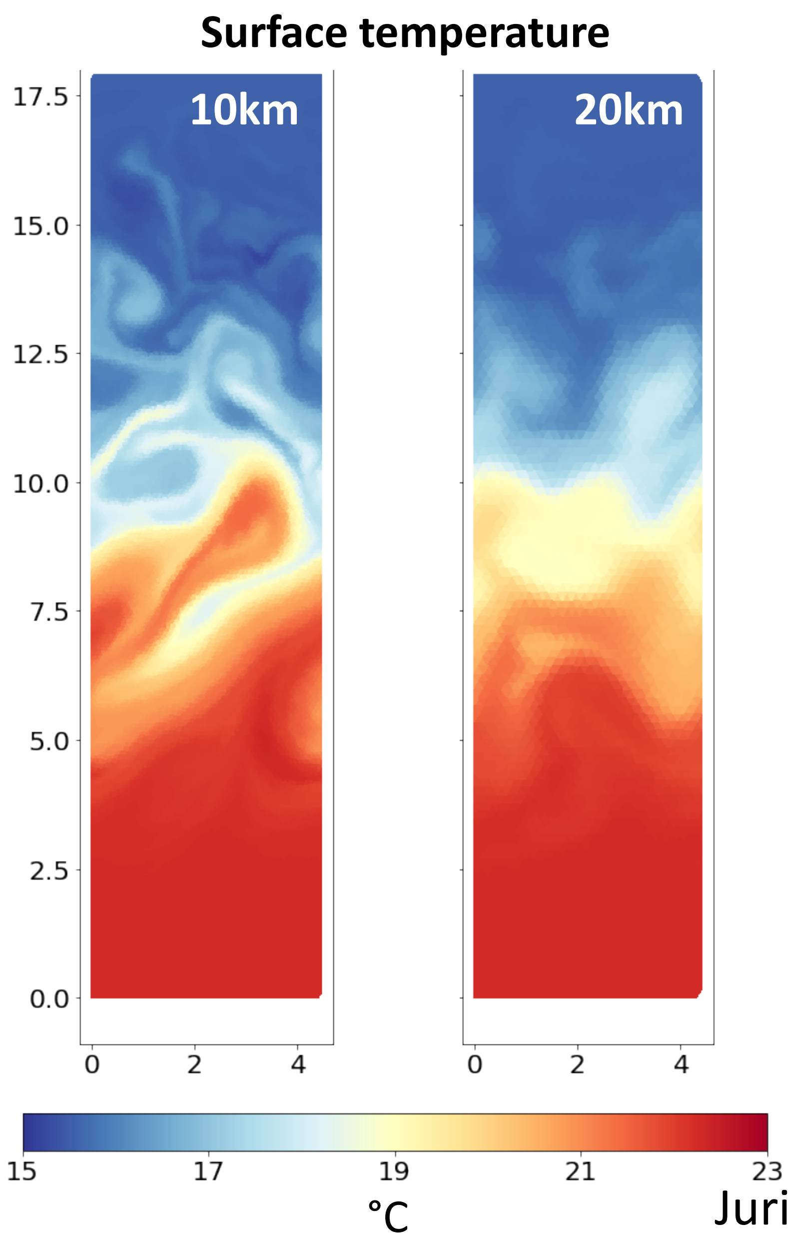
Region	Sea surface height mean bias	Sea surface height standard deviation bias
Global	11%	7%
Southern Ocean (30-60°S)	14%	34%
Agulhas (30-60°S, 0-60°E)	21%	42%

	Temperature mean bias	Salinity mean bias
Global surface	11%	12%
Indian transect	31%	28%

General bias reductions in variability and mean of currents, and in mean temperature and salinity both in specific regions (up to 40%) and globally (around 10%)

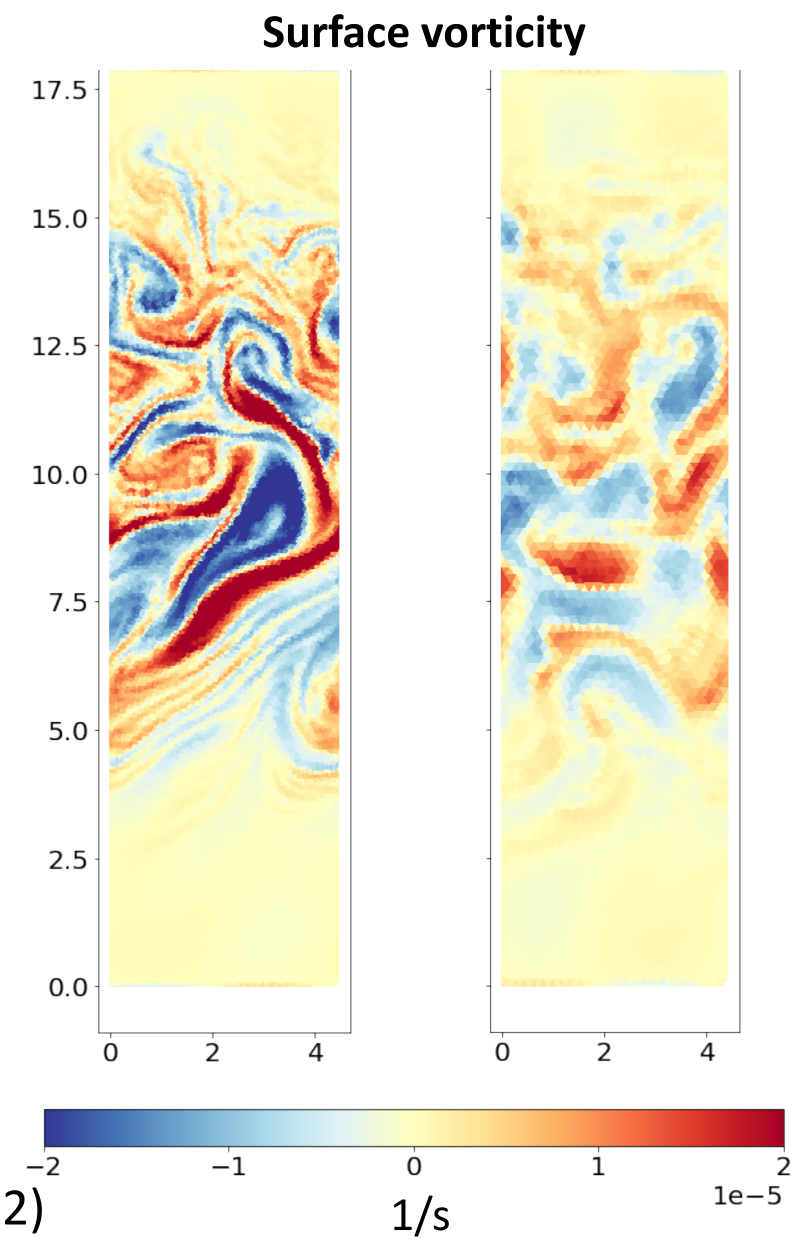
Juricke et al. (2020a)

Kinetic energy backscatter: Idealized setups



Making use of a hierarchy of model setups, e.g. Soufflet et al. (2016) setup

→ Rigorous intercomparison of new developments between modelling groups (e.g. FESOM, NEMO, ICON-O etc.)

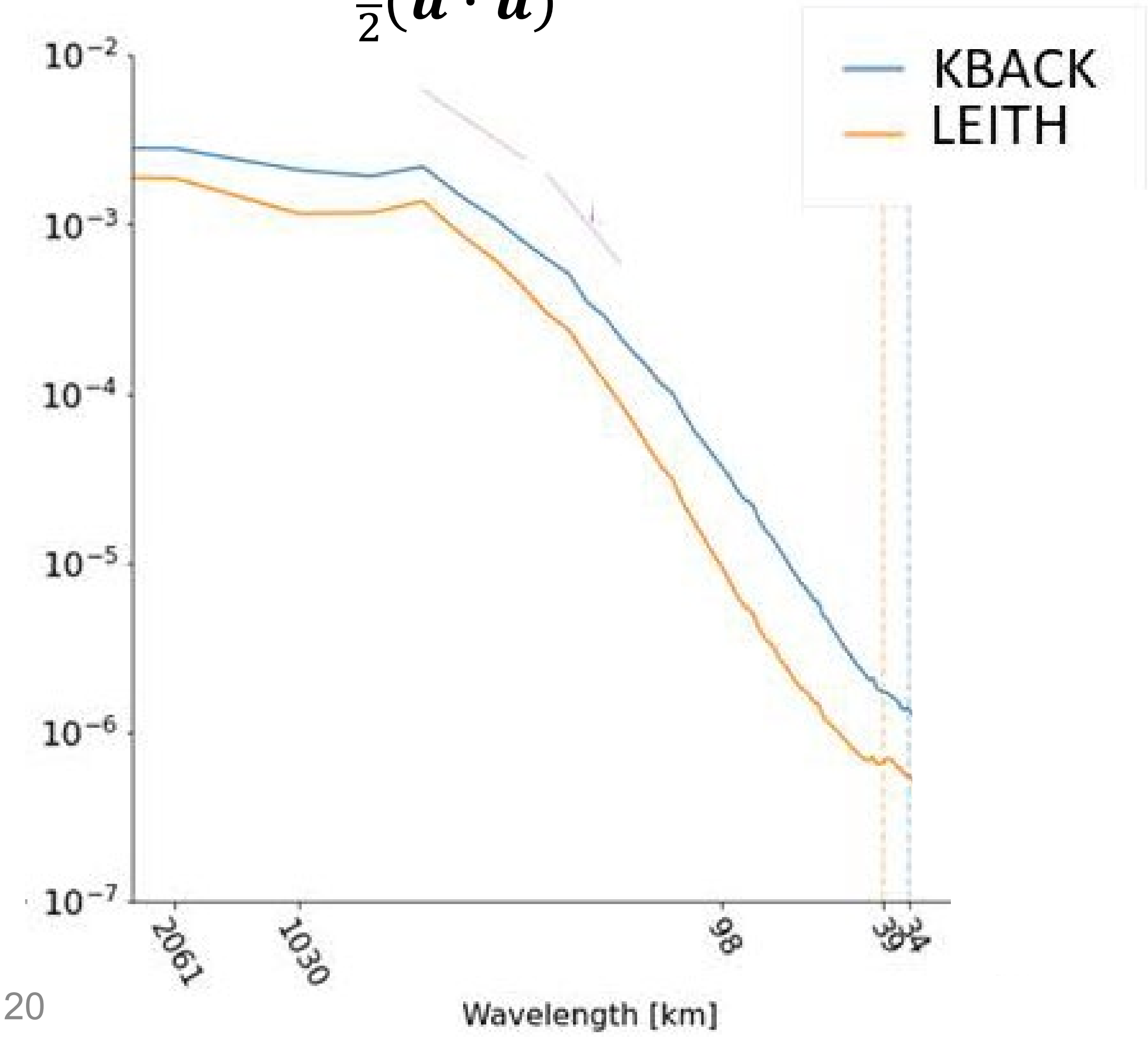


Juricke et al. (2019, 2020b, 2022)

Kinetic energy backscatter: Idealized setups

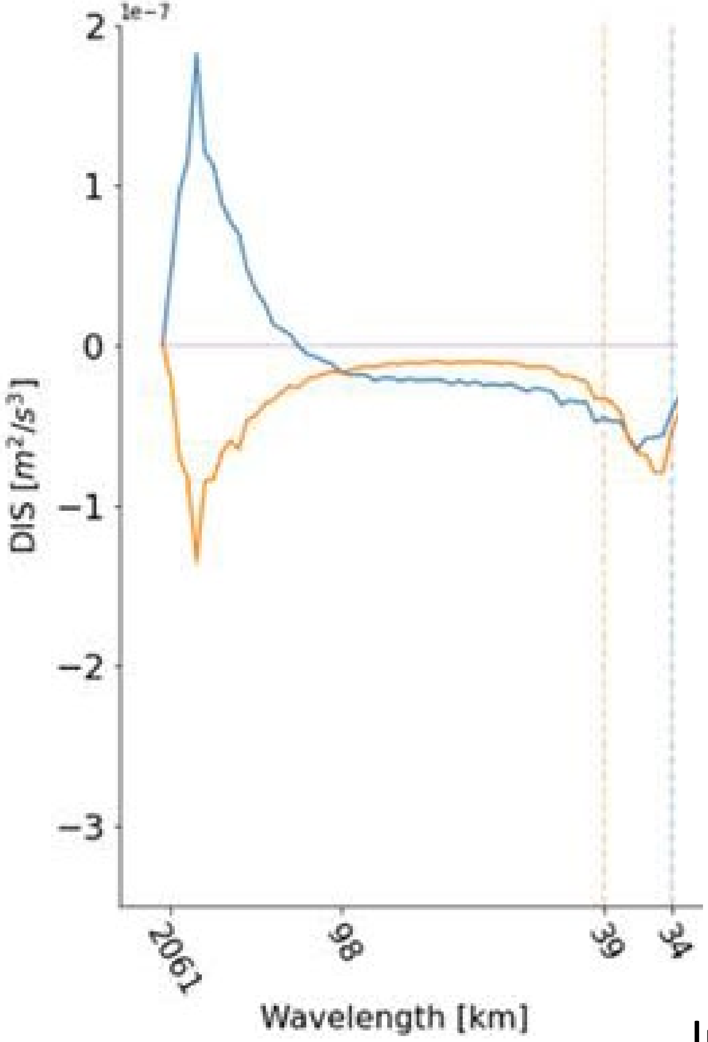
Kinetic energy spectrum

$$\frac{1}{2}(\vec{u} \cdot \vec{u})$$



Dissipation power spectrum

$$\vec{u} \cdot (V(\vec{u}) + B(\vec{u}))$$



Juricke et al. (2022)

Summary

- Kinetic energy backscatter leads to large improvements not just in eddy variability but also mean flow and water mass properties
- Different backscatter options are available depending on demands on efficiency, flexibility, level of sophistication, stability, etc.
- Improved viscosity coefficients can further reduce overdissipation
- Idealized settings allow for rigorous intercomparison of various momentum closures under controlled conditions before applying them to global simulations

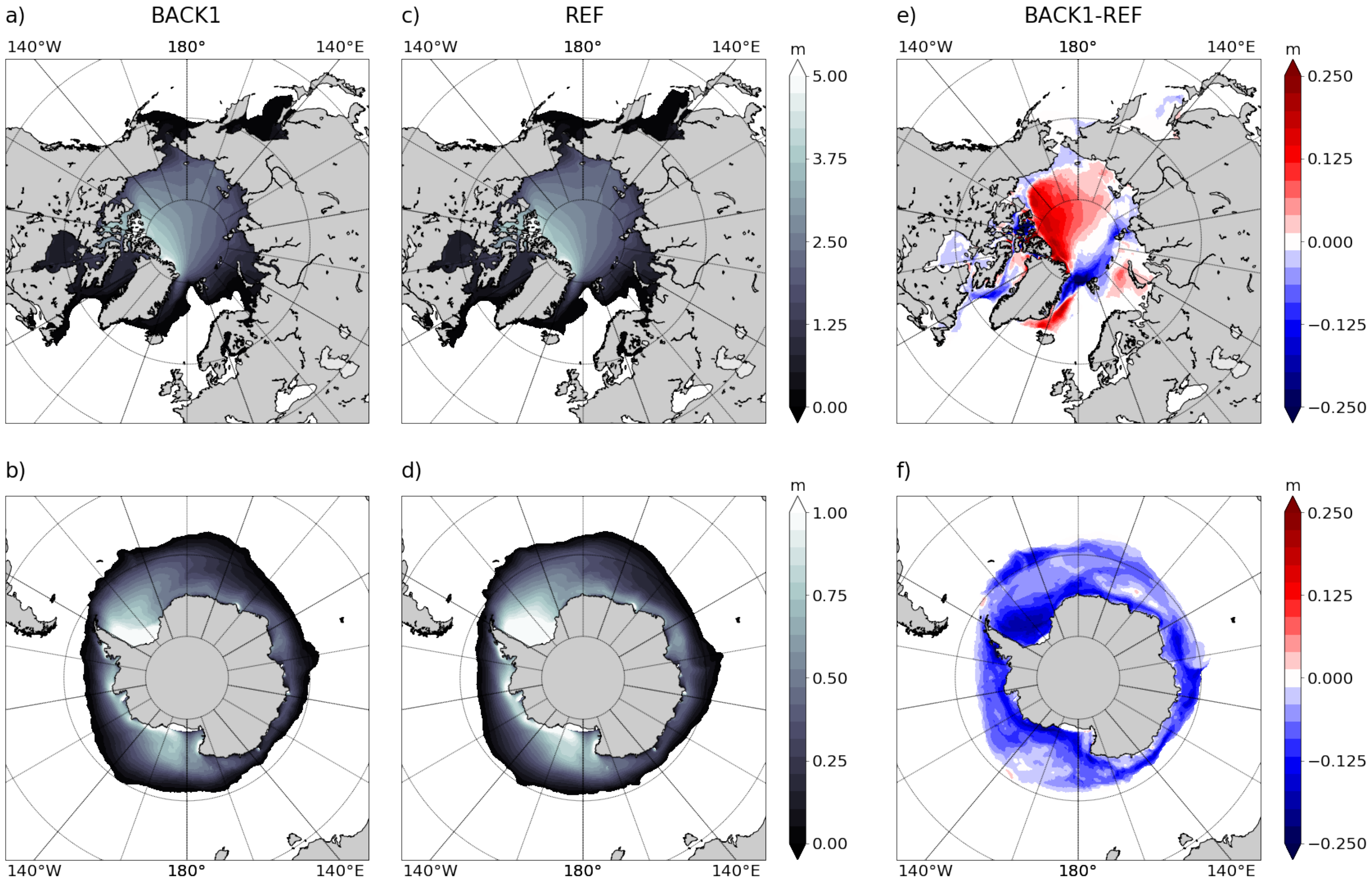
Outlook

- Application in coupled simulations with AWI-CM3 (Streffing et al., 2022)
- Improvements of backscatter with respect to:
  - Choice of viscosity and backscatter operator and coefficient
  - Formulation of subgrid energy budget (e.g. including advection)
  - Choice of physical dissipation coefficient
  - Inclusion of stochasticity (together with other stochastic schemes)
- Combined Gent-McWilliams and backscatter parameterization for all resolutions
- Rigorous intercomparison of momentum closures

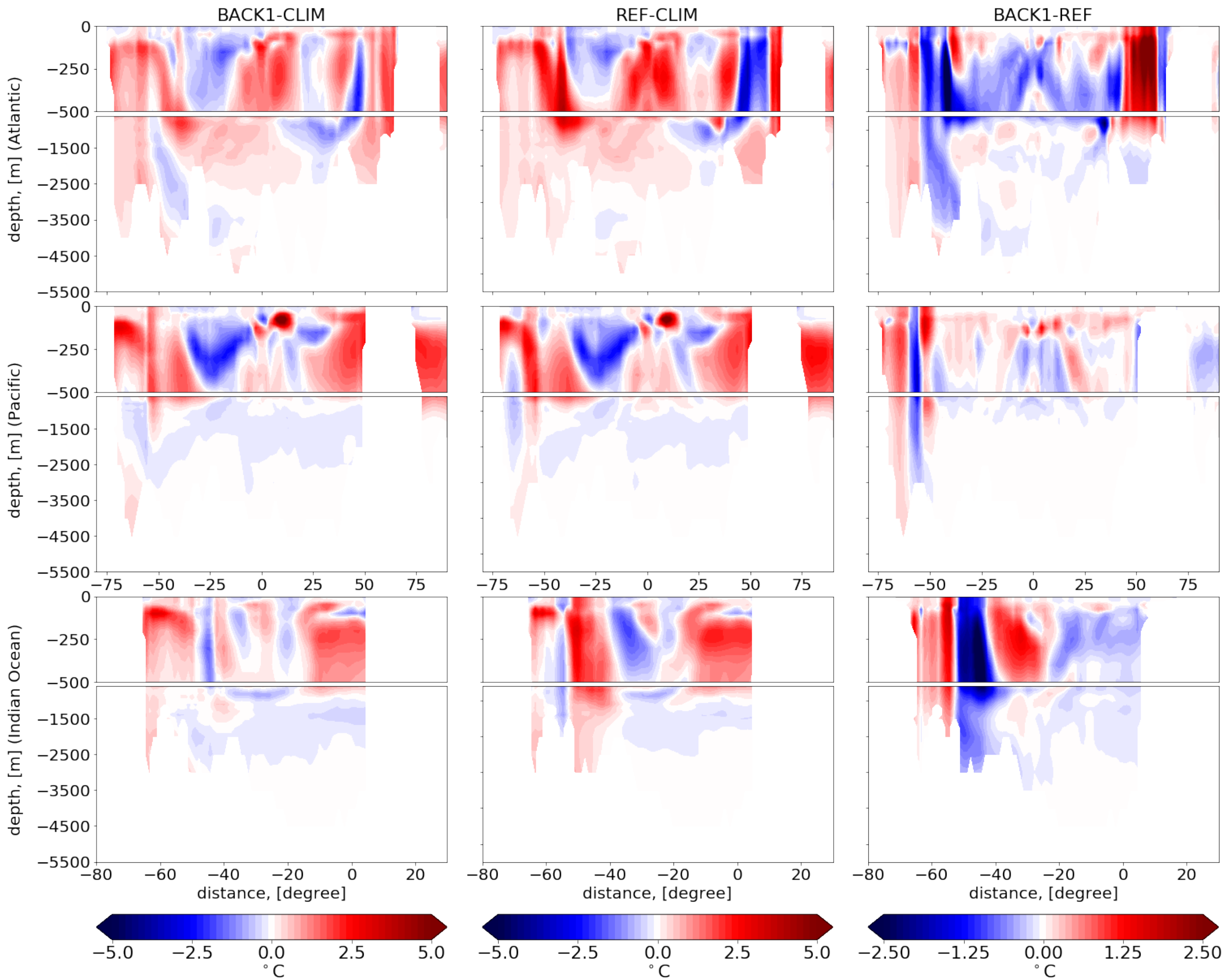
Eddies and Waves: Theory, Models, and Observations

14th - 16th February 2023, Hamburg, Germany

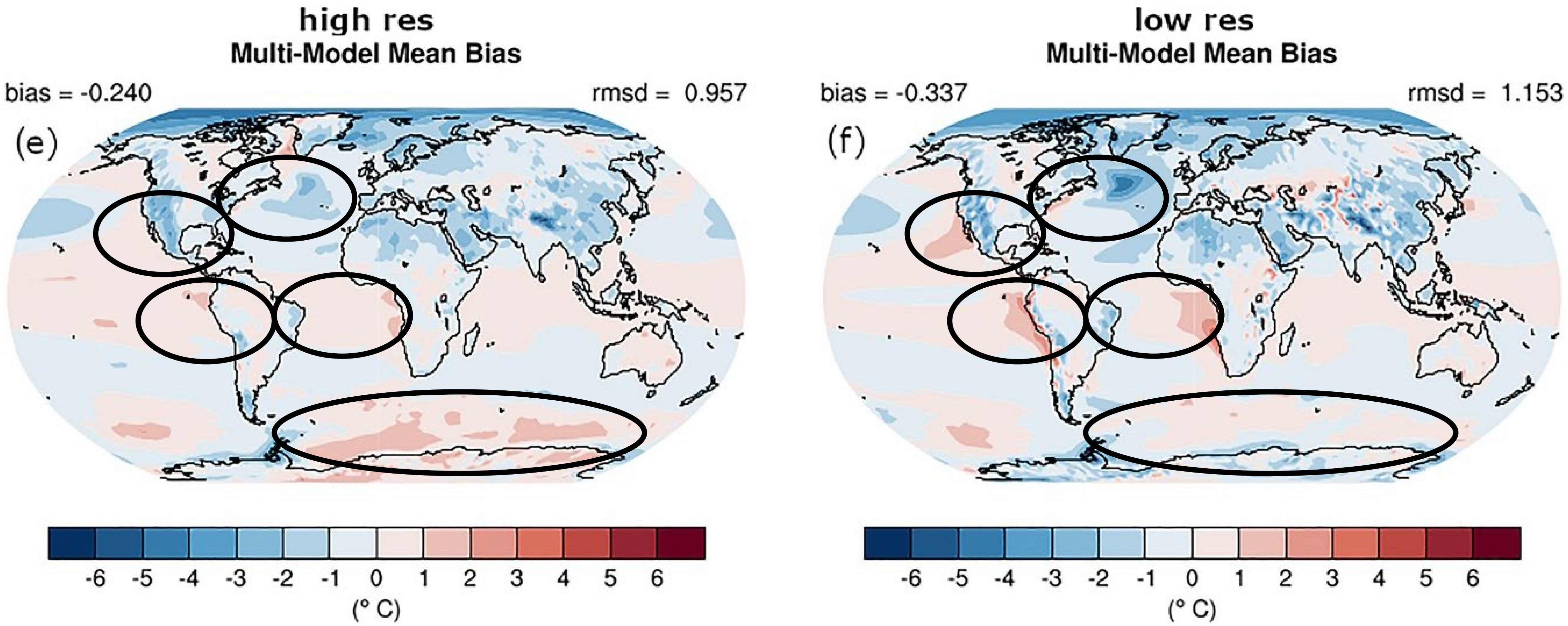
Kinetic energy backscatter: Global results (DB)



Kinetic energy backscatter: Global results (DB)



Ocean modelling



Resolution increase can help but is not the full answer

Bock et al., 2020

Ocean modelling

AWI-CM3 CMPI: 0.931

	arctic MAM	arctic JJA	arctic SON	arctic DJF	northmid MAM	northmid JJA	northmid SON	northmid DJF	tropics MAM
siconc	1.07	0.92	0.74	0.98	0.67	1.07	1.23	0.84	
tas	1.08	0.42	0.42	0.80	0.63	0.97	0.92	0.69	0.79
clt	0.90	1.16	1.19	1.07	0.70	0.76	0.66	0.78	0.85
pr	0.77	0.87	1.02	1.07	0.87	1.22	1.10	0.91	1.11
rlut	1.02	0.88	0.61	0.49	1.01	0.67	0.63	0.90	1.21
uas	0.65	0.85	0.64	0.91	0.70	0.84	0.56	0.67	0.98
vas	0.62	0.80	0.69	0.82	0.73	0.74	0.74	0.65	0.95
300hPa ua	0.75	0.99	0.95	1.23	0.94	1.23	0.86	1.12	0.95
500hPa zg	0.29	0.62	1.31	1.05	0.41	0.85	0.78	0.63	0.38
SD zos	0.66	0.42	0.61	0.61	0.88	0.93	0.90	0.87	1.02
SD tos	1.06	1.04	0.97	1.06	0.81	1.77	1.49	0.97	1.07
mlotst	1.25	0.55	0.70	1.09	2.32	0.64	0.86	1.85	1.41

	tropics MAM	tropics JJA	tropics SON	tropics DJF	nino34 MAM	nino34 JJA	nino34 SON	nino34 DJF	southmid MAM	southmid JJA	southmid SON	southmid DJF	antarctic MAM	antarctic JJA	antarctic SON	antarctic DJF
siconc									0.97	1.15	1.23	1.16	1.79	3.49	3.50	1.68
tas	0.79	0.62	0.70	0.75	0.35	1.06	0.70	0.30	1.64	1.35	1.44	1.60	1.66	1.59	1.23	0.80

AWI-CM3-DART CMPI: 0.808

	arctic MAM	arctic JJA	arctic SON	arctic DJF	northmid MAM	northmid JJA	northmid SON	northmid DJF	tropics MAM	tropics JJA	tropics SON	tropics DJF	nino34 MAM	nino34 JJA	nino34 SON	nino34 DJF	southmid MAM	southmid JJA	southmid SON	southmid DJF	antarctic MAM	antarctic JJA	antarctic SON	antarctic DJF
siconc	1.26	1.16	1.27	0.86	0.57	1.04	1.54	0.66									0.97	1.14	1.20	1.16	1.48	2.36	2.10	1.36
tas	0.54	0.33	0.52	0.56	0.60	0.68	0.56	0.57	0.50	0.46	0.53	0.61	0.39	0.31	0.67	0.40	0.87	0.85	0.92	0.84	1.05	1.05	0.67	0.32
clt	1.29	1.05	1.14	1.27	0.72	0.77	0.77	0.93	0.70	0.70	0.70	0.74	0.85	0.41	0.31	0.88	0.97	1.21	1.06	0.93	0.92	0.89	0.73	0.75
pr	1.60	0.86	1.05	1.37	0.72	1.20	0.97	0.85	0.78	0.74	0.73	0.66	0.98	0.80	0.96	1.03	1.15	0.70	1.02	1.18	1.02	1.06	1.03	0.82
rlut	0.61	0.83	0.51	0.55	0.58	0.55	0.51	0.52	0.82	0.74	0.81	0.74	1.02	0.67	0.66	0.89	0.39	0.49	0.44	0.59	0.92	1.56	0.66	0.89
uas	0.40	0.64	0.40	0.39	0.38	0.76	0.32	0.31	0.59	0.54	0.59	0.51	0.65	0.47	0.34	0.44	0.45	0.63	0.57	0.46	0.30	0.37	0.37	0.27
vas	0.43	0.57	0.38	0.37	0.37	0.55	0.36	0.36	0.56	0.51	0.55	0.51	0.75	0.97	1.03	0.66	0.58	0.48	0.54	0.52	0.33	0.30	0.31	0.32
300 hPa ua	0.61	0.95	0.80	0.48	0.61	1.08	0.53	0.49	0.67	0.47	0.64	0.61	0.64	0.49	0.45	0.43	0.47	1.17	1.03	0.53	0.65	1.02	0.90	0.64
500 hPa zg	0.21	0.43	1.02	0.33	0.34	0.61	0.48	0.37	0.13	0.14	0.12	0.23	0.05	0.11	0.01	0.15	0.47	0.66	0.53	0.50	0.55	0.95	0.49	0.57
SD zos	0.59	0.48	0.56	0.58	0.64	0.60	0.63	0.65	0.63	0.66	0.70	0.69	1.36	1.30	1.53	1.21	0.59	0.62	0.61	0.61	0.86	0.72	0.89	0.94
SD tos	0.96	1.05	0.91	0.88	0.90	1.46	1.16	1.16	1.04	0.98	0.91	0.94	0.51	0.20	0.30	0.16	1.27	1.52	1.19	1.14	0.61	1.70	1.80	0.64
mlotst	0.72	0.58	0.53	0.66	1.50	0.61	0.60	1.12	1.13	0.98	1.40	1.05	1.75	1.90	2.08	2.36	0.88	1.26	1.83	1.61	2.82	3.24	3.14	5.45

Streffing et al., 2022