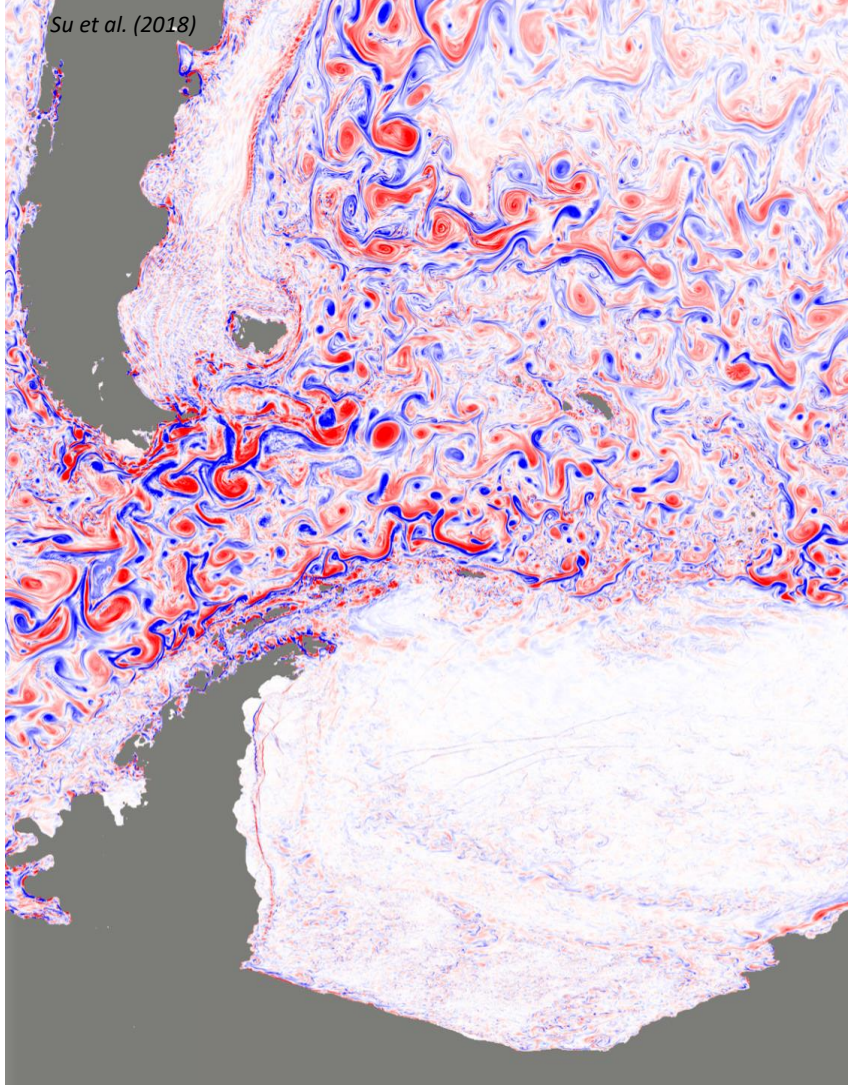

Image credit: 66 North


Su et al. (2018)


"Ocean vortex" generated by https://app.wombo.art/

An idealized Weddell Gyre and its extreme sensitivity to resolution

Andrew Styles[1], David Marshall[1], Mike Bell[2]

[1]Department of Physics | University of Oxford

[2]Met Office

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The Weddell Gyre

The Weddell Gyre is exposed to an **extreme** and **unique** environment:

- Low temperatures
- Extensive sea ice
- South of the Antarctic Circumpolar Current
- Large topographic features

It is a very **productive site** for **dense water masses**

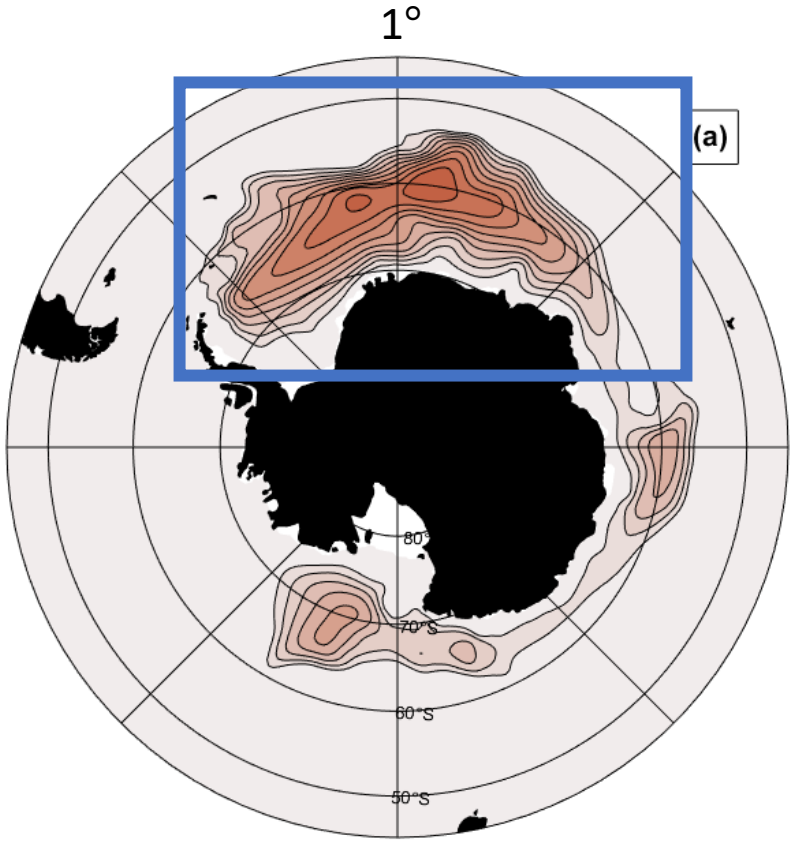

Figure by Dave Storkey
Time-averaged stream function from NEMO (ORCA1)

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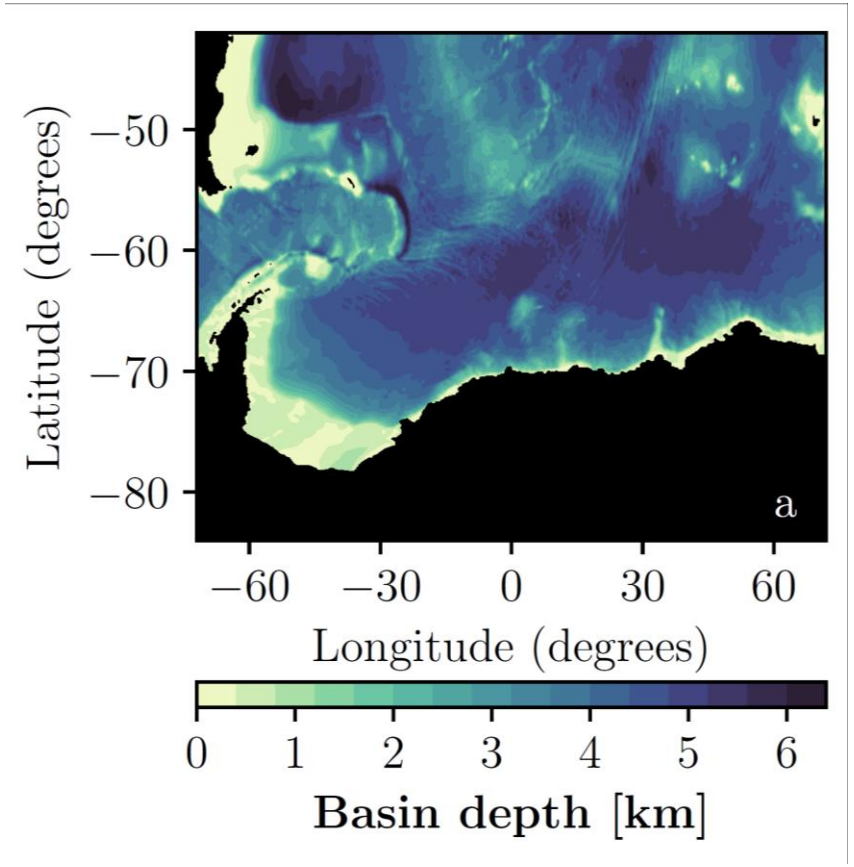
The Weddell Gyre

The bathymetry of the Weddell Gyre is also very extreme:

- Antarctic continental shelf
- Submarine ridge
  - **Partial barrier** between the Weddell Gyre and the ACC
  - Influences the **stratification** in the region *(Wilson et al., 2022)*



Bathymetry derived from the ETOPO1 data set (Amante & Eakins, 2009)

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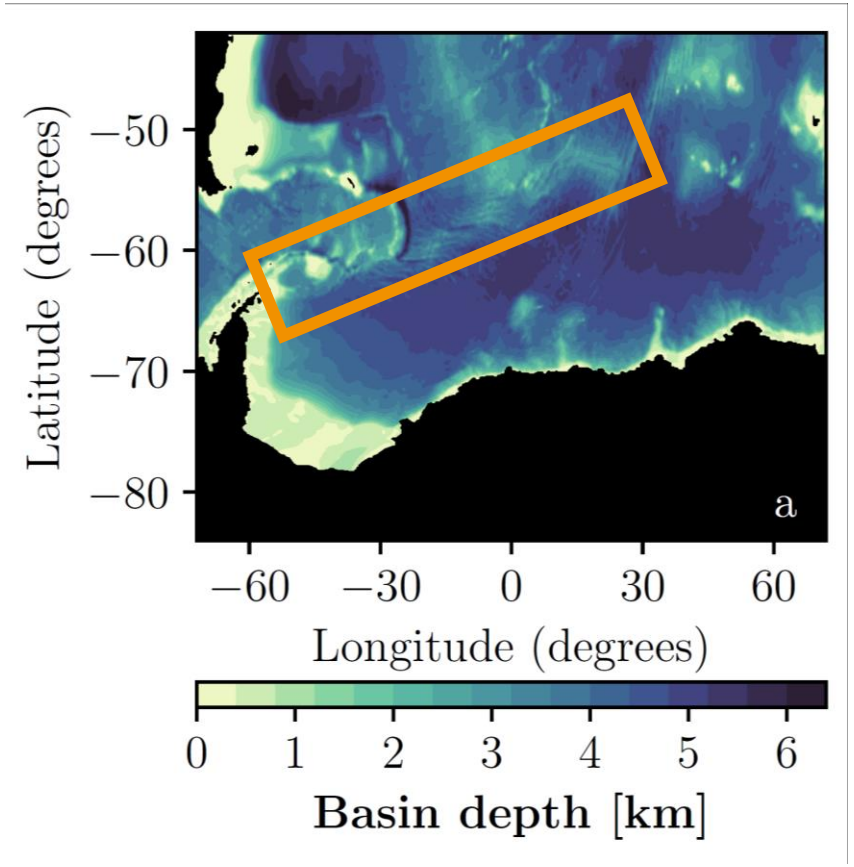

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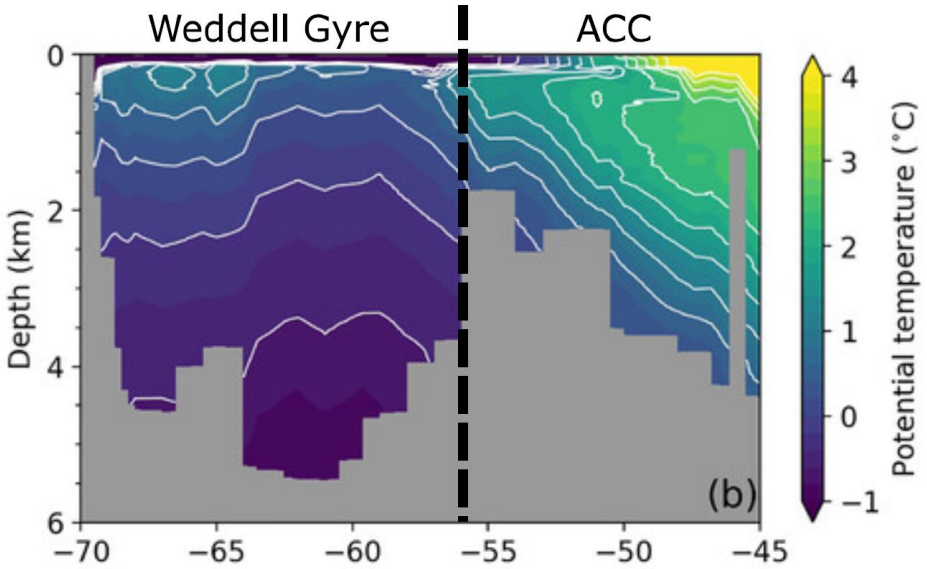

Reproduced from Wilson et al. (2022). A hydrographic section of potential temperature through the Weddell Sea. Data from the R/V Polarstern during the 1992 ANT/X research cruise

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Performance in ocean models

The **strength** of the Weddell Gyre varies significantly with **model resolution**

1°: **Eddy parametrized** 1/4°: **Eddy-permitting** 1/12°: **Eddy rich**

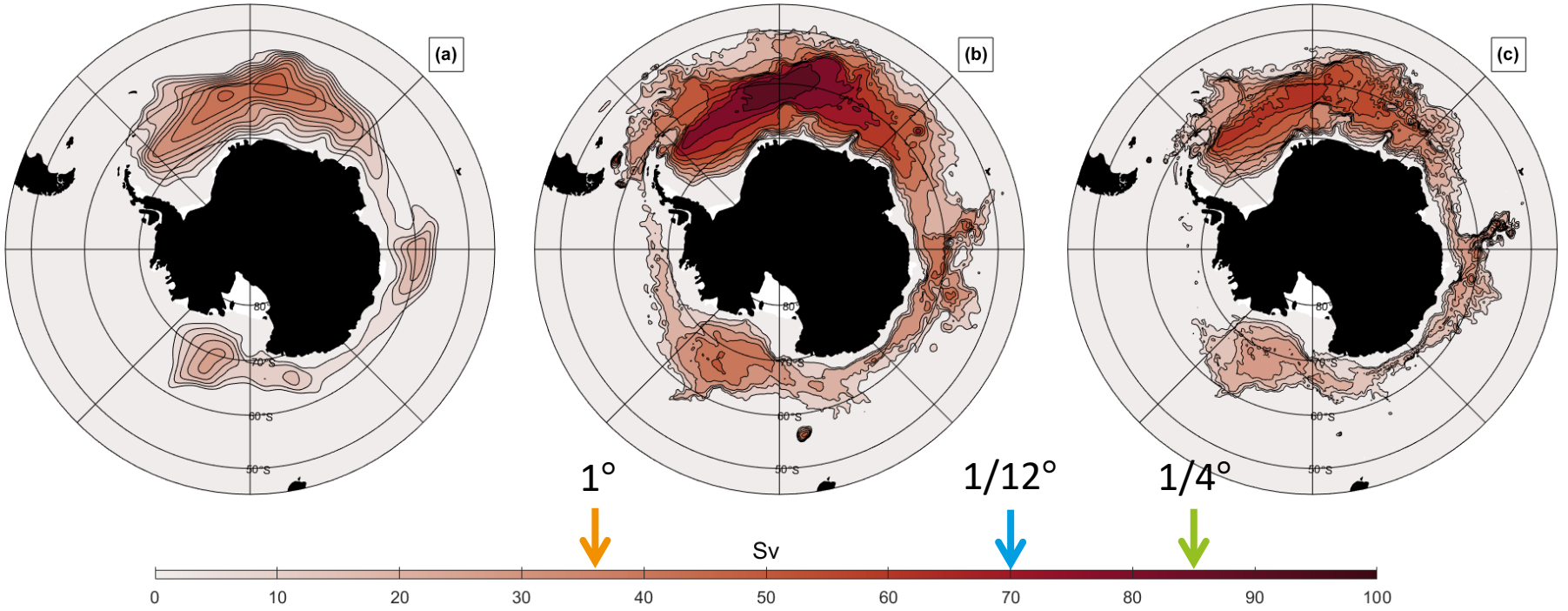

Figure by Dave Storkey

Time-averaged stream function from NEMO (a) ORCA1 (b) ORCA025 (c) ORCA12

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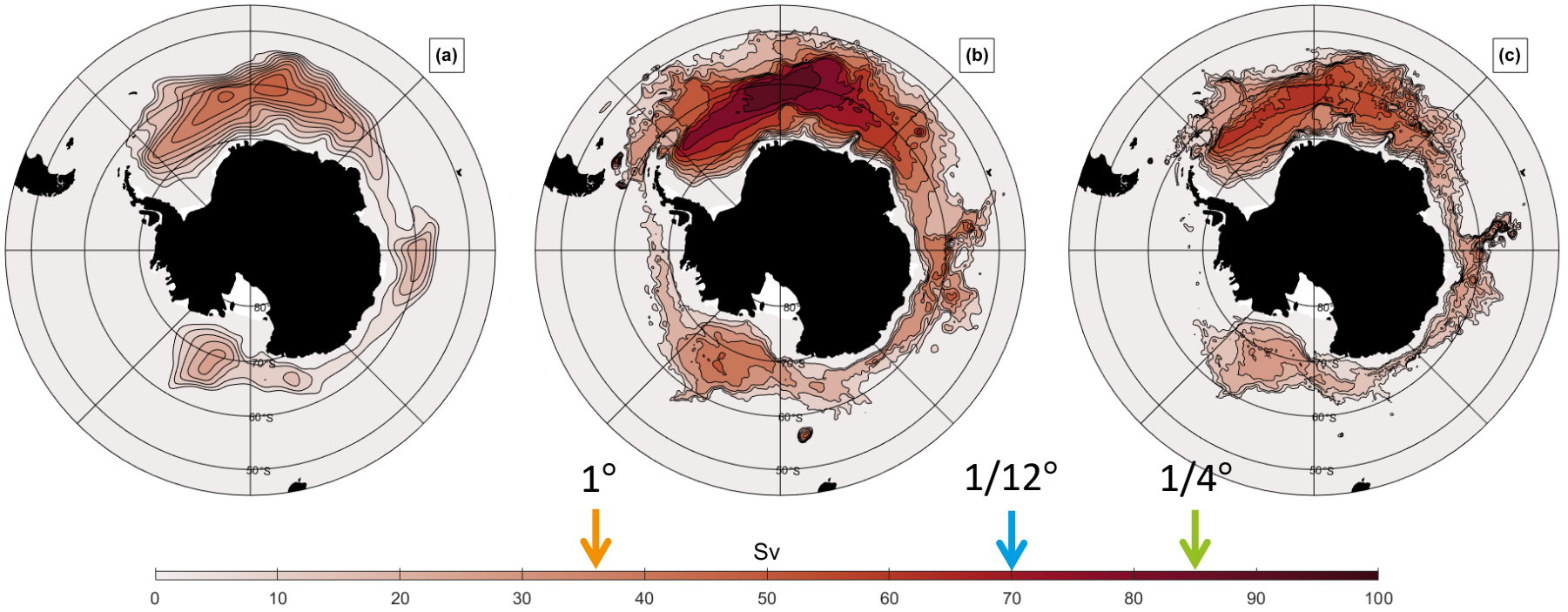

Figure by Dave Storkey
Time-averaged stream function from NEMO (a) ORCA1 (b) ORCA025 (c) ORCA12

This is also an issue **between** climate projections.

CMIP5 estimates of the Weddell Gyre strength range from **10 to 80 Sv** *Wang (2013)*

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The experiment

Use an **idealized model** to investigate why the Weddell Gyre is so **sensitive to model resolution**

The idealized model is:

- Highly **configurable**
- Computationally **affordable**
- Easier to **interpret**
- Easier to **expand on**

The experiment

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The idealized model is:

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- Easier to **interpret**
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In total
53
simulations

The experiment

Use an **idealized model** to investigate why the Weddell Gyre is so **sensitive to model resolution**

The idealized model is:

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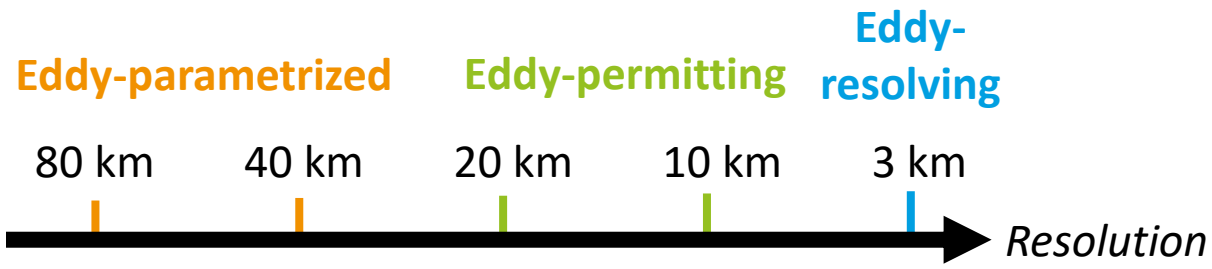
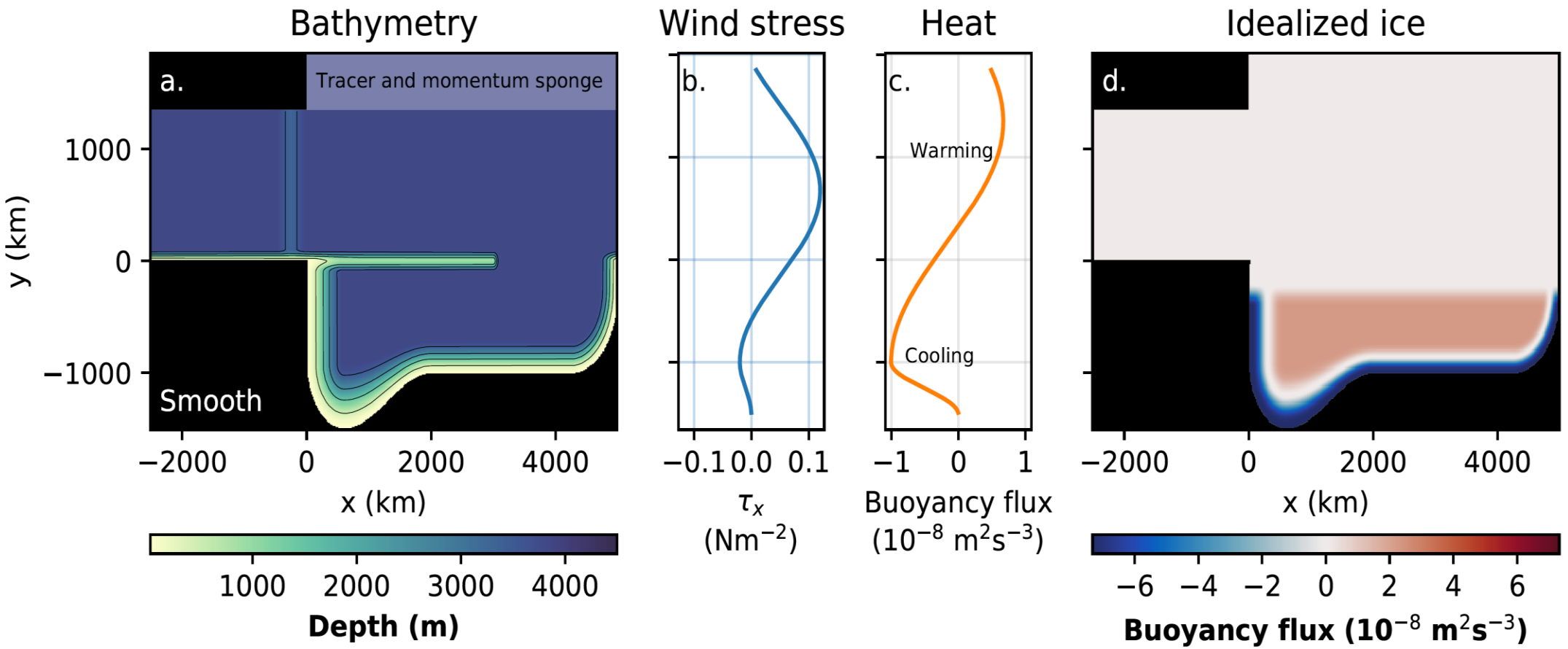


Only **eddy-parametrized** simulations use GM

Diffusion coefficients scale **linearly** with resolution

Model design



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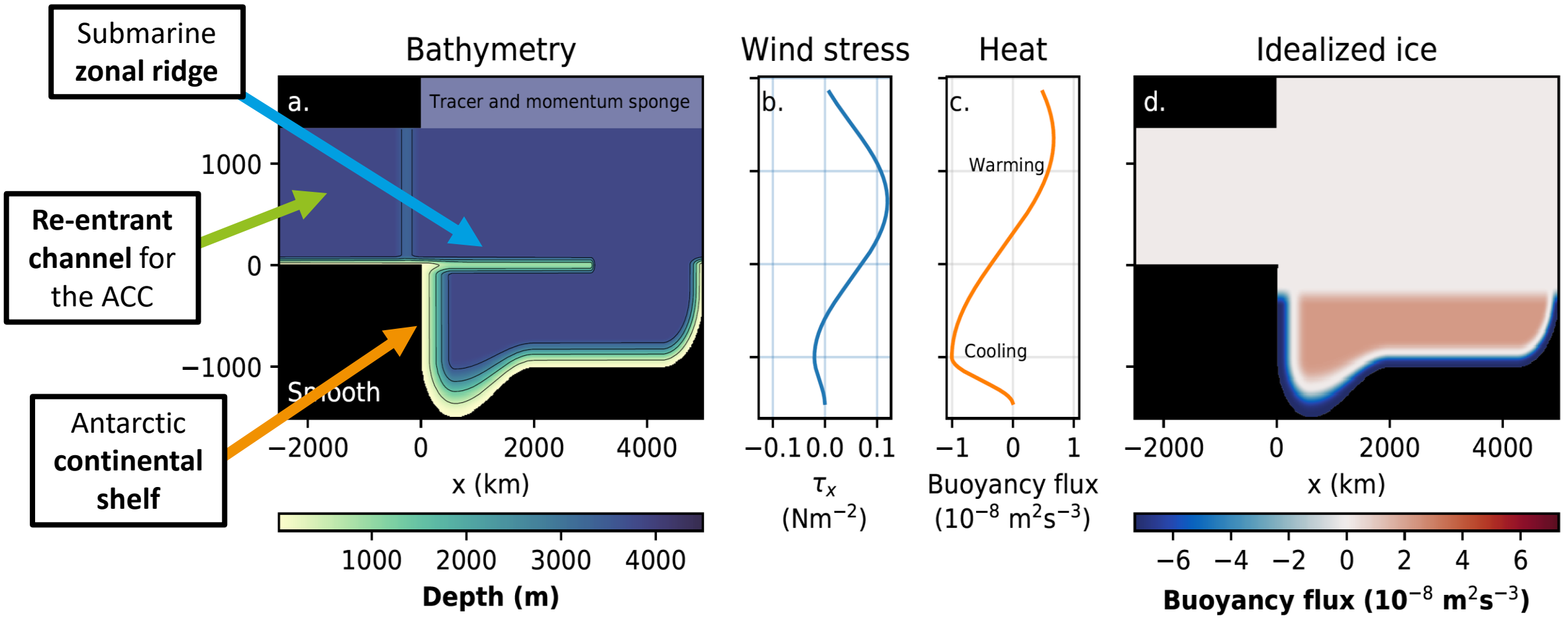
Model design



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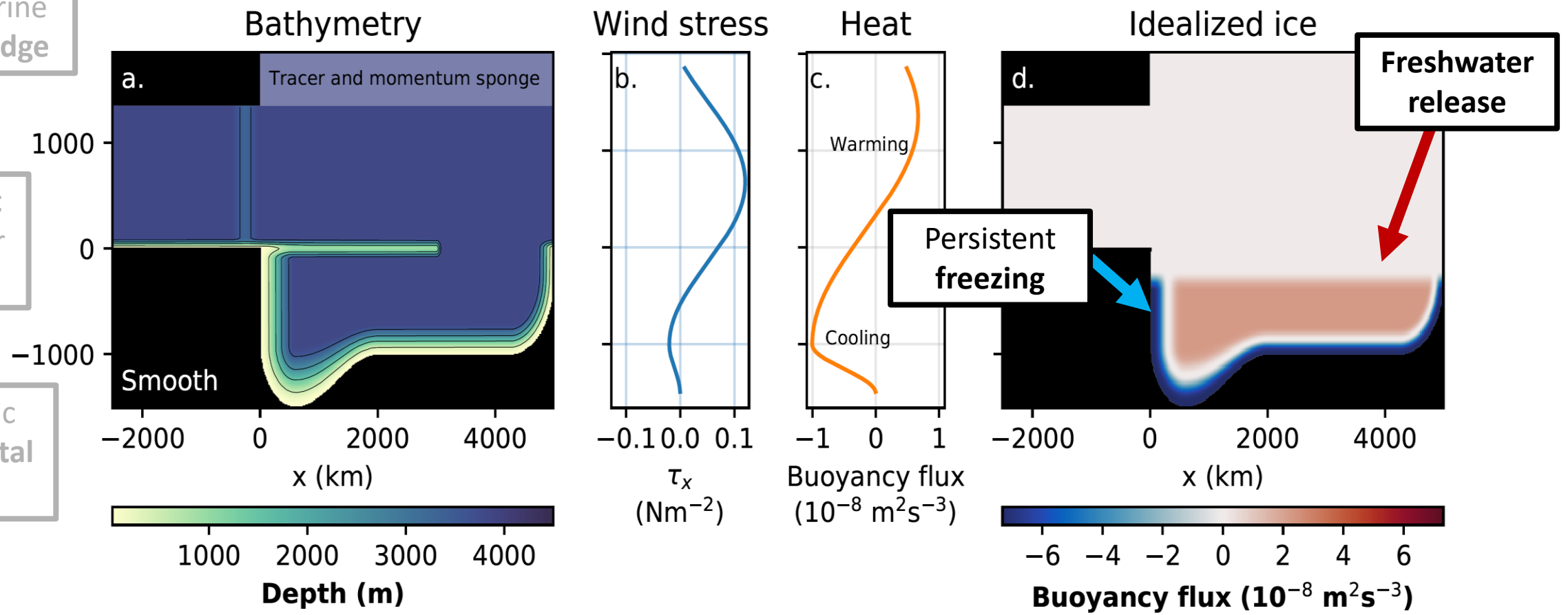
Model design

Submarine **zonal ridge**

Re-entrant channel for the ACC

Antarctic **continental shelf**



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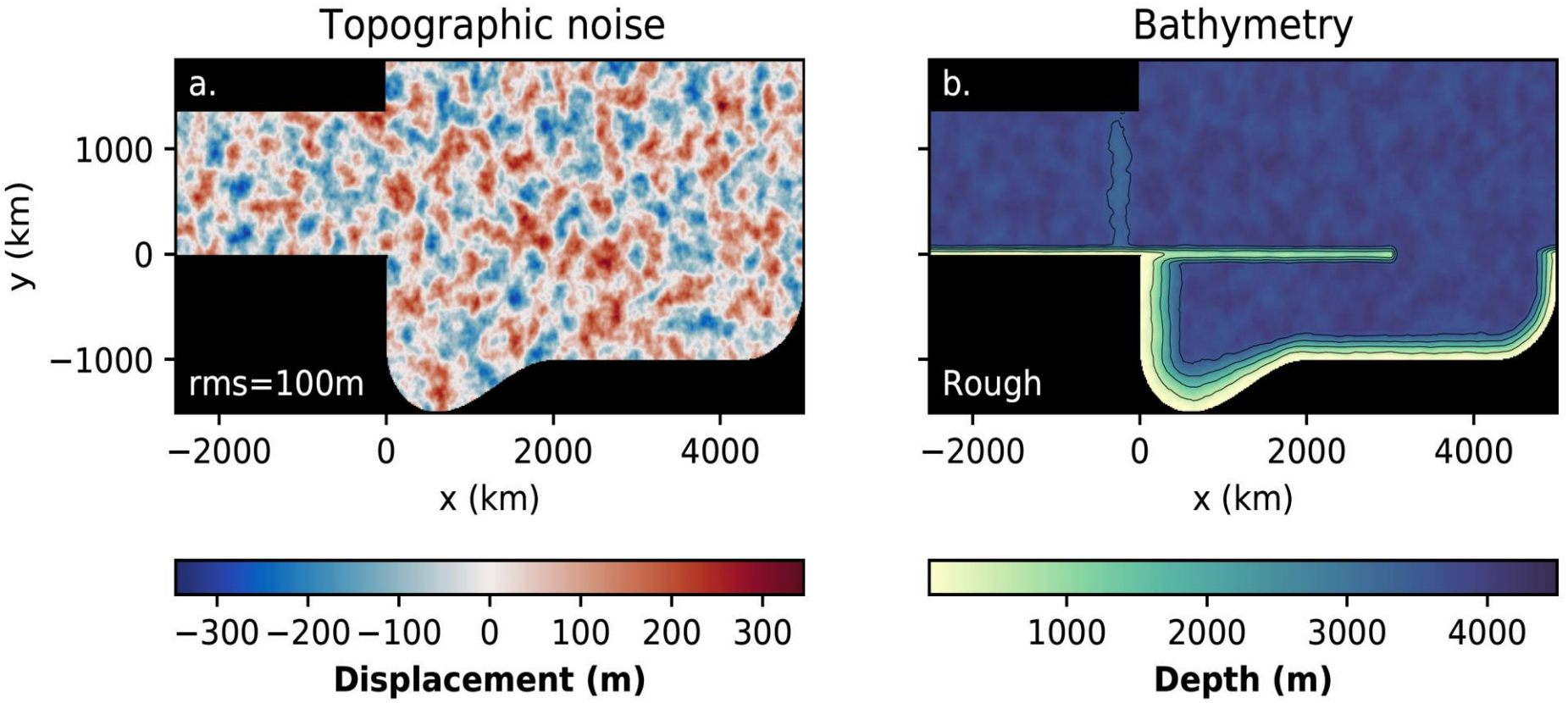
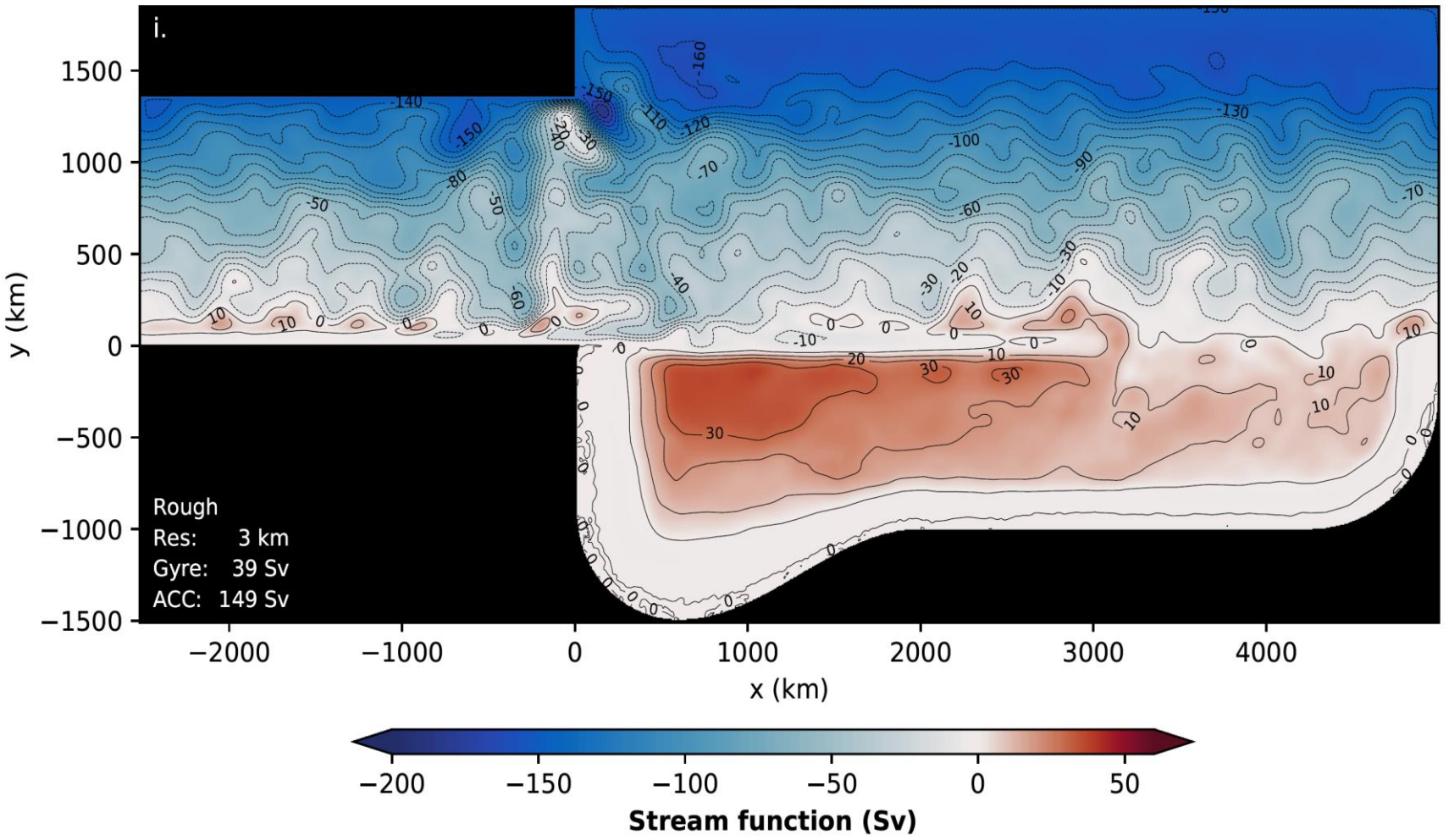
Topographic noise



Also introduce topographic noise for a **rough bathymetry.**

Results: Eddy resolving stream function



Stream function for the **eddy-resolving 3km** simulation

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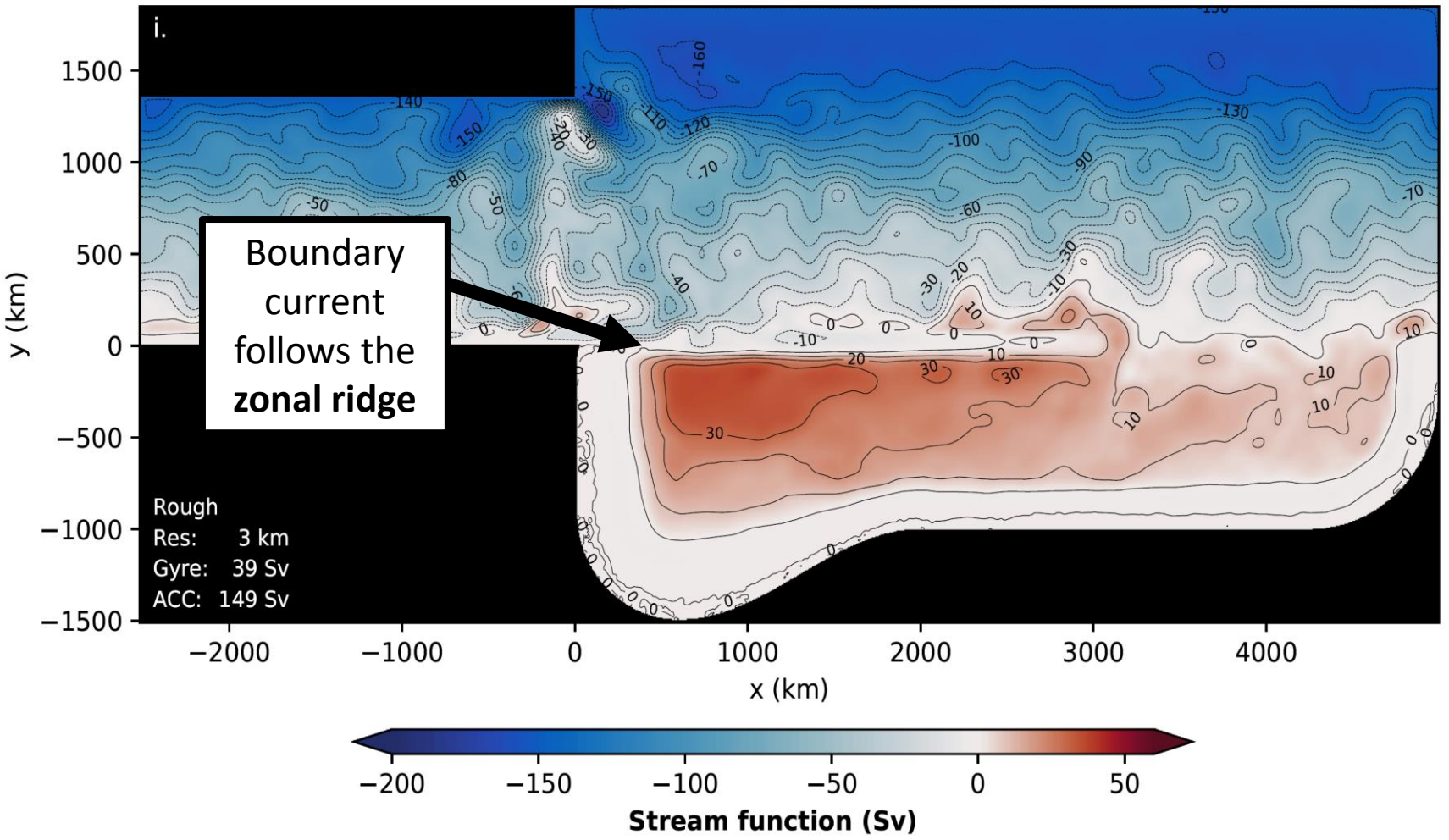
Results: Eddy resolving stream function



Stream function for the **eddy-resolving 3km** simulation

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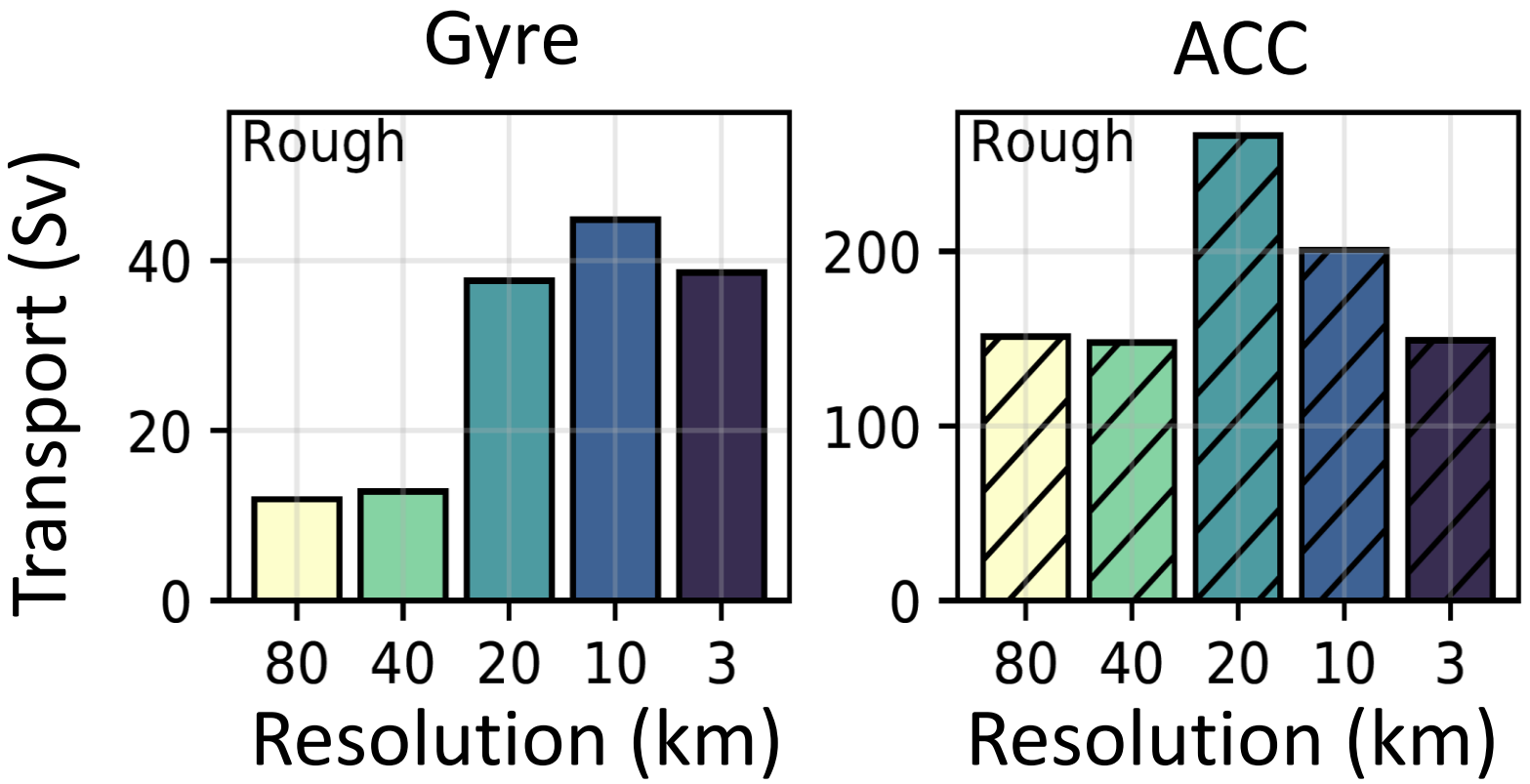
Results: Sensitivity to resolution

Both the **Weddell Gyre** and **ACC transports** are strongest at **eddy-permitting** resolutions (20-10km)



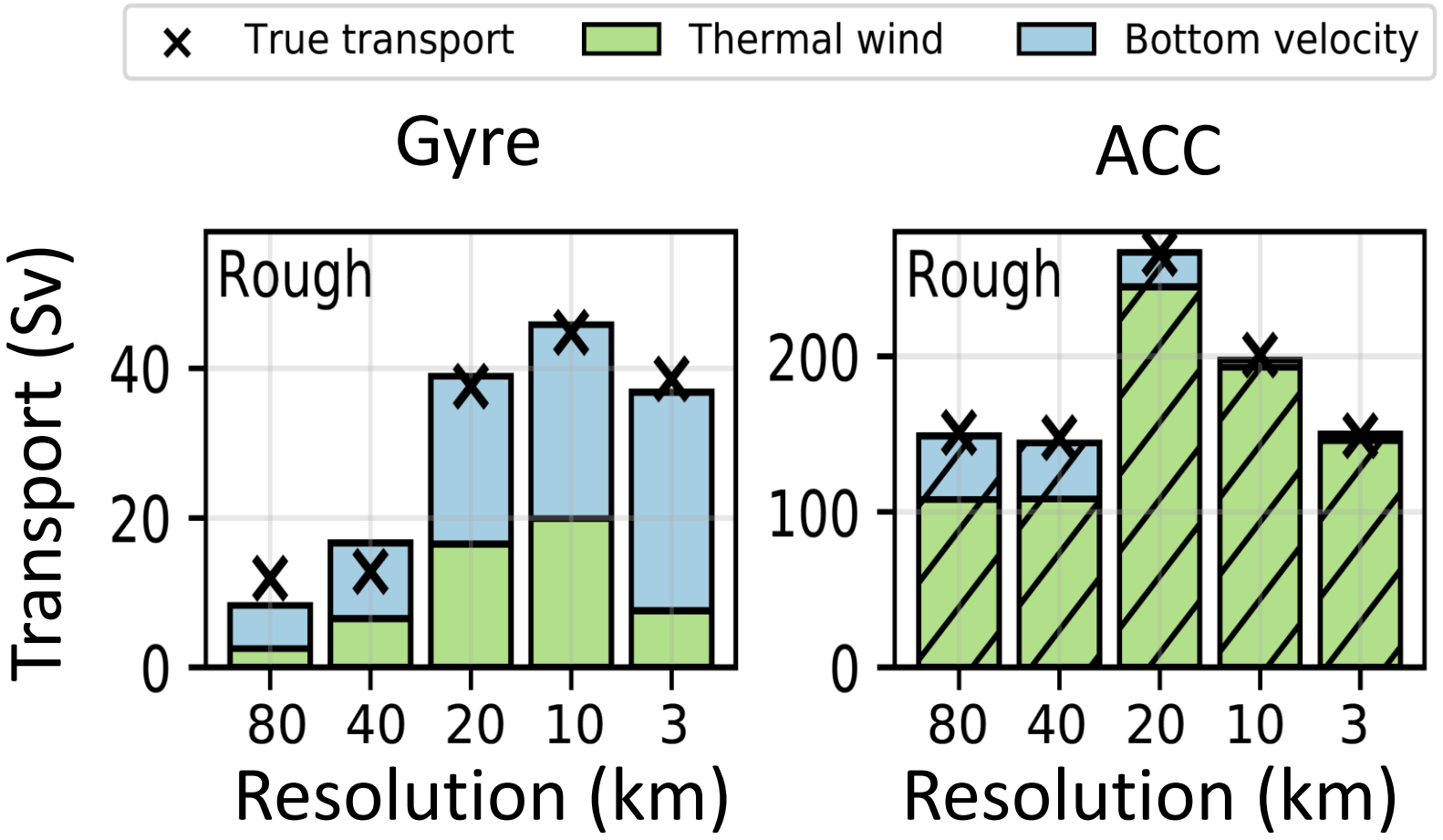
Results: Thermal wind decomposition

We **decompose** the transport into two parts:

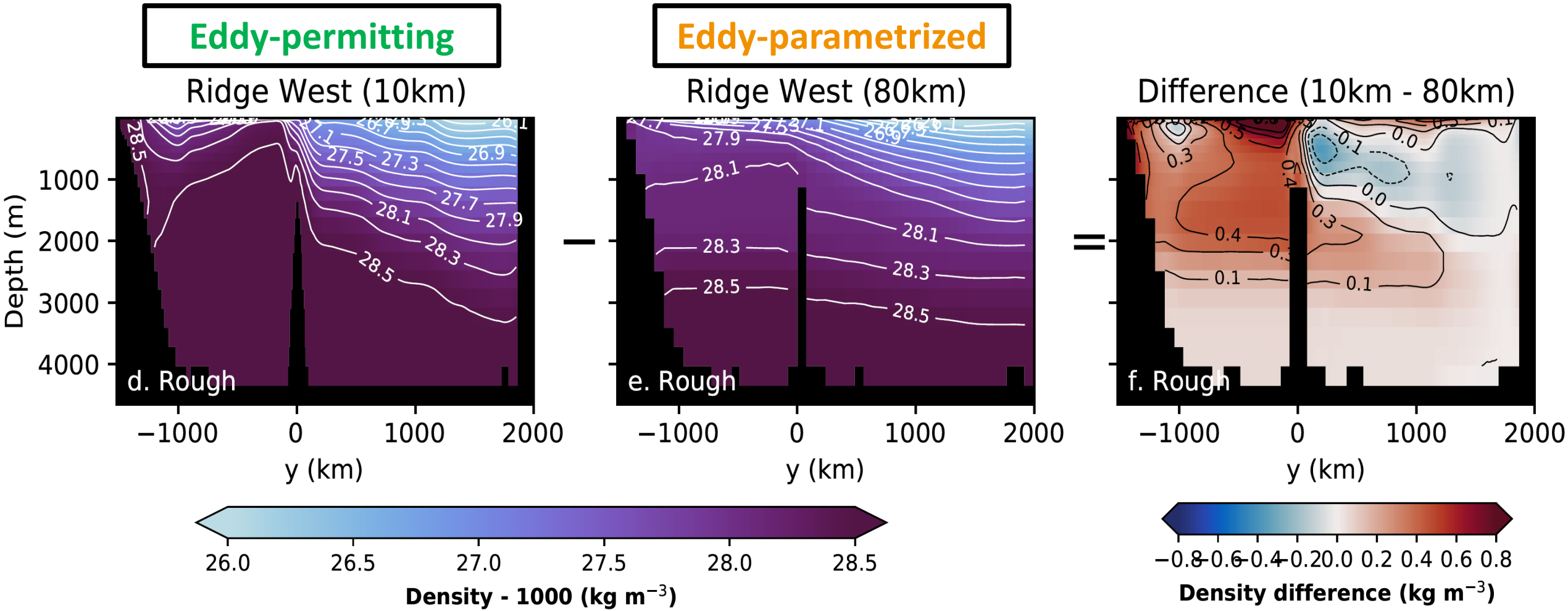
- **Bottom flow**
  Transport = $u_b H$

- **Thermal wind**
  Geostrophic transport from **density gradients**

$$f\frac{\partial \boldsymbol{u}}{\partial z} = -\frac{g}{\rho_0}\left(\hat{\boldsymbol{k}} \times \nabla_{\mathbf{h}}\rho\right)$$



Results: Isopycnal tilt



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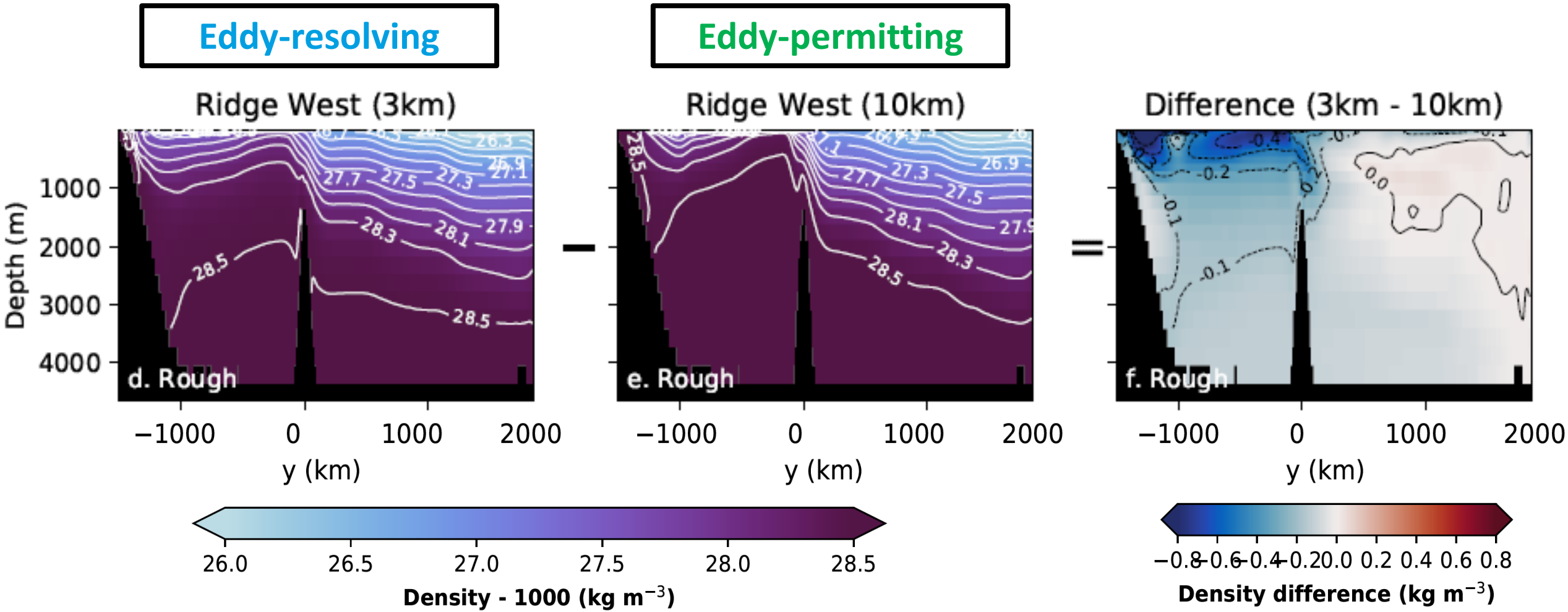
Results: Isopycnal tilt



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Summary

- An idealized model of the Weddell Gyre is very sensitive to **model resolution**
- The gyre transport is largest at **eddy-permitting** resolutions
- The peak gyre transport can be partially explained by **increased isopycnal tilt**
- The remainder is caused by an increase in the **bottom flow**

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Thank you for listening

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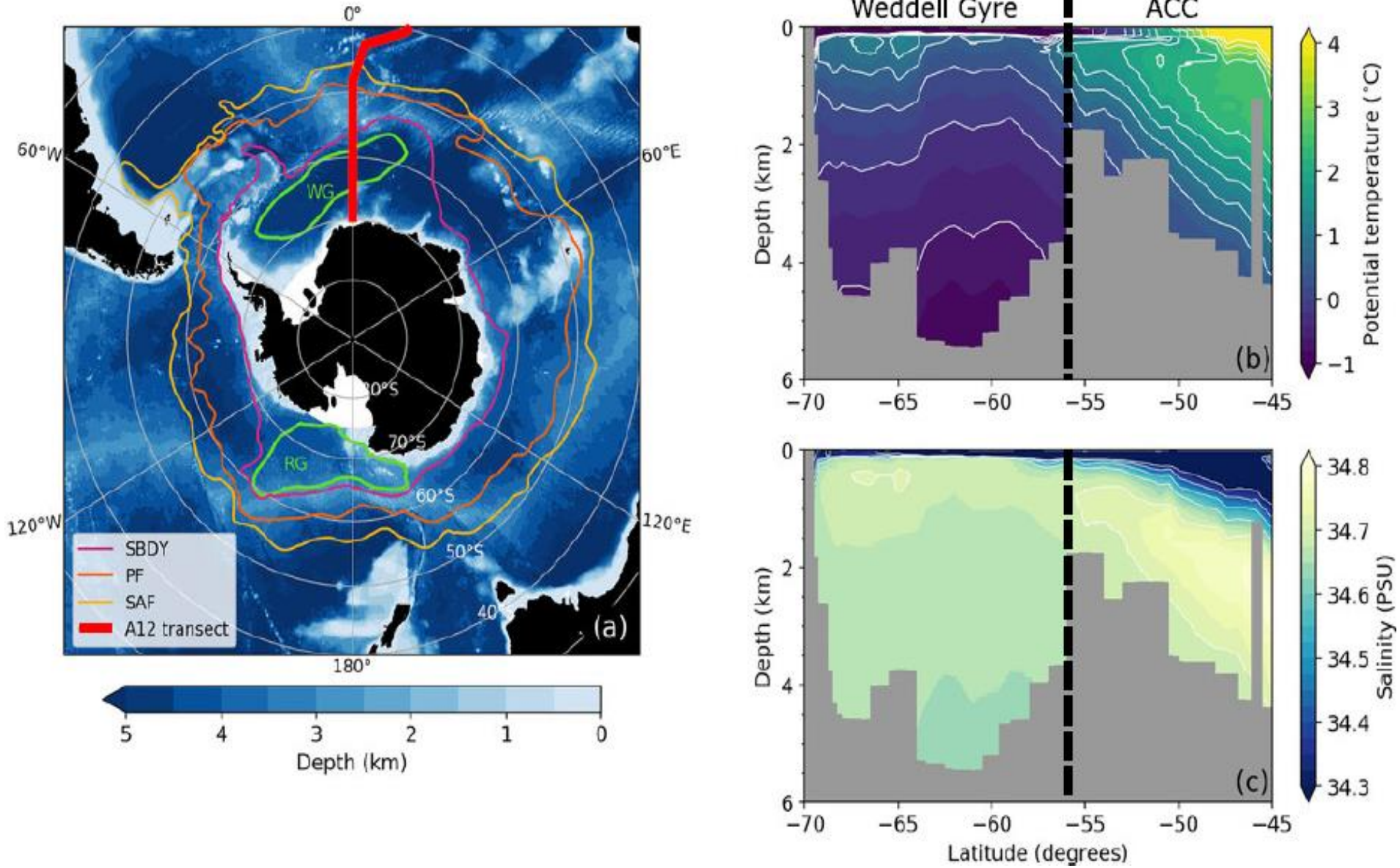
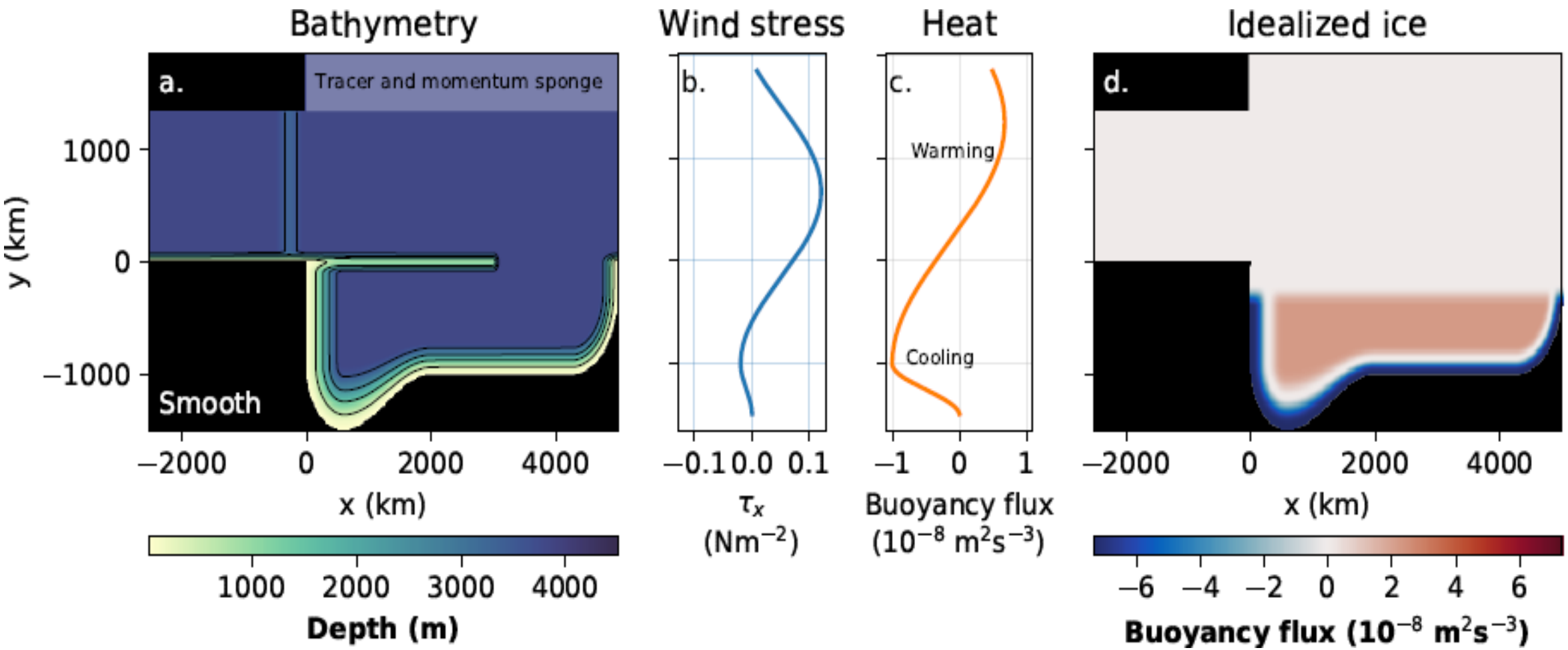
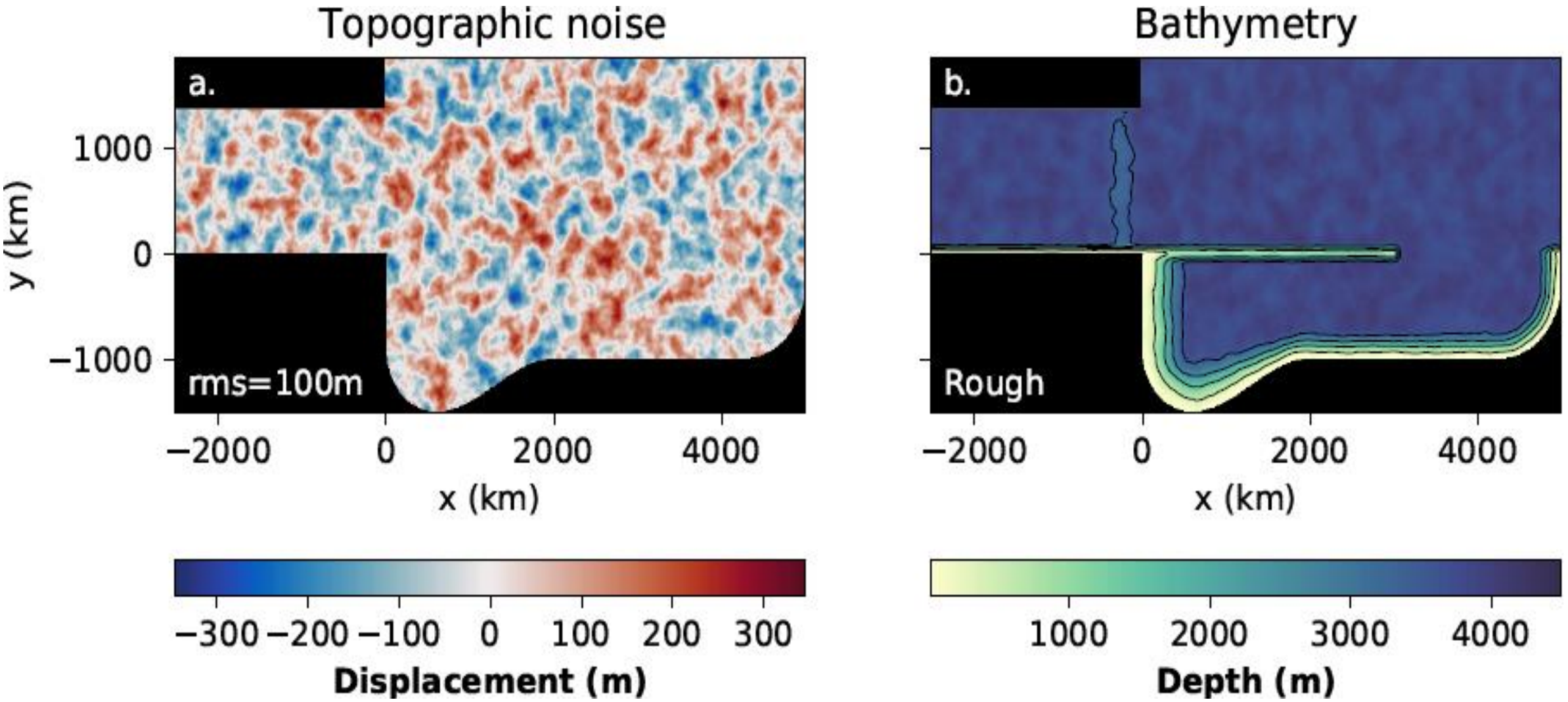
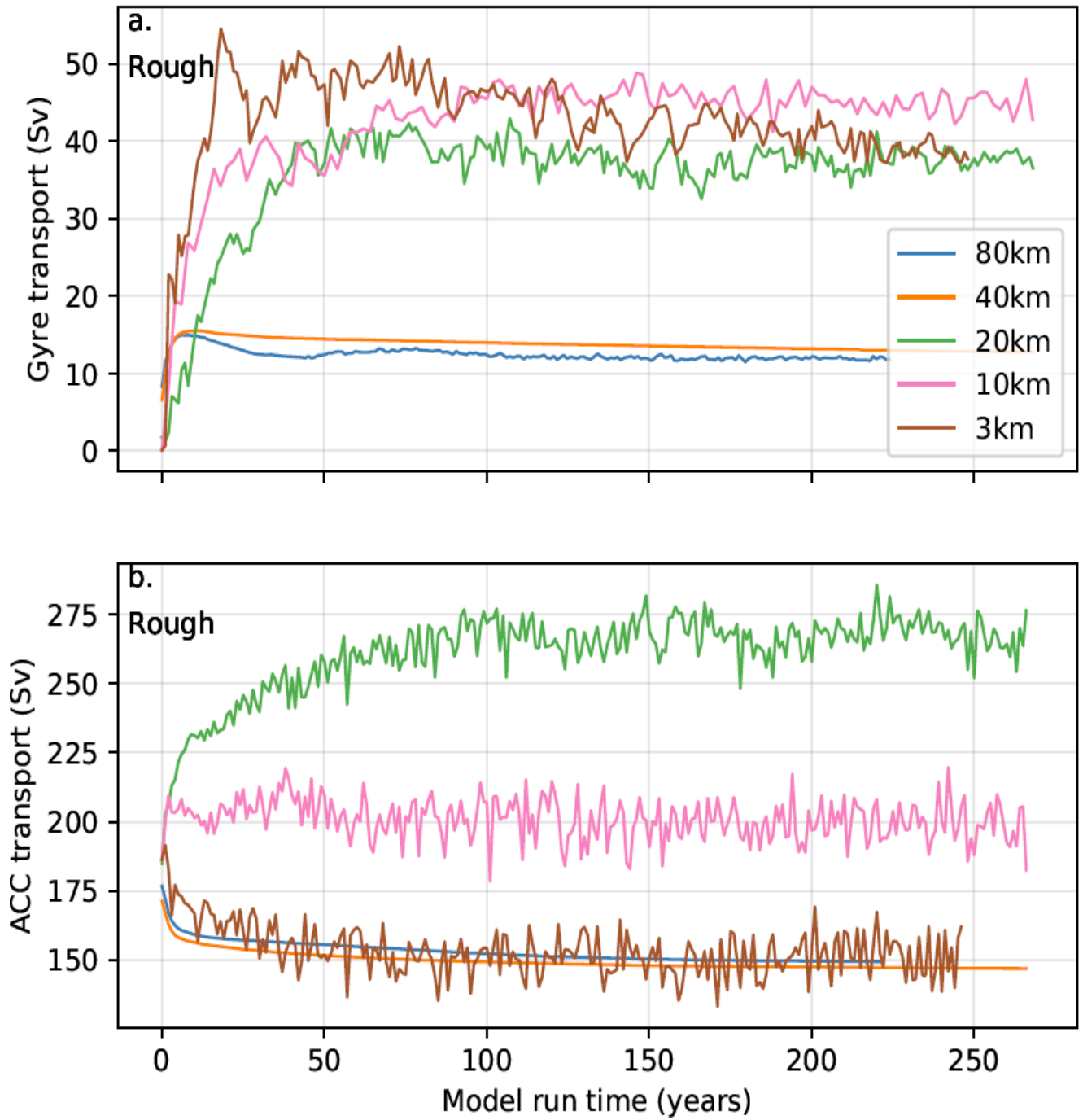
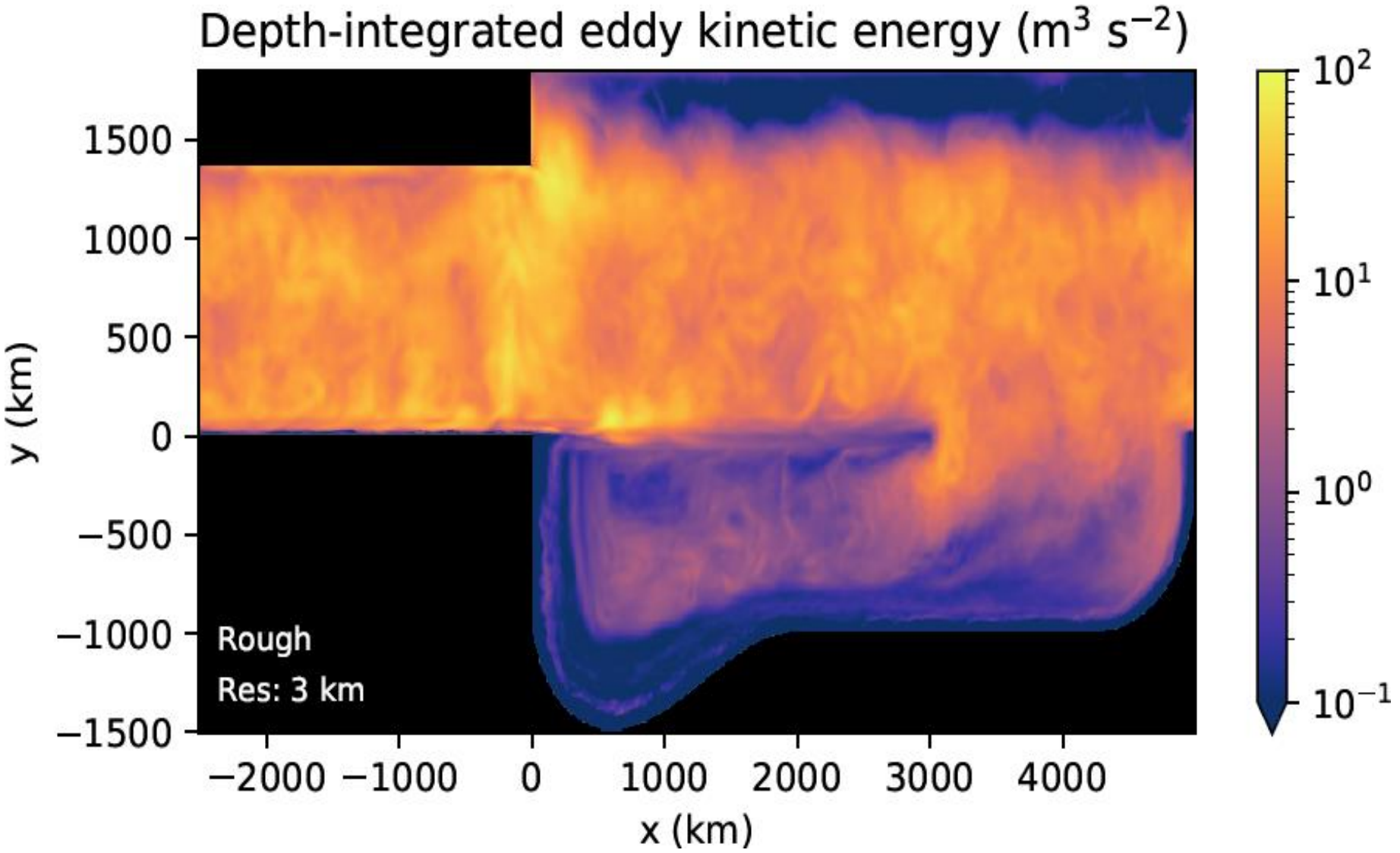
Extra Slides

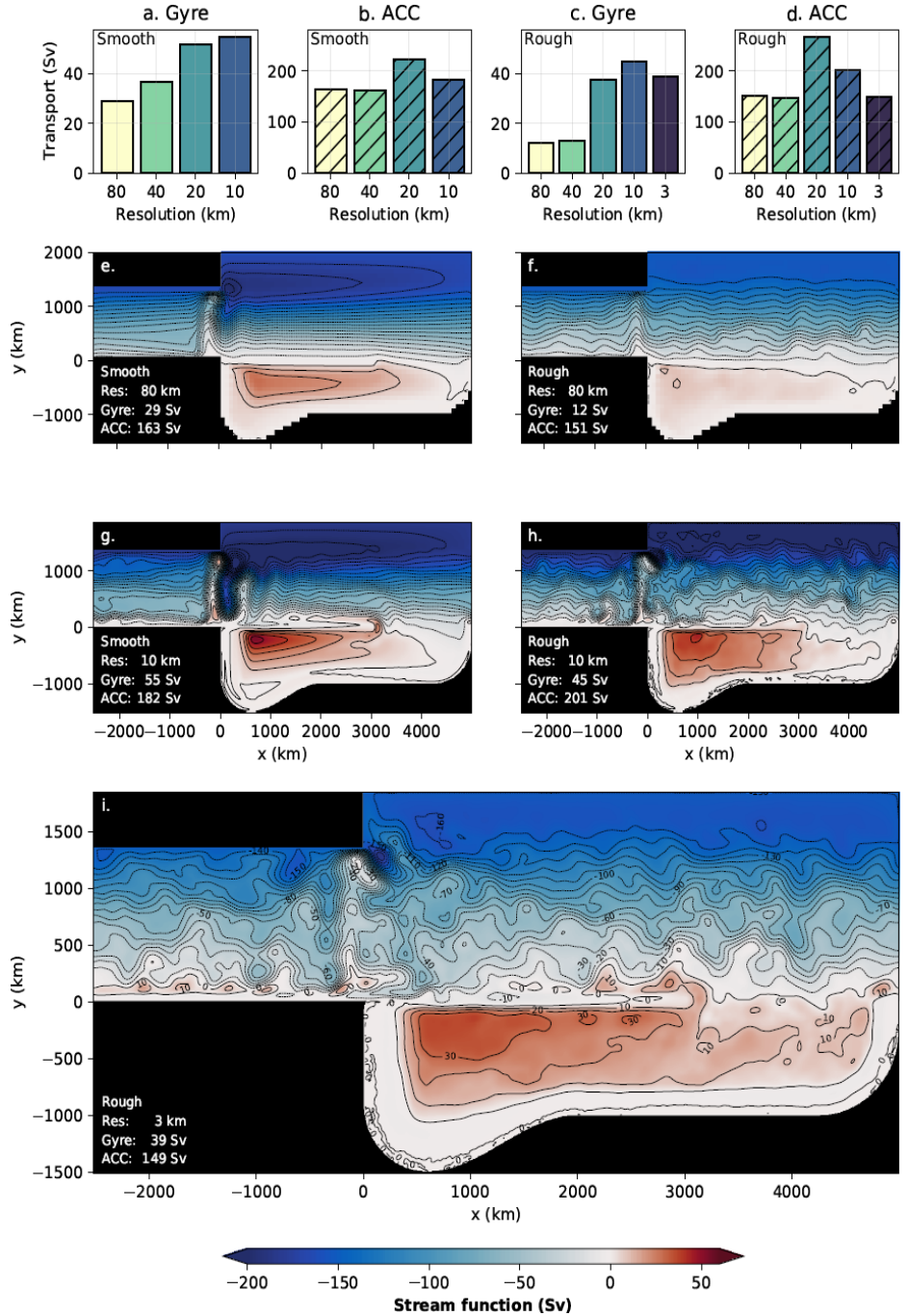

0°
60°W
60°E
120°W
120°E
180°
WG
RG
70°S
60°S
50°S
40°
SBDY
PF
SAF
A12 transect
(a)
5
4
3
2
1
0
Depth (km)
Weddell Gyre
ACC
Depth (km)
Potential temperature (°C)
(b)
Salinity (PSU)
(c)
−70
−65
−60
−55
−50
−45
Latitude (degrees)

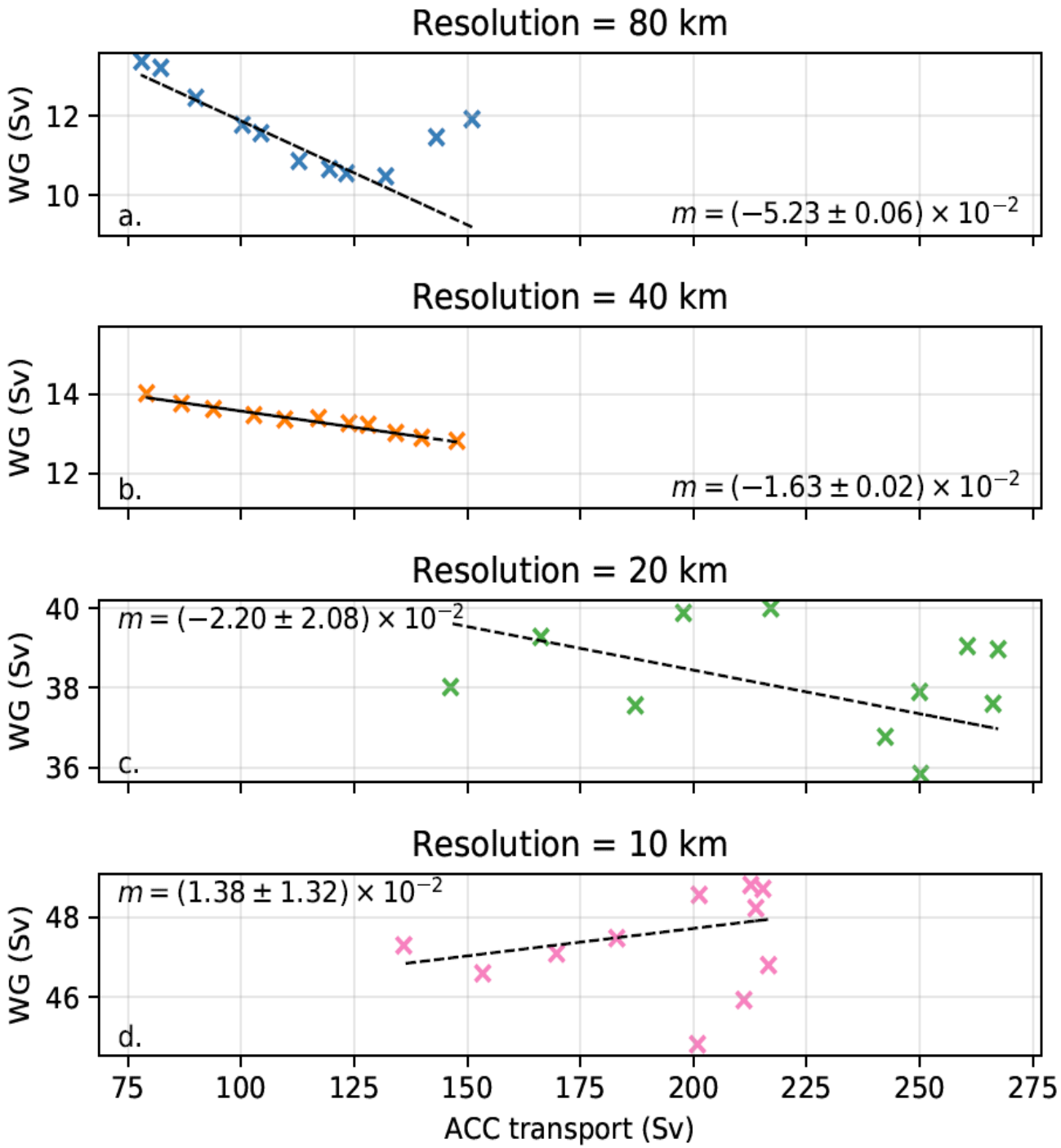

Bathymetry
Wind stress
Heat
Idealized ice
a.
Tracer and momentum sponge
Smooth
b.
c.
Warming
Cooling
d.
y (km)
1000
0
−1000
−2000
0
2000
4000
x (km)
−0.1 0.0 0.1
τ_x
(Nm^{-2})
−1
0
1
Buoyancy flux
(10^{-8} m^{2}s^{-3})
1000
2000
3000
4000
Depth (m)
−6
−4
−2
0
2
4
6
Buoyancy flux (10^{-8} m^{2}s^{-3})

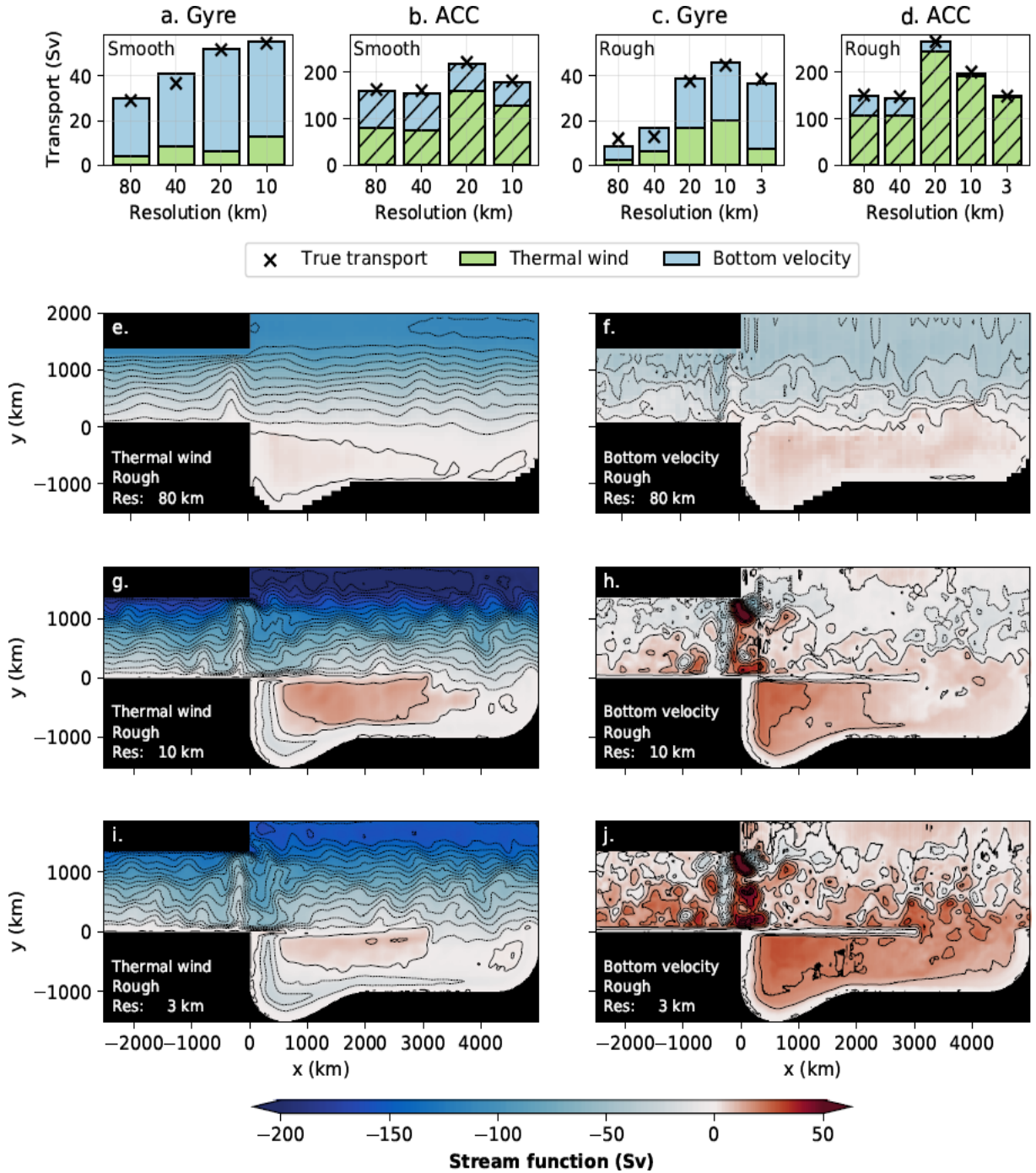

Topographic noise
a.
rms=100m
1000
0
−1000
y (km)
−2000
0
2000
4000
x (km)
−300 −200 −100 0 100 200 300
Displacement (m)
Bathymetry
b.
Rough
−2000
0
2000
4000
x (km)
1000 2000 3000 4000
Depth (m)

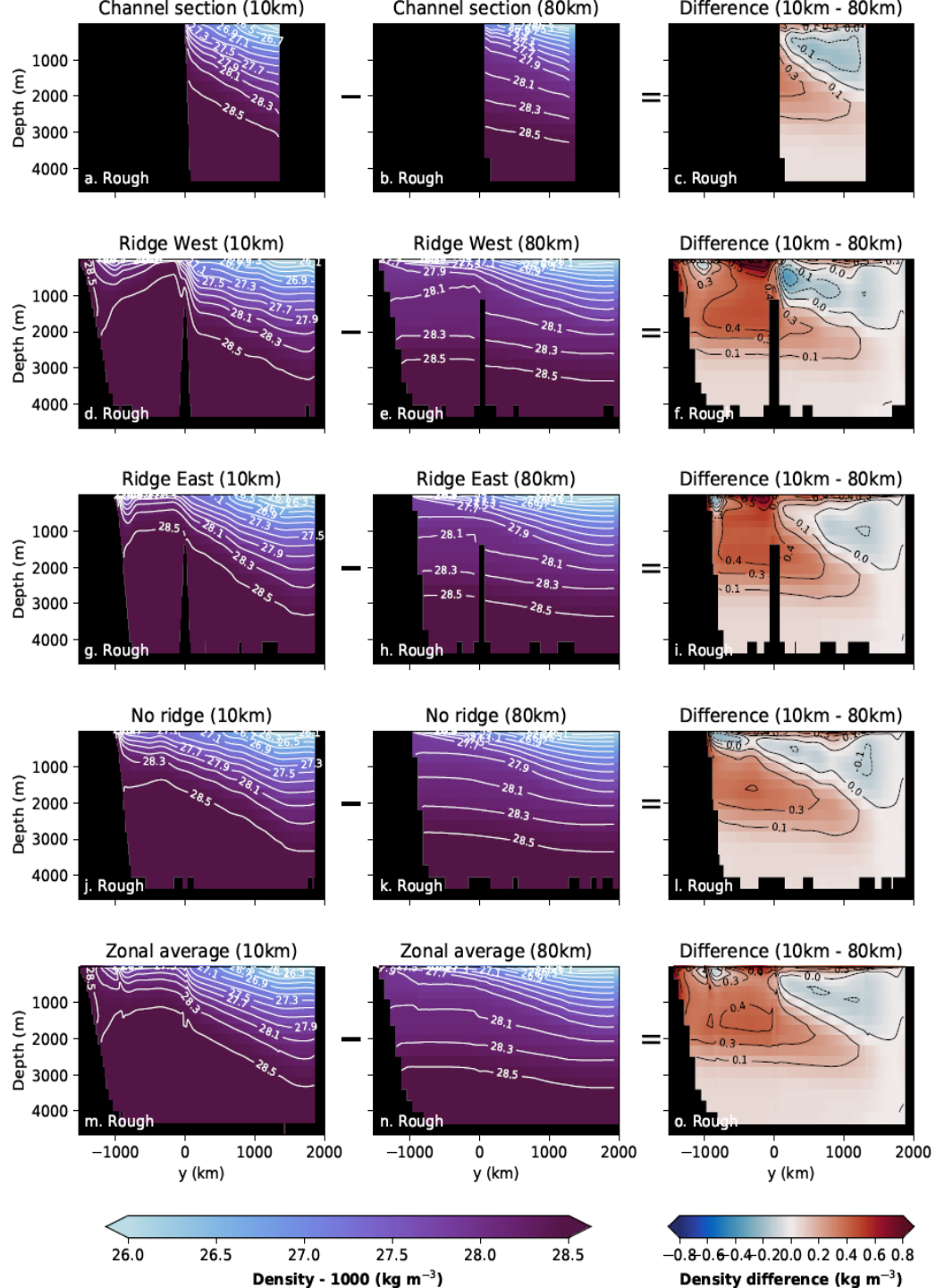

a.
Rough
Gyre transport (Sv)
0
10
20
30
40
50
80km
40km
20km
10km
3km
b.
Rough
ACC transport (Sv)
150
175
200
225
250
275
0
50
100
150
200
250
Model run time (years)

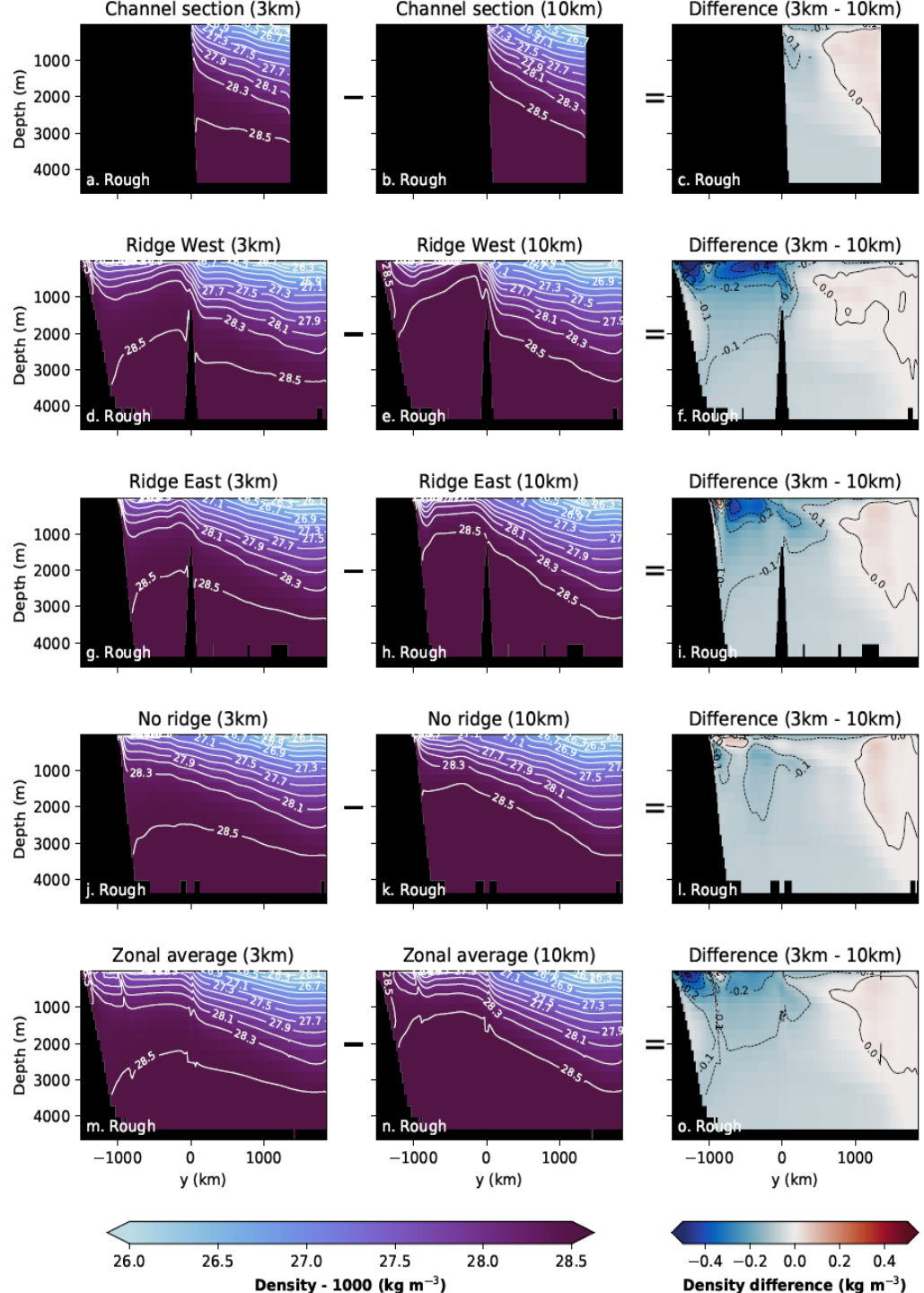

Depth-integrated eddy kinetic energy ($m^3\ s^{-2}$)
1500
1000
500
0
−500
−1000
−1500
y (km)
−2000
−1000
0
1000
2000
3000
4000
x (km)
Rough
Res: 3 km
10^2
10^1
10^0
10^{-1}


a. Gyre
b. ACC
c. Gyre
d. ACC
Smooth
Smooth
Rough
Rough
Transport (Sv)
Resolution (km)
e.
f.
g.
h.
i.
Smooth
Res: 80 km
Gyre: 29 Sv
ACC: 163 Sv
Rough
Res: 80 km
Gyre: 12 Sv
ACC: 151 Sv
Smooth
Res: 10 km
Gyre: 55 Sv
ACC: 182 Sv
Rough
Res: 10 km
Gyre: 45 Sv
ACC: 201 Sv
Rough
Res: 3 km
Gyre: 39 Sv
ACC: 149 Sv
y (km)
x (km)
Stream function (Sv)


Resolution = 80 km
WG (Sv)
12
10
a.
$m = (-5.23 \pm 0.06) \times 10^{-2}$
Resolution = 40 km
WG (Sv)
14
12
b.
$m = (-1.63 \pm 0.02) \times 10^{-2}$
Resolution = 20 km
WG (Sv)
40
38
36
c.
$m = (-2.20 \pm 2.08) \times 10^{-2}$
Resolution = 10 km
WG (Sv)
48
46
d.
$m = (1.38 \pm 1.32) \times 10^{-2}$
75
100
125
150
175
200
225
250
275
ACC transport (Sv)


a. Gyre
b. ACC
c. Gyre
d. ACC
Smooth
Smooth
Rough
Rough
Transport (Sv)
Resolution (km)
True transport
Thermal wind
Bottom velocity
e.
f.
g.
h.
i.
j.
Thermal wind
Rough
Res: 80 km
Bottom velocity
Rough
Res: 80 km
Thermal wind
Rough
Res: 10 km
Bottom velocity
Rough
Res: 10 km
Thermal wind
Rough
Res: 3 km
Bottom velocity
Rough
Res: 3 km
y (km)
x (km)
Stream function (Sv)


Channel section (10km)
Channel section (80km)
Difference (10km - 80km)
Ridge West (10km)
Ridge West (80km)
Difference (10km - 80km)
Ridge East (10km)
Ridge East (80km)
Difference (10km - 80km)
No ridge (10km)
No ridge (80km)
Difference (10km - 80km)
Zonal average (10km)
Zonal average (80km)
Difference (10km - 80km)
Depth (m)
y (km)
a. Rough
b. Rough
c. Rough
d. Rough
e. Rough
f. Rough
g. Rough
h. Rough
i. Rough
j. Rough
k. Rough
l. Rough
m. Rough
n. Rough
o. Rough
Density - 1000 (kg m^{-3})
Density difference (kg m^{-3})


Channel section (3km)
Channel section (10km)
Difference (3km - 10km)
Ridge West (3km)
Ridge West (10km)
Difference (3km - 10km)
Ridge East (3km)
Ridge East (10km)
Difference (3km - 10km)
No ridge (3km)
No ridge (10km)
Difference (3km - 10km)
Zonal average (3km)
Zonal average (10km)
Difference (3km - 10km)
Depth (m)
1000
2000
3000
4000
a. Rough
b. Rough
c. Rough
d. Rough
e. Rough
f. Rough
g. Rough
h. Rough
i. Rough
j. Rough
k. Rough
l. Rough
m. Rough
n. Rough
o. Rough
−1000
0
1000
y (km)
26.0
26.5
27.0
27.5
28.0
28.5
Density - 1000 (kg m^{-3})
−0.4
−0.2
0.0
0.2
0.4
Density difference (kg m^{-3})