The Role of Large-Scale Seasonal Cycle Advection in Maintaining the Mean Ocean Salinity Distribution

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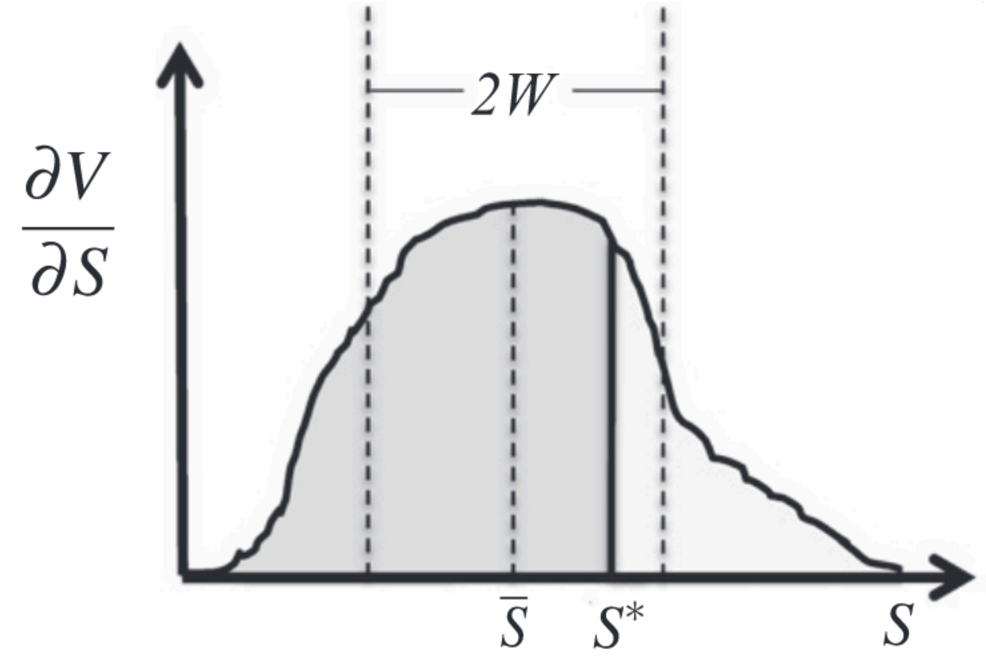
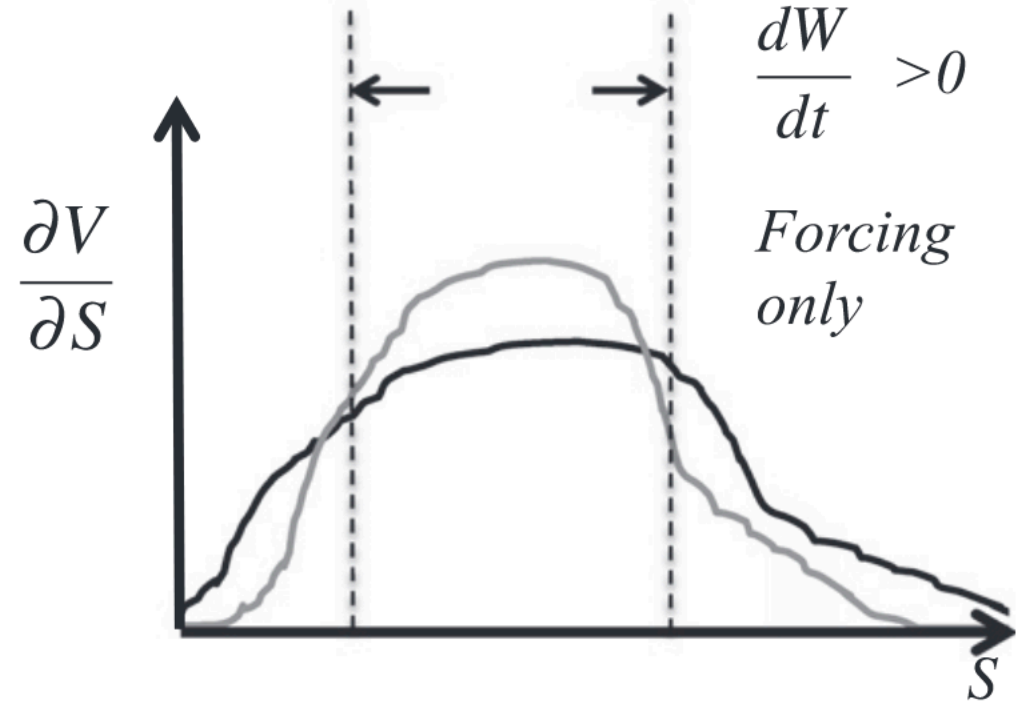
Motivation Zika et al. 2015 framework



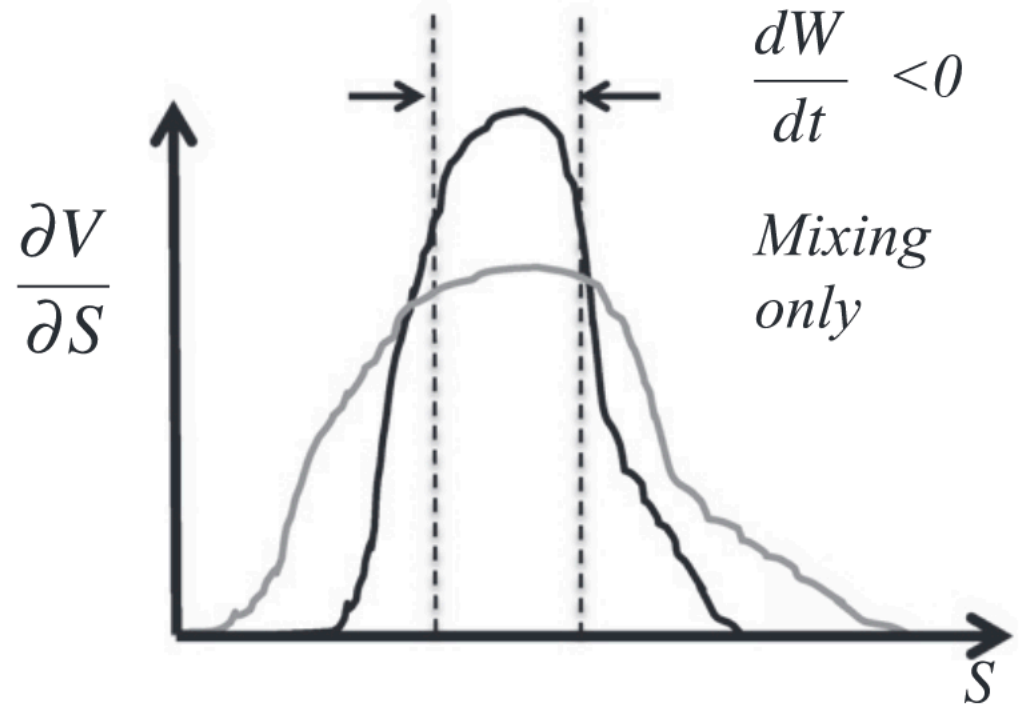
$$W = \frac{1}{V_0} \iiint |S - \bar{S}| \, dx \, dy \, dz,$$

= width of the distribution

$$\frac{dW}{dt} = \text{Water-cycle forcing - Mixing}$$



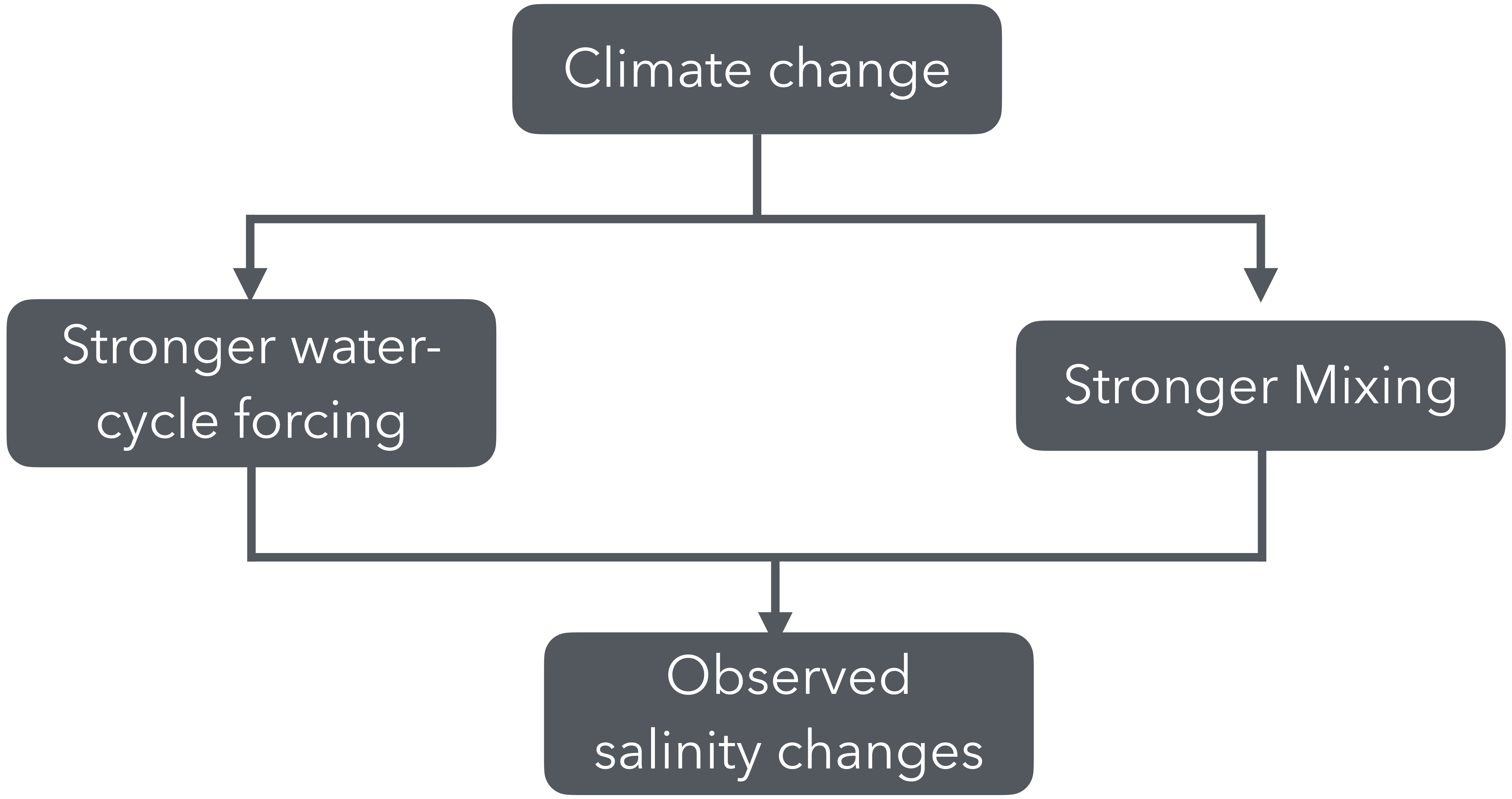
Water cycle acts to broaden the distribution



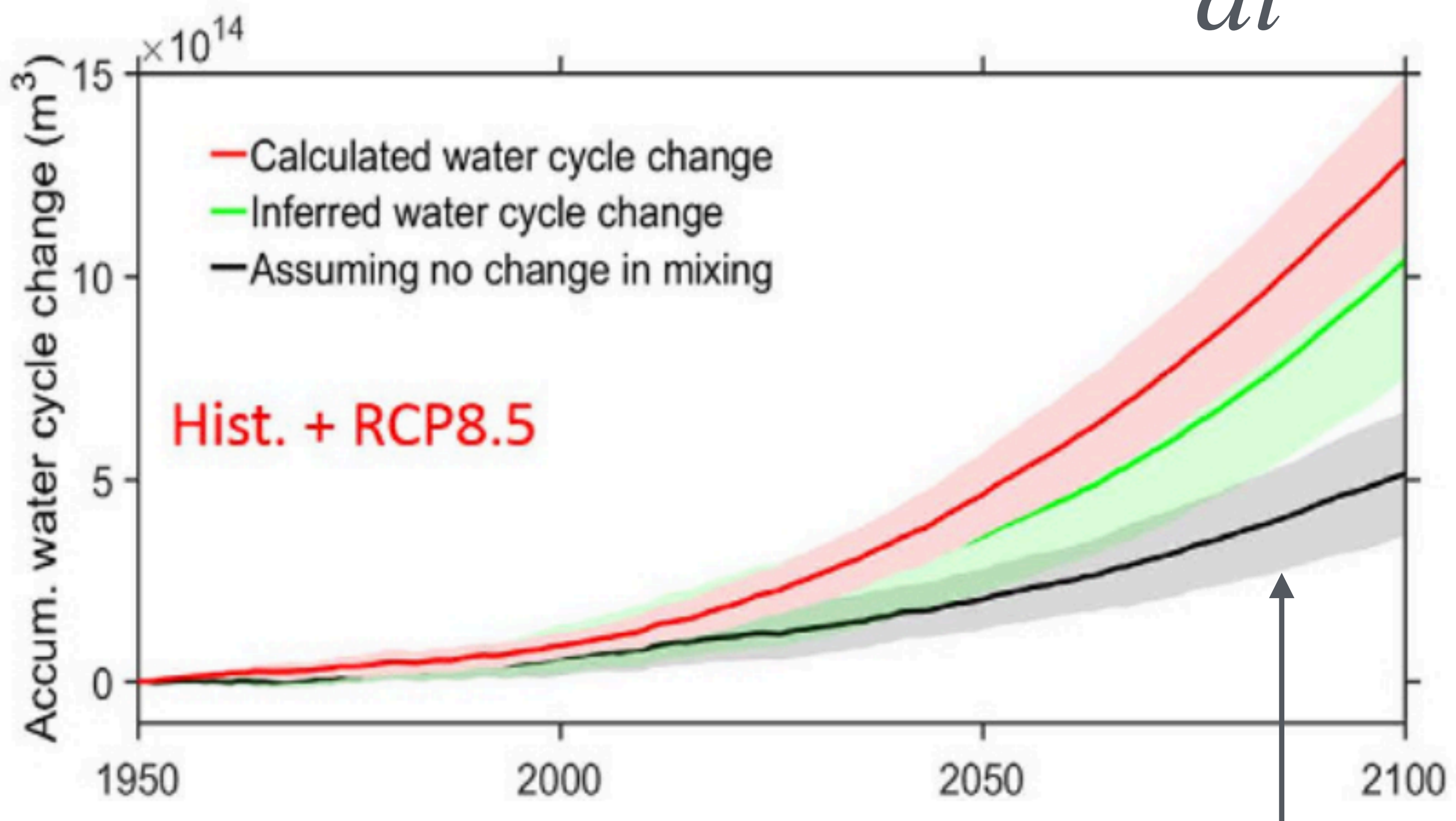
Mixing acts to narrow the distribution

Observed Salinity distribution = balance of water cycle and mixing

Climate change effect on W, influence of mixing



$$\text{Water-cycle forcing} = \frac{dW}{dt} + \text{Mixing}$$



Skliris et al 2016

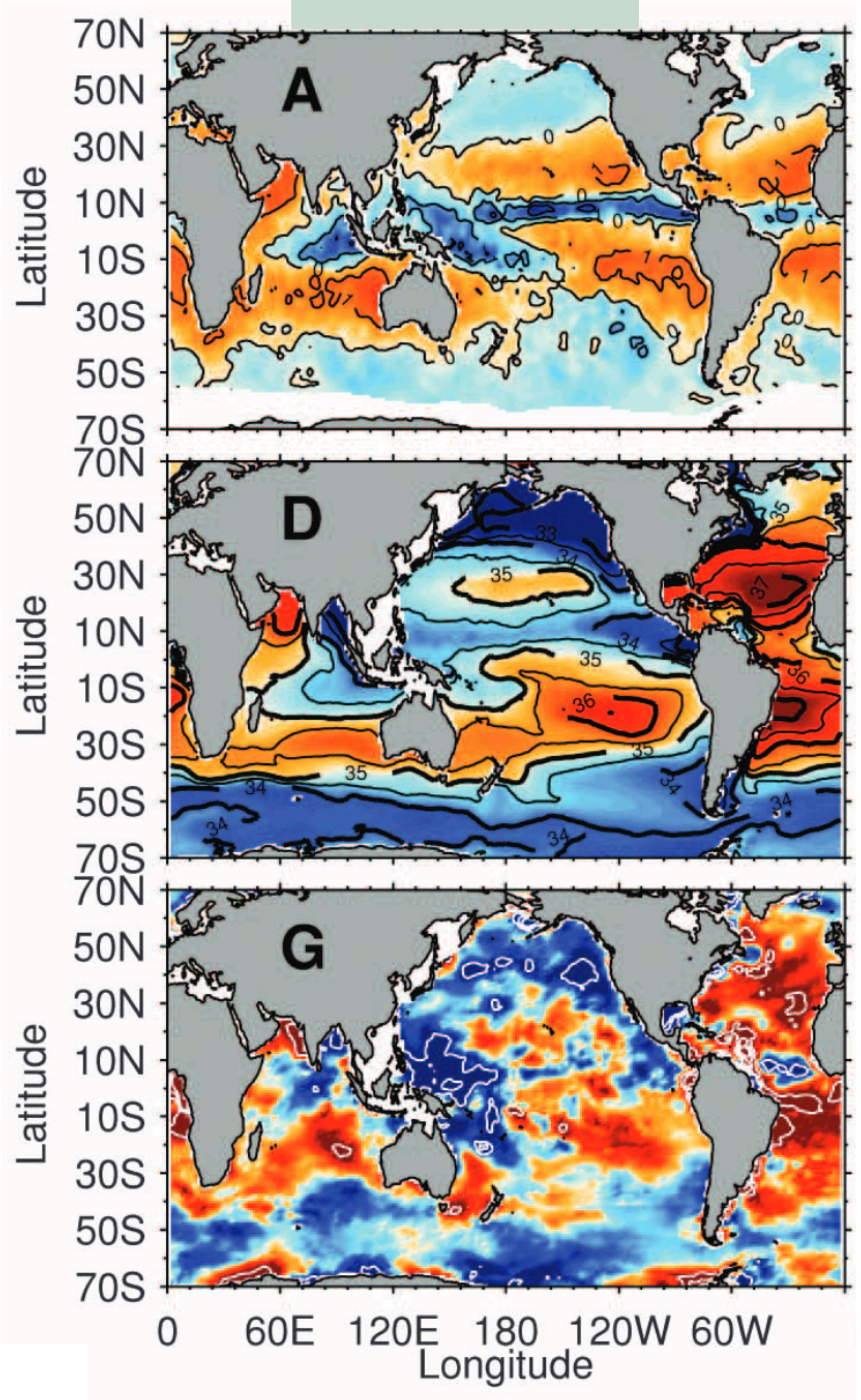
Assuming a constant mixing leads to an under estimation of water cycle changes

We need a better understanding of the mechanisms acting to mix the ocean if we want to be able to link salinity to freshwater flux.

Problem: Zika's framework is global and cannot be used to capture local dynamics. → Need a new framework

Climate change increases the spatial variance of sea surface salinity

1950-2000



Durack, Wijffels et al. 2012

E-P

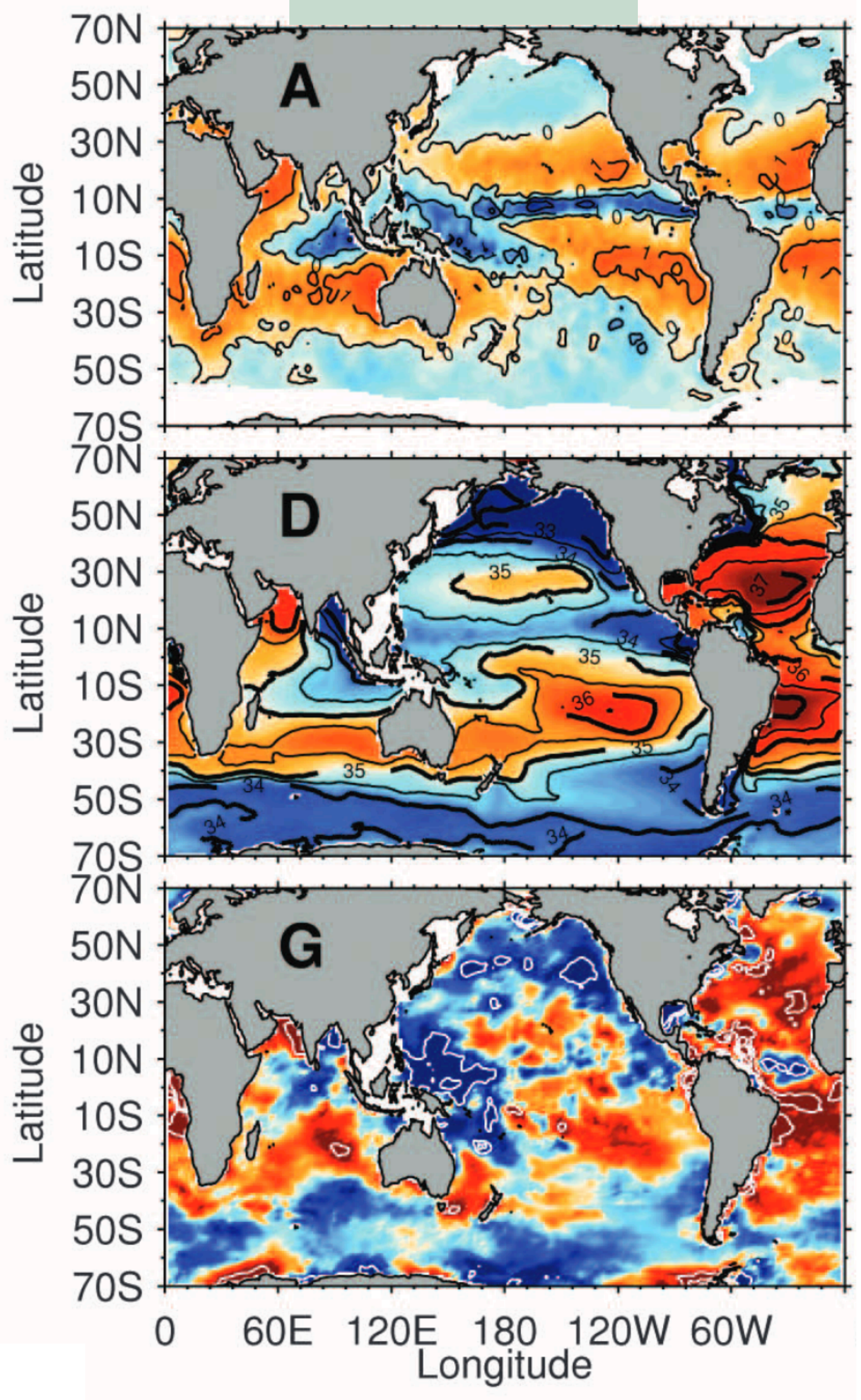
SSS anomalies

$$SSS^* = SSS - \langle SSS \rangle$$

50 yr SSS change

Climate change increases the spatial variance of sea surface salinity

1950-2000



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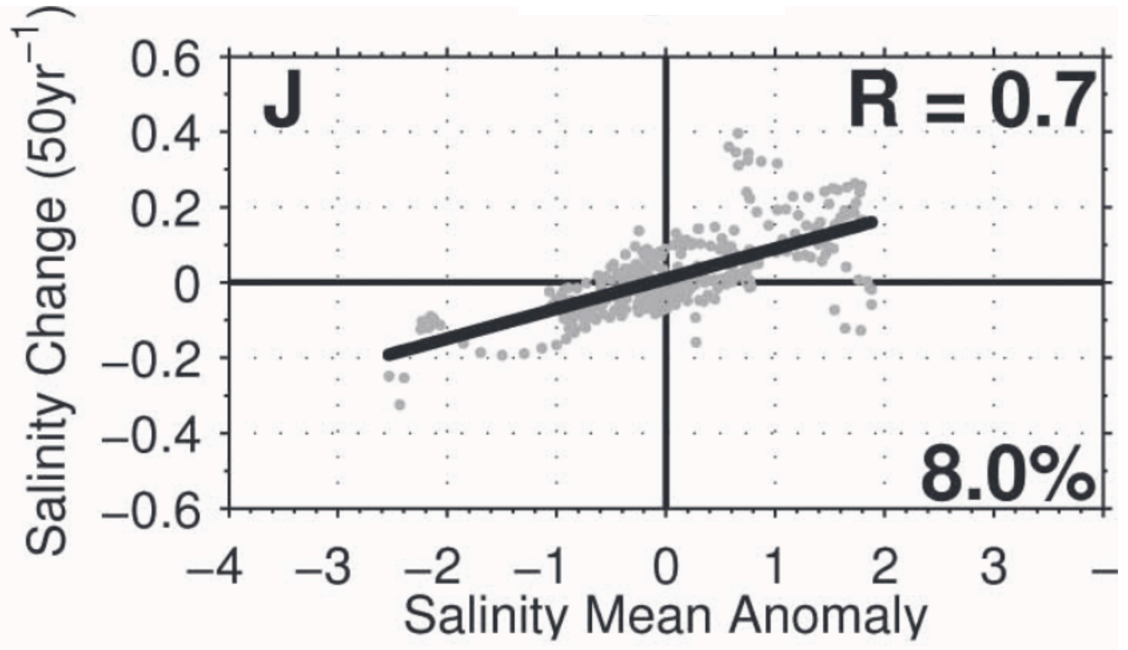

Salinity increases in regions where SSS*>0

And decreases in regions where SSS*<0

$$\frac{\partial SSS^*}{\partial t} > 0 \text{ where SSS*>0}$$

$$\frac{\partial SSS^*}{\partial t} < 0 \text{ where SSS*<0}$$

Climate change increases the spatial variance of sea surface salinity

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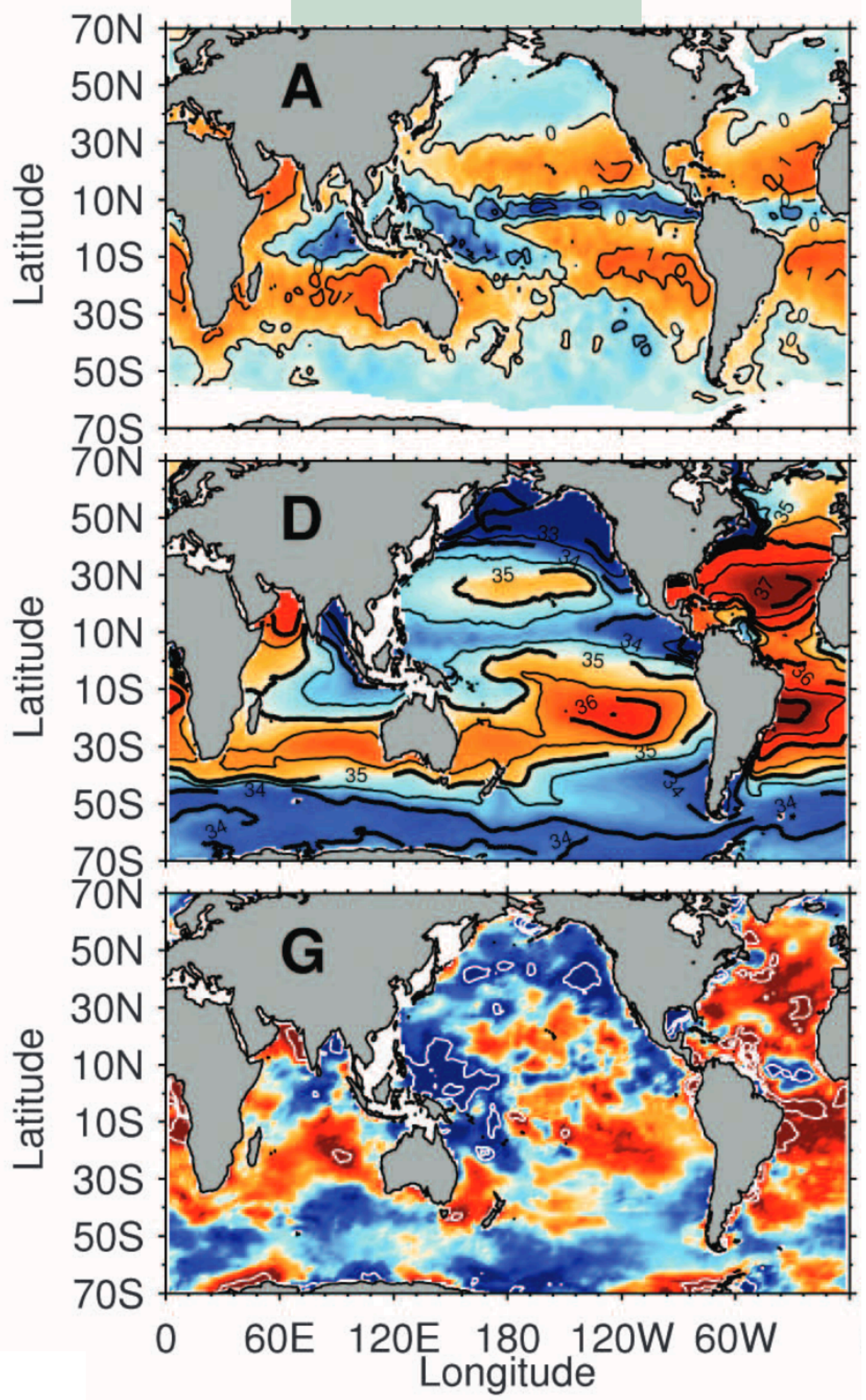

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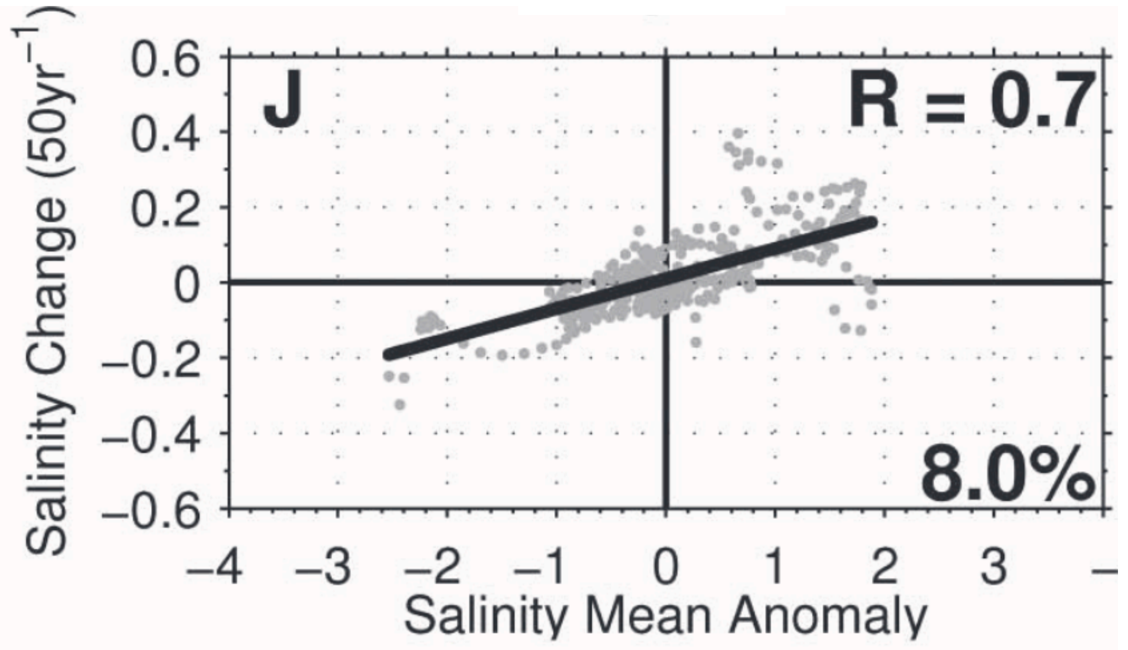

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$$\frac{\partial SSS^*}{\partial t} > 0 \text{ where SSS*>0}$$

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$$SSS^* \frac{\partial SSS^*}{\partial t} = \frac{1}{2} \frac{\partial SSS^{*2}}{\partial t} > 0$$

Spatial SSS variance increases with climate change

What mechanisms control the spatial variance of salinity ?

Objectives

1. Develop a local version of Zika et al. 2015's framework using a spatial salinity variance equation

2. Understand the main mechanisms controlling the local spatial salinity variance

-Mesoscale variability strongly influences salinity distribution (e.g., Treguier et al., 2012, 2014)

-larger-scale variability remains less understood.

Salinity variance equation

$$X = \overline{X} + X'$$

Everything faster
e.g. interannual, seasonal, subseasonal

Slowly varying field
~O(10 years)

$$\frac{\partial \overline{S}}{\partial t} = \overline{\mathrm{ADV}} + \overline{F} + \overline{D}$$

- Isopycnal mixing
- Vertical mixing
- Convective adjustment

- resolved large-scale advection
- parametrized advection (GM)

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$$\frac{\partial \overline{S}}{\partial t} = \overline{\mathrm{ADV}} + \overline{F} + \overline{D}$$

$$\omega = \overline{S} - \langle S \rangle$$

$$\mathscr{W} = \frac{1}{V_0}\int_V \omega^2 \mathrm{d}V = \frac{1}{V_0}\int_V \left(\overline{S} - \langle S \rangle\right)^2 \mathrm{d}V$$

$\overline{S}$ spatial variance

$$W = \frac{1}{V_0}\iiint |S - \overline{S}|\, dx\, dy\, dz\,,$$

Salinity variance equation.

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$\overline{S}$ spatial variance

$$W = \frac{1}{V_0}\iiint |S - \overline{S}|\, dx\, dy\, dz,$$

$$\frac{1}{2}\frac{\partial \omega^2}{\partial t} = \omega\overline{\mathrm{ADV}} + \omega\overline{D} + \omega\overline{F}$$

Salinity variance equation.

$$X = \overline{X} + X'$$

Everything faster e.g. interannual, seasonal, subseasonal

Slowly varying field ~O(10 years)

$$\frac{\partial \overline{S}}{\partial t} = \overline{\mathrm{ADV}} + \overline{F} + \overline{D}$$

$$\omega = \overline{S} - \langle S \rangle \longrightarrow \mathscr{W} = \frac{1}{V_0}\int_V \omega^2 \mathrm{d}V = \frac{1}{V_0}\int_V \left(\overline{S} - \langle S \rangle\right)^2 \mathrm{d}V$$

$\overline{S}$ spatial variance

$$W = \frac{1}{V_0}\iiint |S - \overline{S}|\, dx\, dy\, dz,$$

$$\frac{1}{2}\frac{\partial \omega^2}{\partial t} = \omega\overline{\mathrm{ADV}} + \omega\overline{D} + \omega\overline{F}$$

→ Local version of Zika et al. 2015's equation

Volume avg

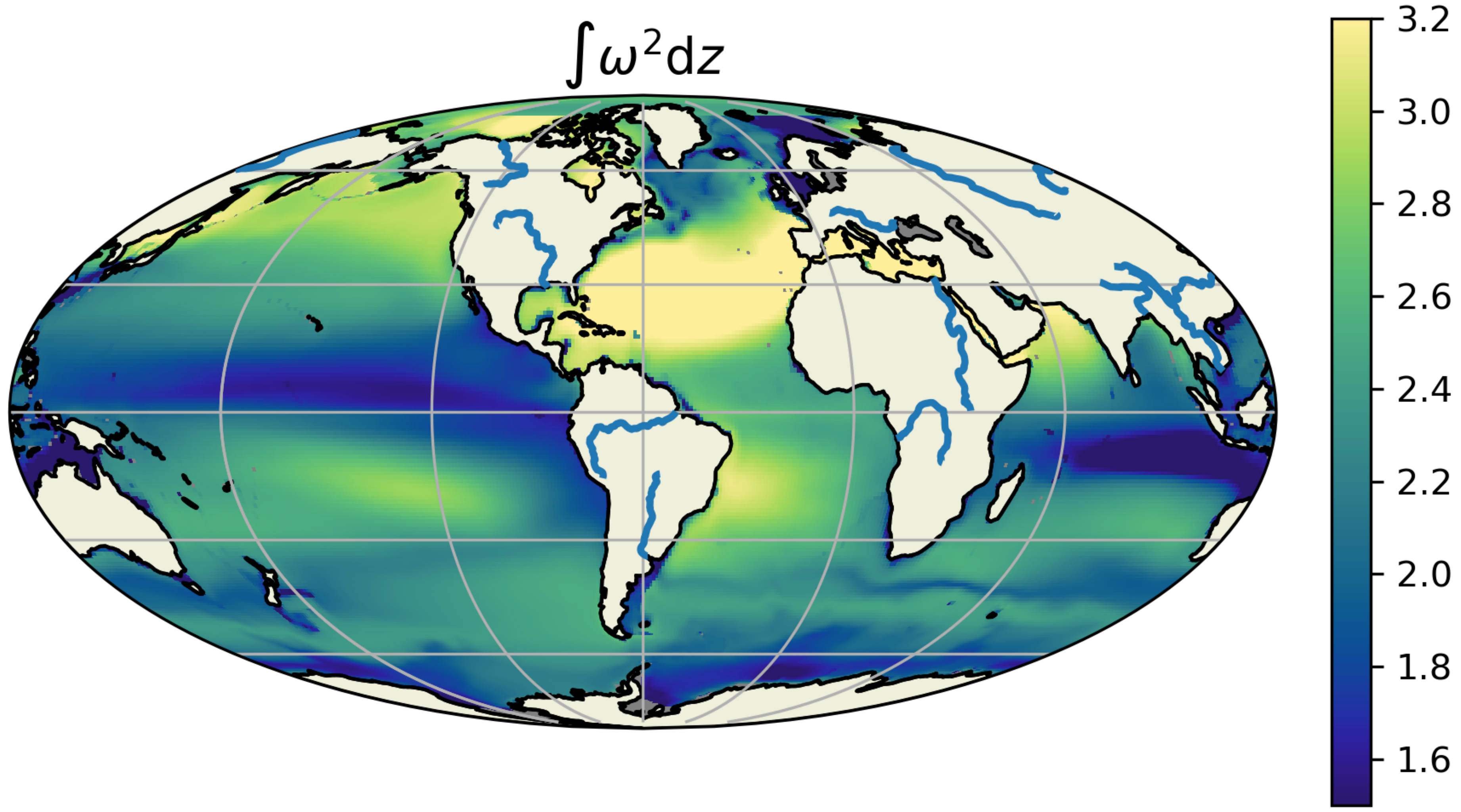
$$\frac{1}{2}\frac{\partial \mathscr{W}}{\partial t} = \left\langle \omega \frac{\partial \overline{S}}{\partial t} \right\rangle = \left\langle \omega\overline{\mathrm{ADV}} \right\rangle + \left\langle \omega\overline{D} \right\rangle + \left\langle \omega\overline{F} \right\rangle$$

→ Similar to Zika et al. 2015

ECCO v4r4

- Ocean state estimate (MITgcm) constrained with observations
- V4r4 covers 1992-2017
- ~1° resolution –> mesoscale eddies are parametrised using GM
- Salinity budget are obtained from monthly mean outputs over 1993-2016

Salinity variance equation: evaluation in ECCO



psu^2[log10]

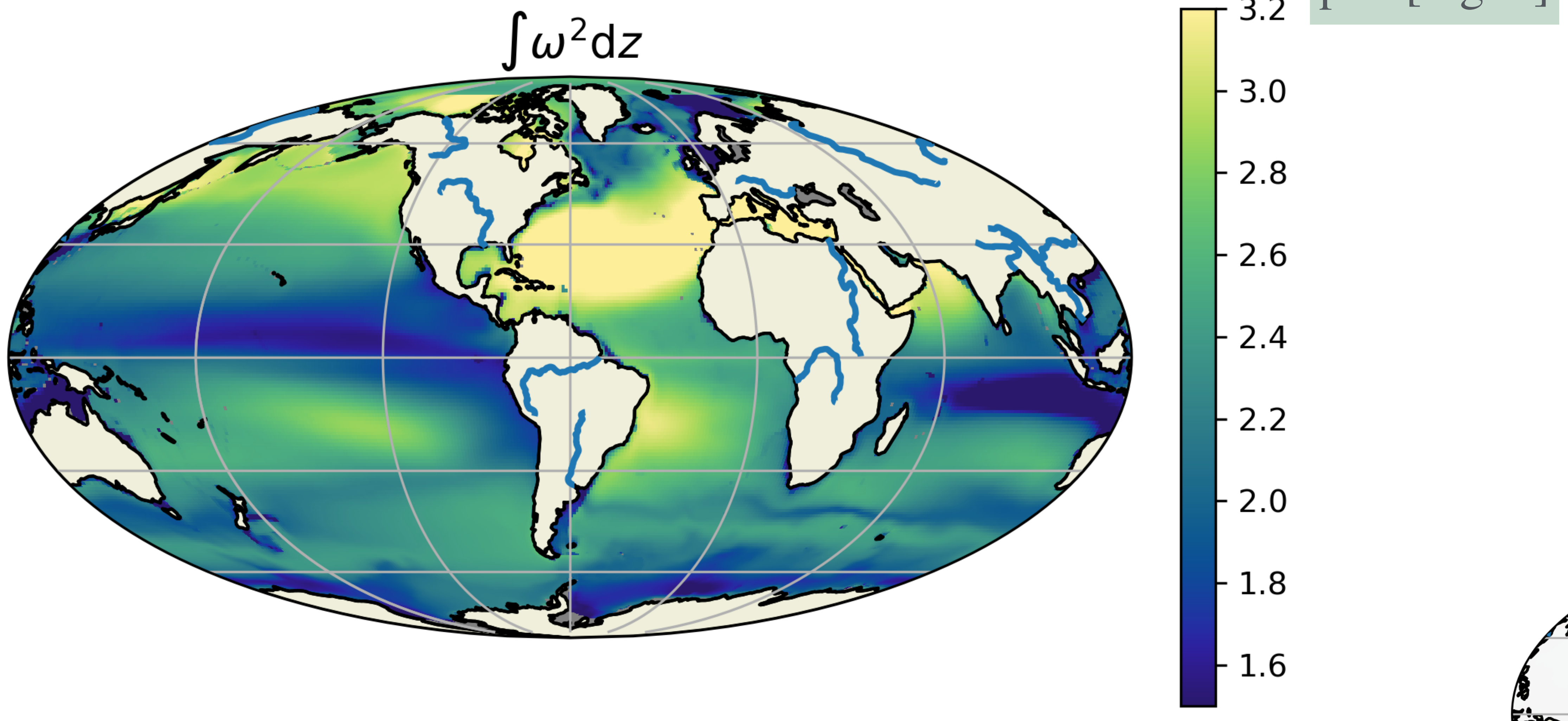
$$\int_H^0 dz$$

$$\frac{1}{2}\frac{\partial \omega^2}{\partial t} = \omega\overline{\mathrm{ADV}} + \omega\overline{D} + \omega\overline{F}$$

If r.h.s. term $> 0 \rightarrow$ source

If r.h.s. term $< 0 \rightarrow$ sink

Salinity variance equation: evaluation in ECCO



$$\int_H^0 \mathrm{d}z \qquad \frac{1}{2}\frac{\partial \omega^2}{\partial t} = \omega\overline{\mathrm{ADV}} + \omega\overline{D} + \omega\overline{F}$$

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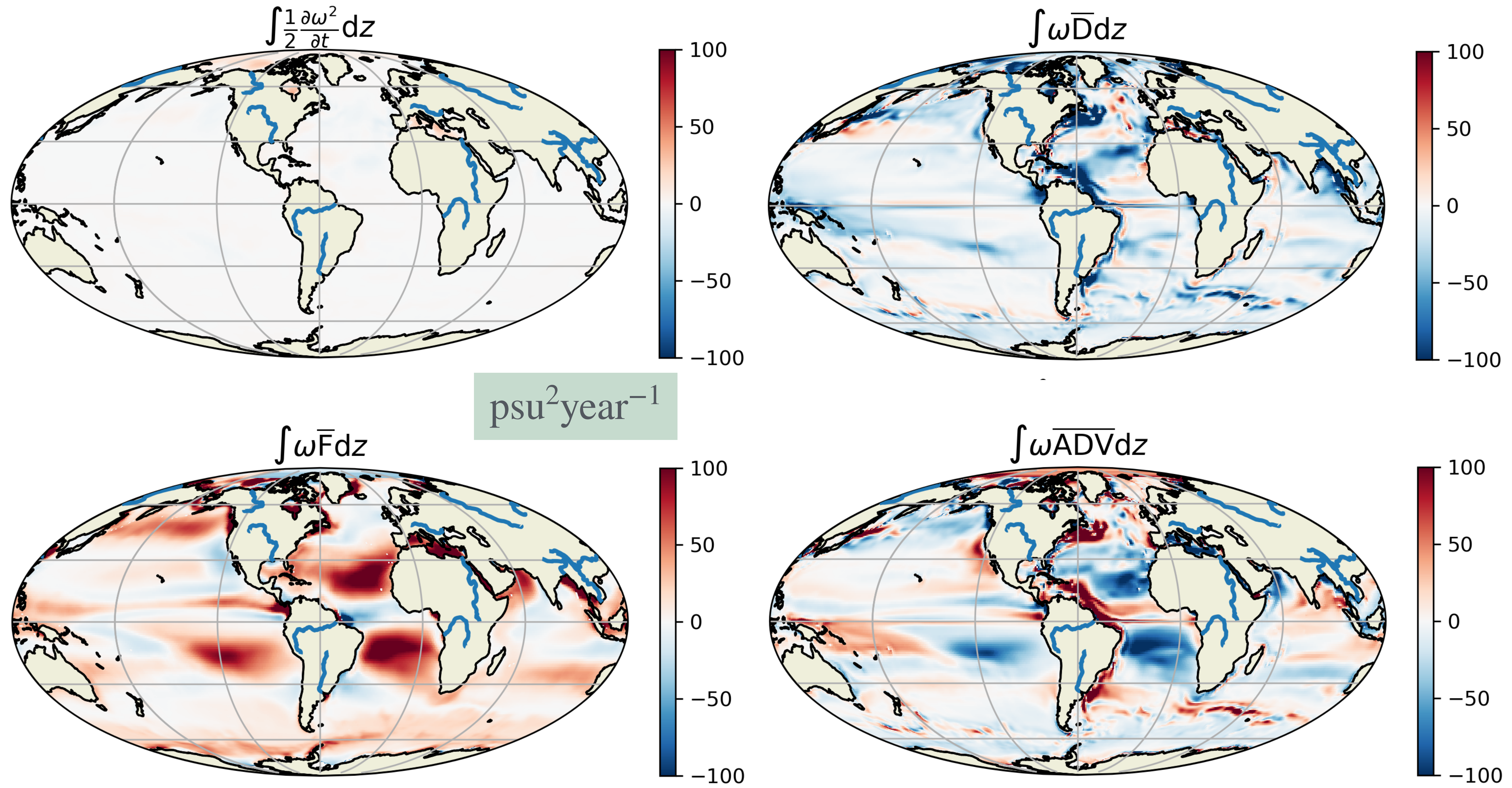
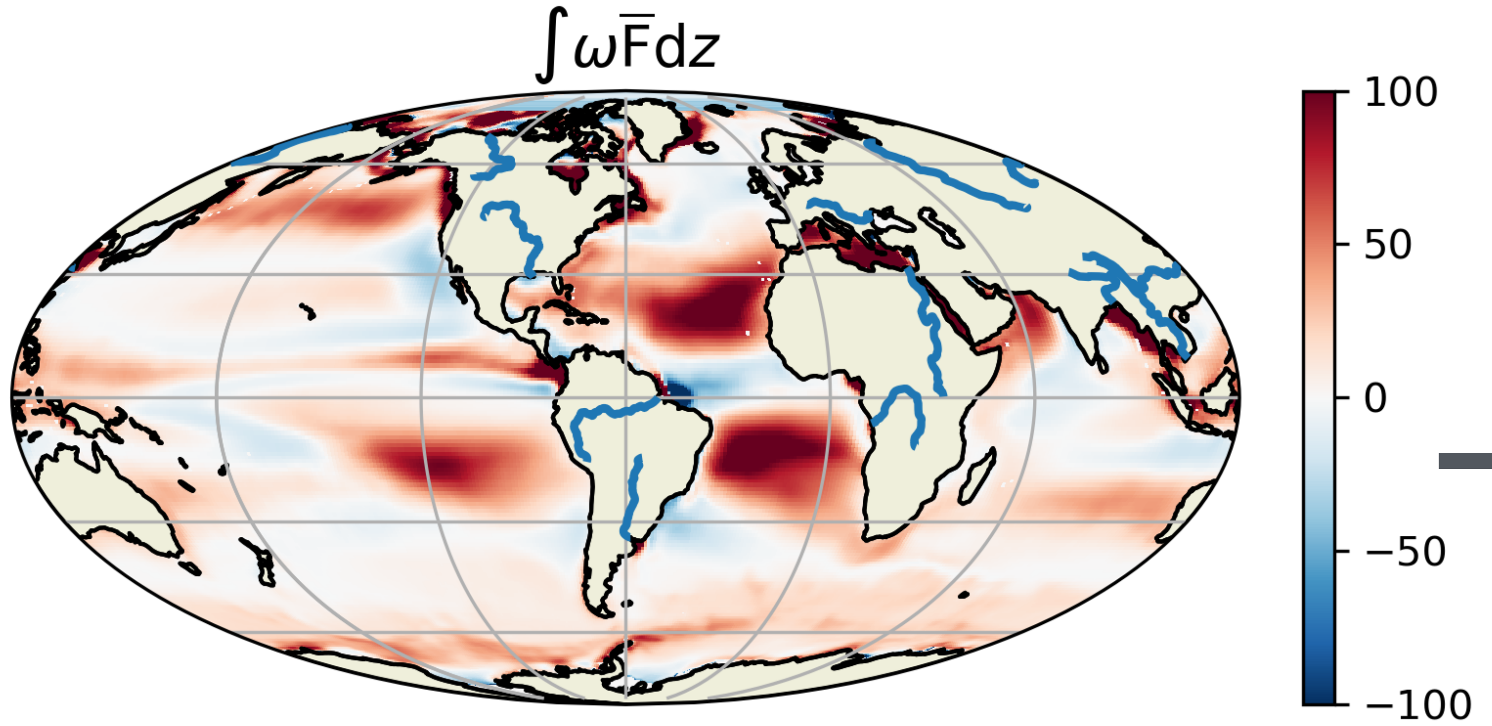
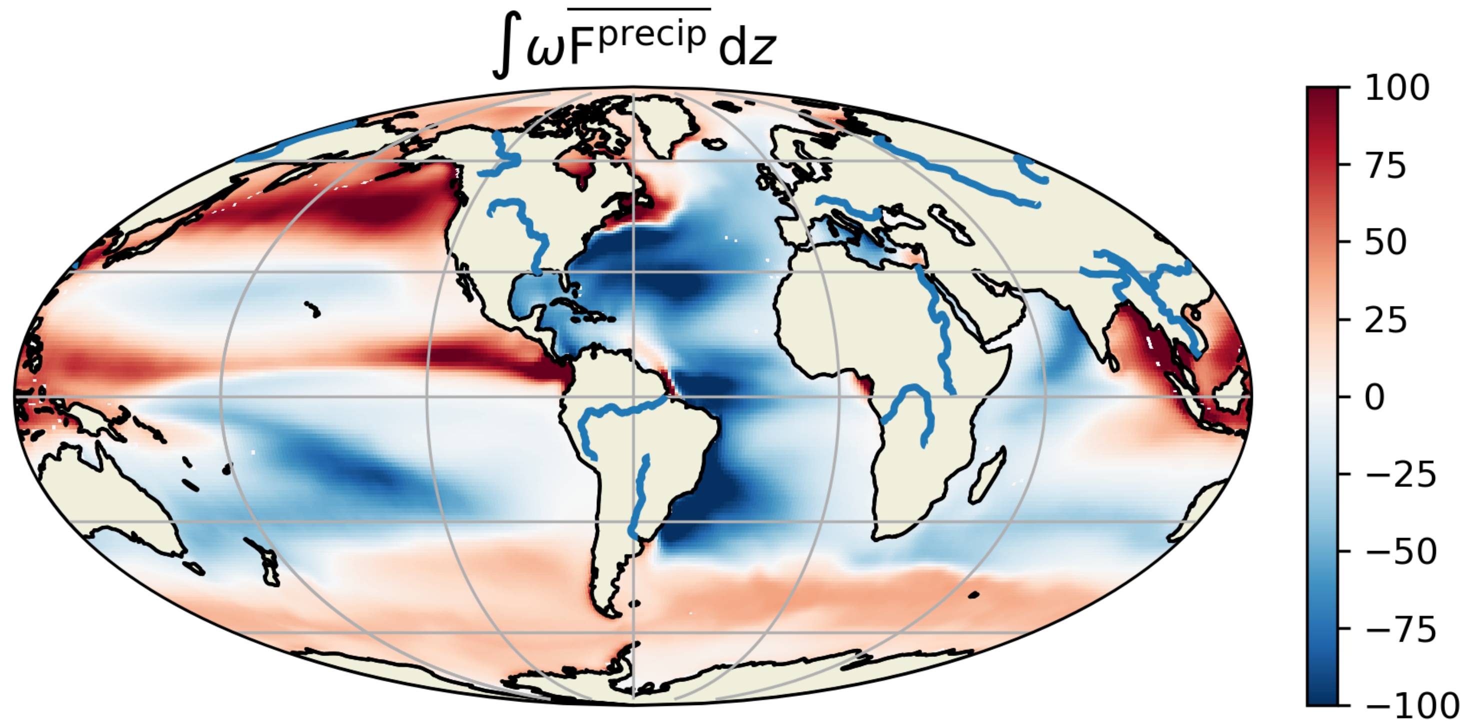
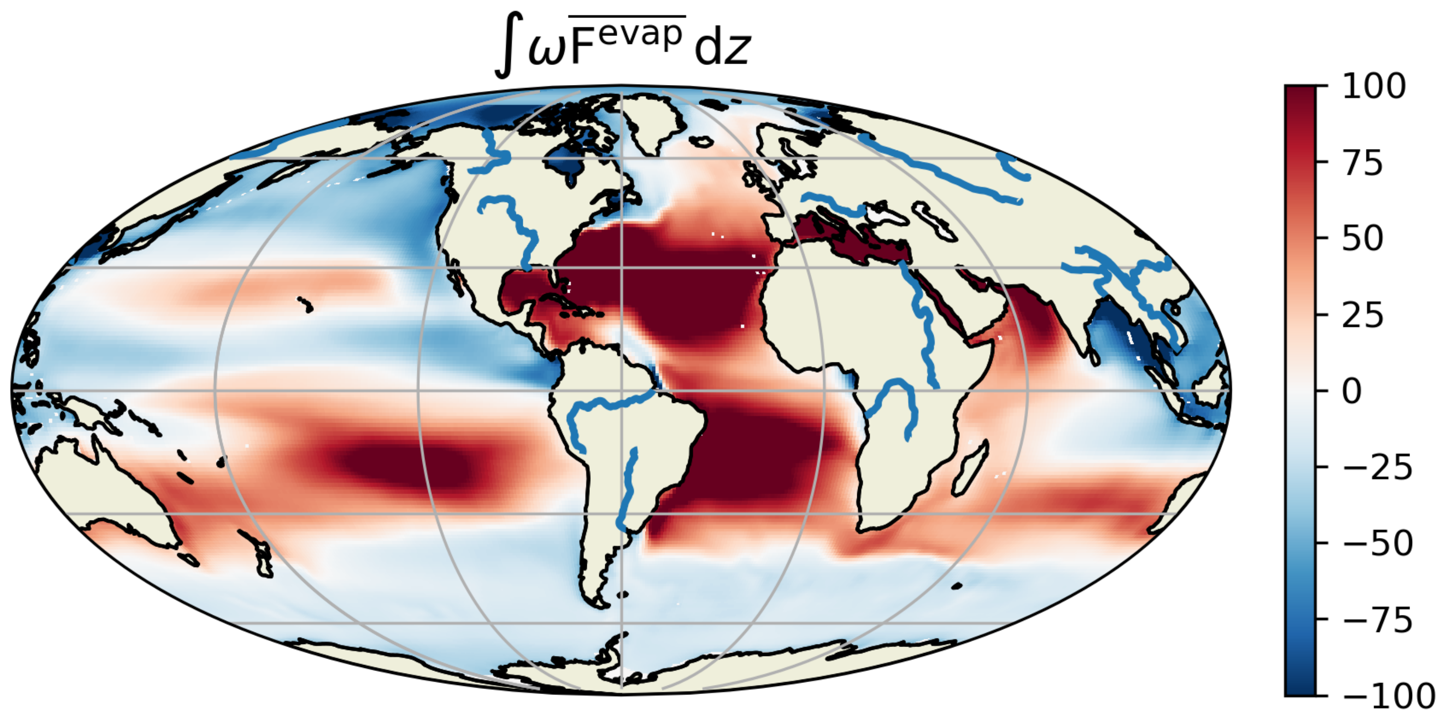


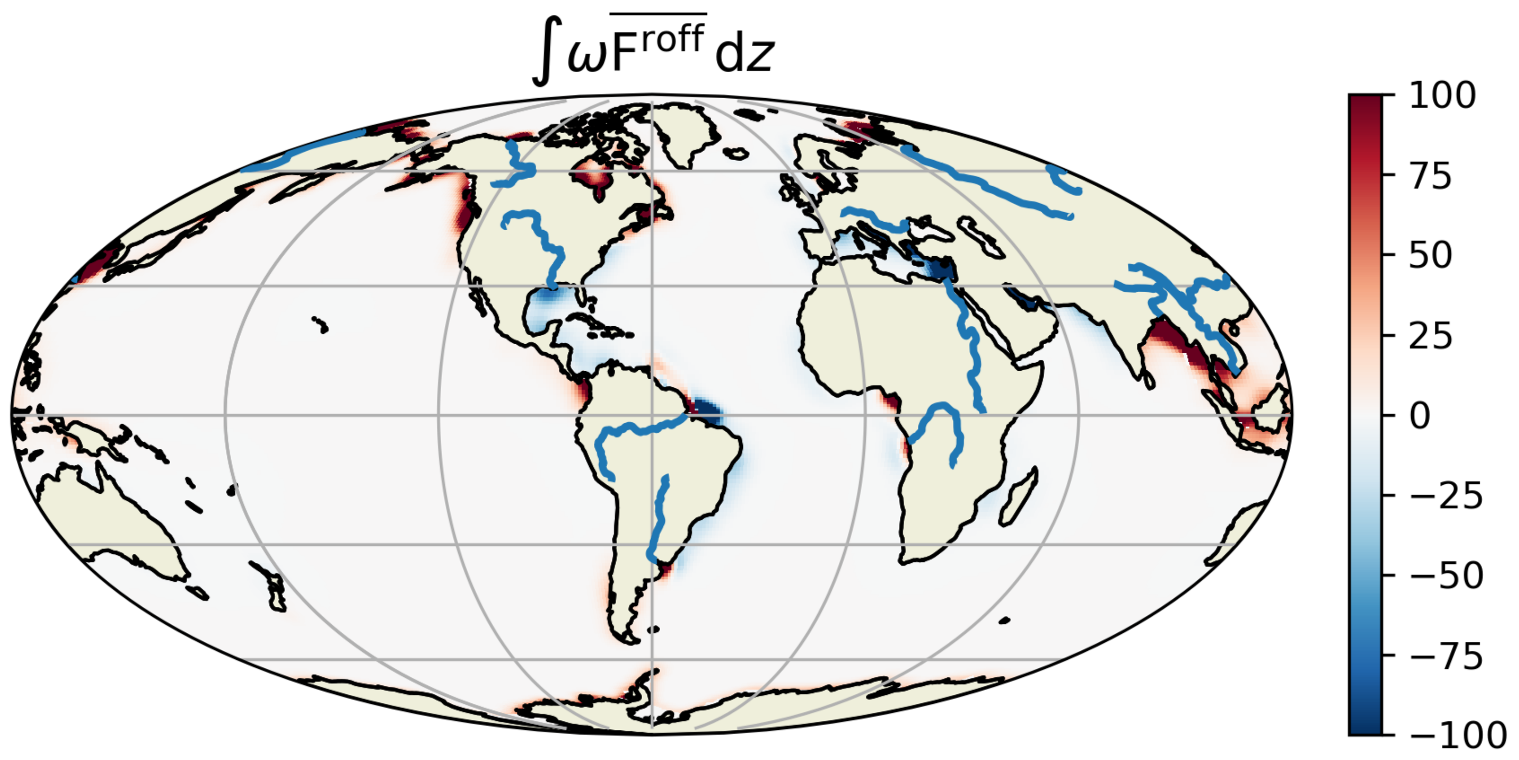
Freshwater flux term decomposition

$\omega\overline{F^{precip}} > 0$ where $\omega < 0$









$\omega\overline{F^{evap}} > 0$ where $\omega > 0$

Advection decomposition into redistributive and mixing terms

$$\omega\overline{\mathrm{ADV}} = -\nabla\cdot\overline{\mathbf{v}}\omega^2 - \nabla\cdot\omega\overline{\mathbf{v}'S'} + \overline{\mathbf{v}'S'}\cdot\nabla\overline{S}$$

Redistribution

« Mixing »
(variance transfer)

Advection decomposition into redistributive and mixing terms

$$\omega\overline{\mathrm{ADV}} = \underbrace{-\nabla\cdot\bar{\mathbf{v}}\omega^2 - \nabla\cdot\omega\overline{\mathbf{v}'S'}}_{\text{Redistribution}} + \underbrace{\overline{\mathbf{v}'S'}\cdot\nabla\bar{S}}_{\text{« Mixing » (variance transfer)}}$$

Redistribution

« Mixing »
(variance transfer)

Volume average

In ECCO

$$\left\langle\omega\overline{\mathrm{ADV}}\right\rangle = \left\langle\overline{\mathbf{v}'S'}\cdot\nabla\bar{S}\right\rangle = \underbrace{\left\langle\overline{\mathbf{v}'_{\mathrm{int}}S'_{\mathrm{int}}}\cdot\nabla\bar{S}\right\rangle + \left\langle\overline{\mathbf{v}'_{\mathrm{sub}}S'_{\mathrm{sub}}}\cdot\nabla\bar{S}\right\rangle}_{\left\langle\overline{\mathbf{v}'_{\mathrm{resolved}}S'}\cdot\nabla\bar{S}\right\rangle} + \left\langle\overline{\mathbf{v}'_{\mathrm{GM}}S'}\cdot\nabla\bar{S}\right\rangle$$

Interannual

Seasonal cycle+sub-annual

Parametrized advective eddy flux

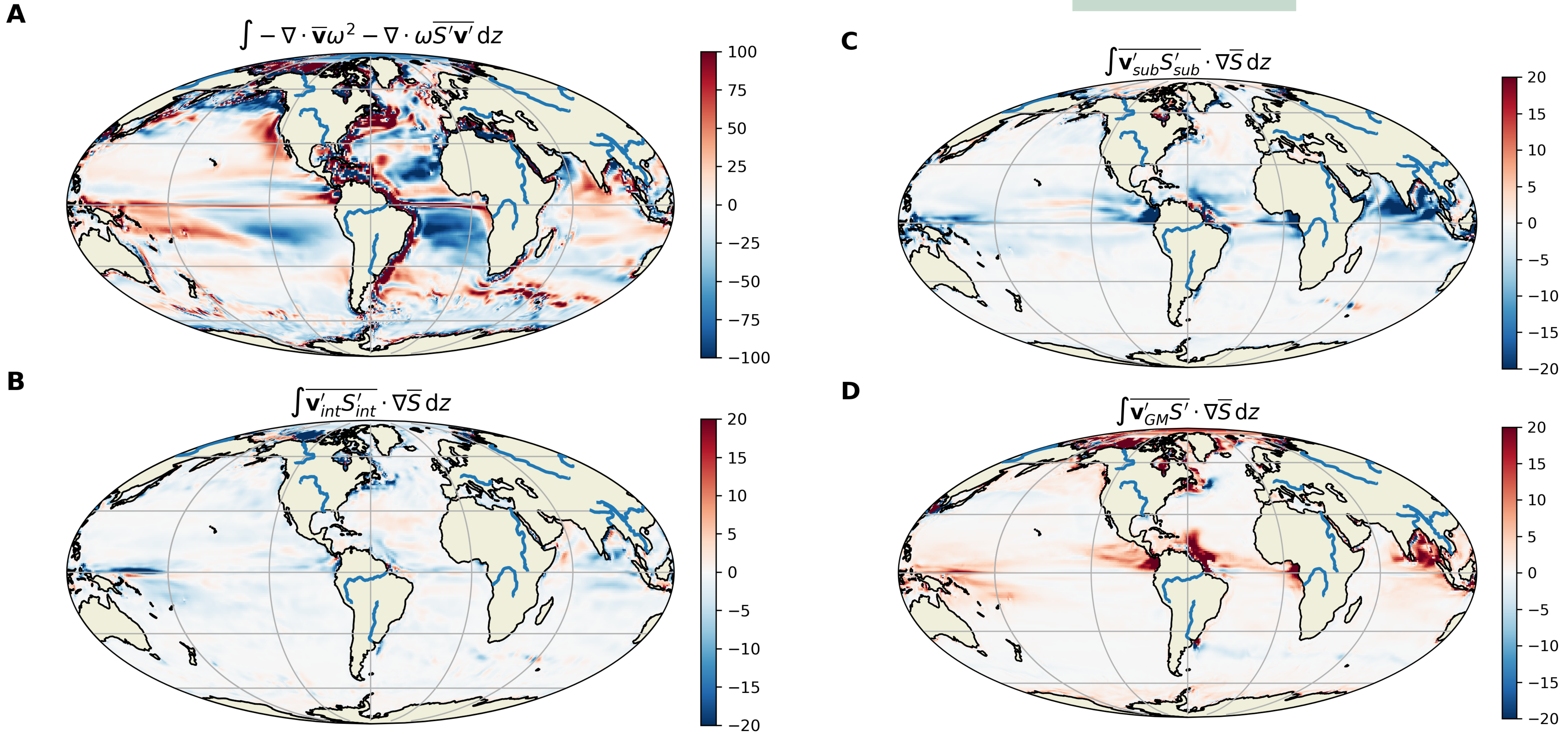
Advective terms

Redistribution

Seasonal

Interannual

GM



-Locally redistribution dominates other terms

-The sink effect of the seasonal cycle is important at low latitudes

-The advective eddy flux acts to increase the $\overline{S}$ variance

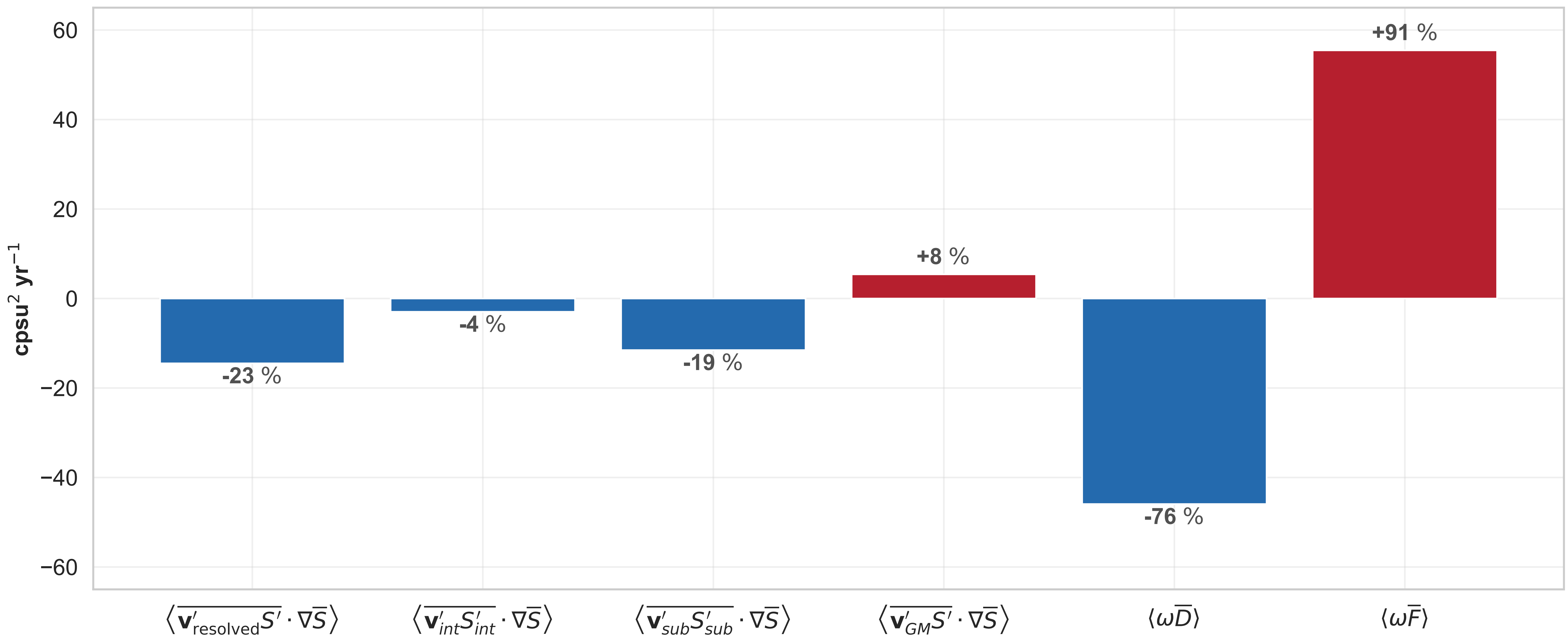
Volume average of the variance budget

$$\frac{1}{2}\frac{\partial \mathscr{W}}{\partial t} = \left\langle \overline{\mathbf{v}'S'} \cdot \nabla \overline{S} \right\rangle + \left\langle \omega \overline{D} \right\rangle + \left\langle \omega \overline{F} \right\rangle$$

Variance transfer

Diffusion

Freshwater forcing



Interannual

Seasonal

GM

Conclusion

-New variance framework links global and regional balances

-Large-scale variability contributes significantly to mixing (~23%)

-Seasonal cycle is the dominant large-scale contributor

Future work:

- Use a similar framework to study the link between surface and subsurface variance
- Study the effect of mesoscale using high resolution simulation

Conclusion

Thank you for your attention !

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