Ocean Dynamics control of the Steric Sea Level Seasonal Cycle

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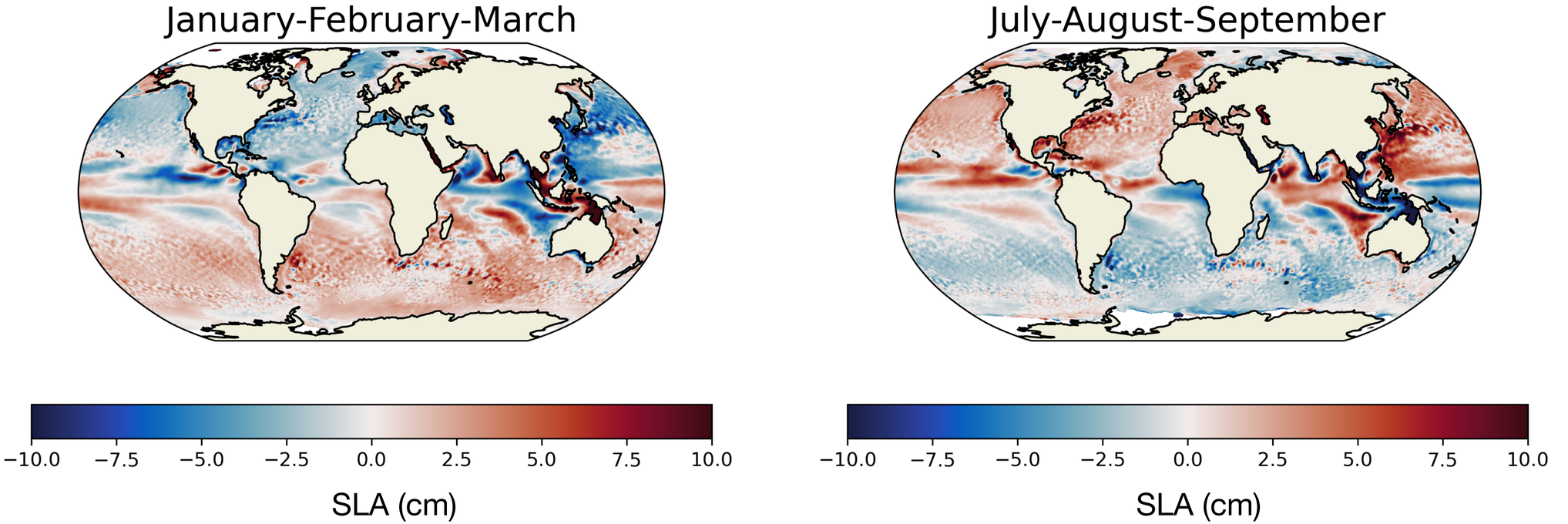
Introduction/motivation

Seasonal
SLA
AVISO
1993-2022



Steric sea level

$$\partial_t \eta \approx \frac{\alpha Q}{\rho_0 C_p}$$

e.g. Gill Niller 1973
Stammer 1997

Introduction/motivation

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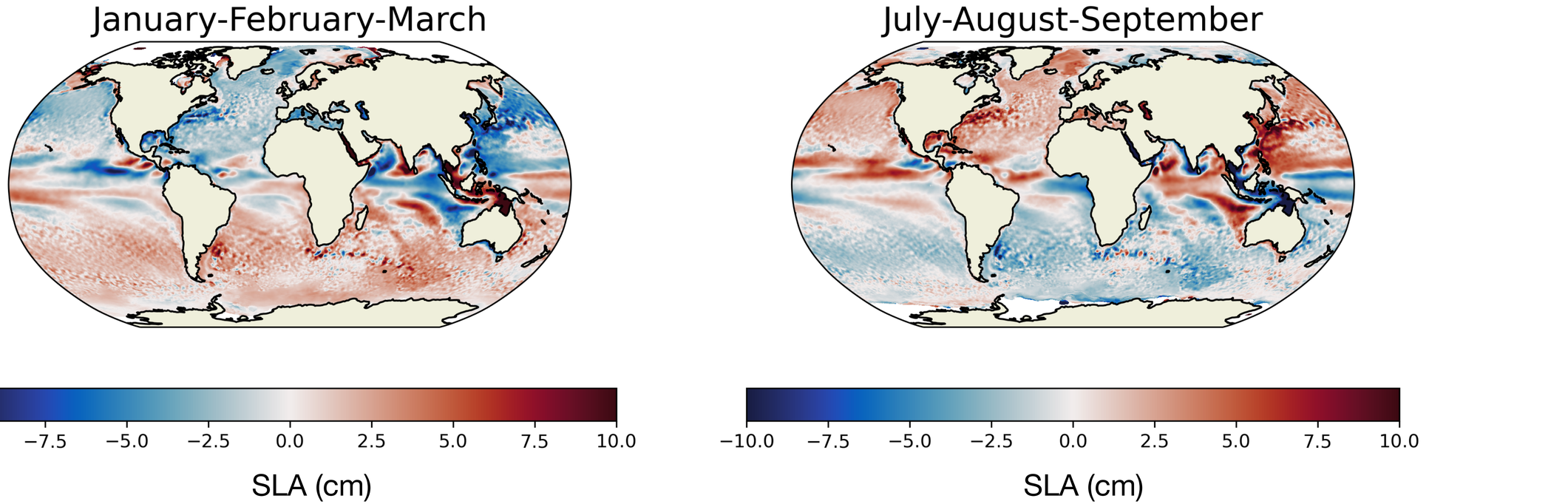


Investigate the sources and sinks of the SSL seasonal cycle
Equation for the variance of the seasonal steric sea level

$$\left(\partial_t \eta \approx \frac{\alpha Q}{\rho_0 C_p}\right) \times \eta$$

e.g. Colin de Verdière et al. 1999, Arzel et al. 2018, Gastineau et al. 2018 …

Hochet et al. 2023 (JGR: ocean) inter-annual variability in the SSL

Introduction/motivation

$$\frac{1}{2}\overline{\frac{\partial \eta^2}{\partial t}} = 0 \approx^{?} \overline{\eta \frac{\alpha Q}{\rho_0 C_p}}$$

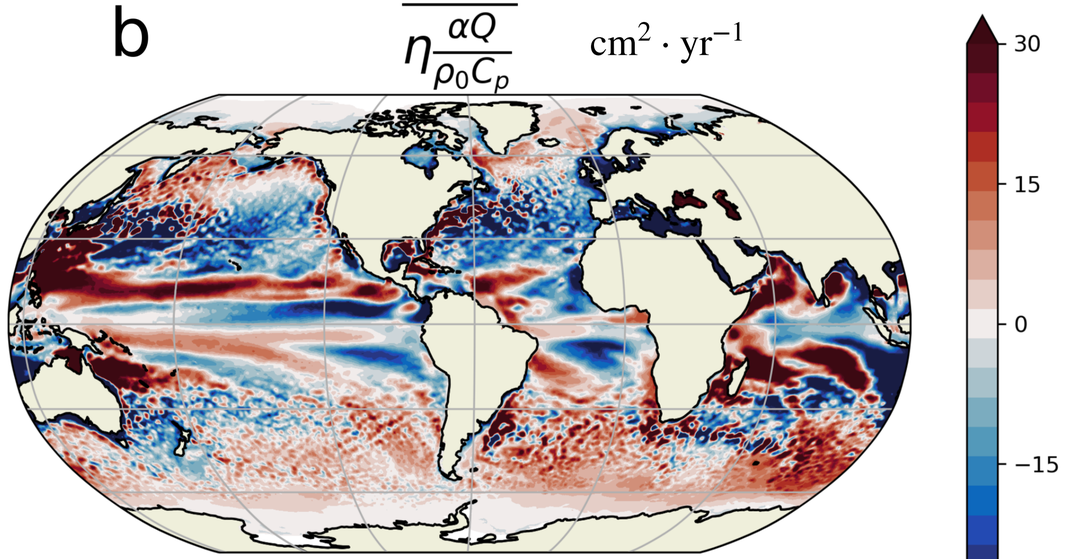
Equation for the variance of the steric sea level

Introduction/motivation

$$\frac{1}{2}\overline{\frac{\partial \eta^2}{\partial t}} = 0 \; ? \; \overline{\eta \frac{\alpha Q}{\rho_0 C_p}}$$

Equation for the variance of the steric sea level

b $\overline{\eta \frac{\alpha Q}{\rho_0 C_p}}$ $\mathrm{cm^2 \cdot yr^{-1}}$



$Q \rightarrow$ **ERA-5**

$\eta \rightarrow$ **AVISO**

What are the missing terms in the variance equation ?
What are the mechanisms driving and damping the SSL seasonal variability ?

Method: budget of steric sea level variance

$X \rightarrow X^{seasonal}$ Monthly average over 1993-2014 on detrended time anomalies

Evolution equation for the seasonal steric sea level:

$$\frac{\partial \eta^{seasonal}}{\partial t} = -\frac{1}{\rho_0}\int_{-H}^{0} \frac{\partial \rho^{seasonal}}{\partial t}\,\mathrm{d}z \qquad \frac{\partial \rho^{seasonal}}{\partial t} = \mathrm{adv} + \mathrm{dif} + \mathrm{flu},$$

Local steric sea level variance budget:

$$\eta^{seasonal}\frac{\partial \eta^{seasonal}}{\partial t} = \frac{1}{2}\frac{\partial (\eta^{\mathrm{seasonal}})^2}{\partial t} = \mathrm{ADV} + \mathrm{DIF} + \mathrm{FLU}$$

if $\mathrm{FLU} > 0$ then $\left(\eta^{\mathrm{seasonal}}\right)^2$ increases: it is a source

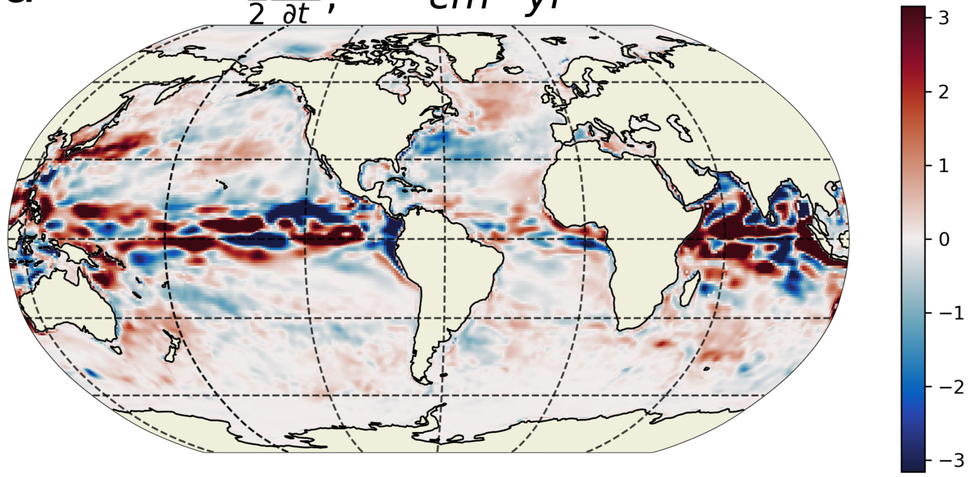
if $\mathrm{FLU} < 0$ then $\left(\eta^{\mathrm{seasonal}}\right)^2$ decreases: it is a sink

Ecco v4r3

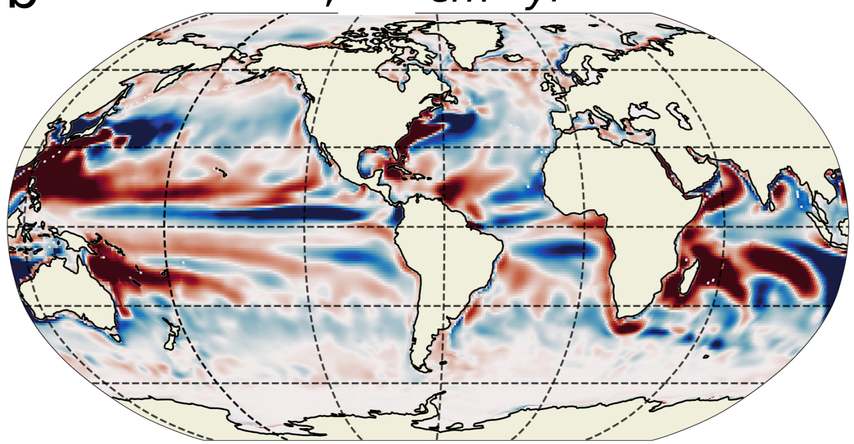
- MITgcm assimilating available observations for the period 1992 to 2017 (Forget et al. 2015)
- Dynamically consistent state estimate without unidentified sources of heat and buoyancy
- LLC90 grid: mean horizontal resolution ~ 1 degree, 50 vertical levels
- Potential temperature and salinity budgets available 1993-2014

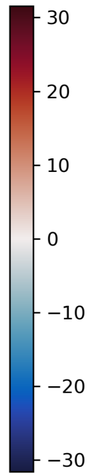
Seasonal steric sea level variance budget ECCOv4r3

a $\overline{\frac{1}{2}\frac{\partial \eta^2}{\partial t}}$, $cm^2\ yr^{-1}$

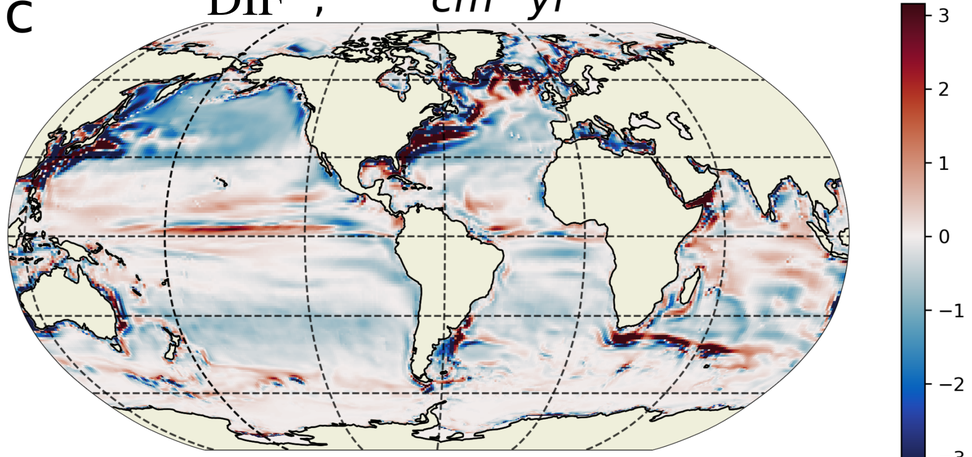


b $\overline{\mathrm{FLU}}$, $cm^2\ yr^{-1}$

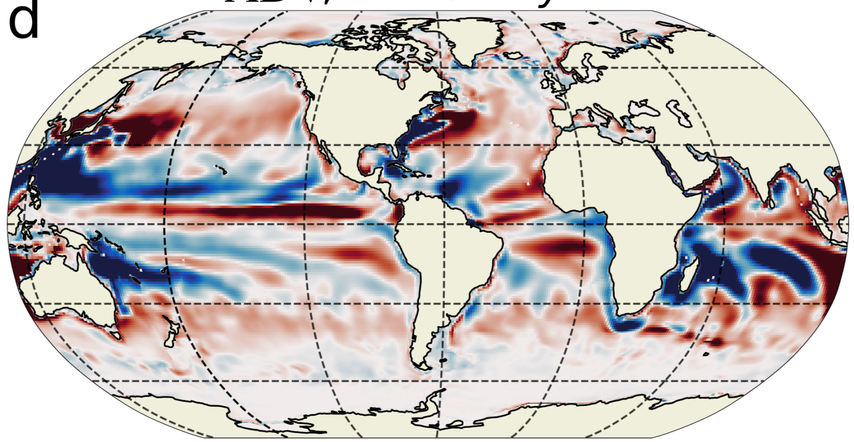


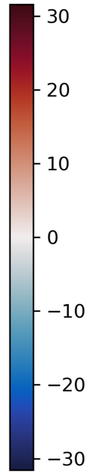


c $\overline{\mathrm{DIF}}$, $cm^2\ yr^{-1}$



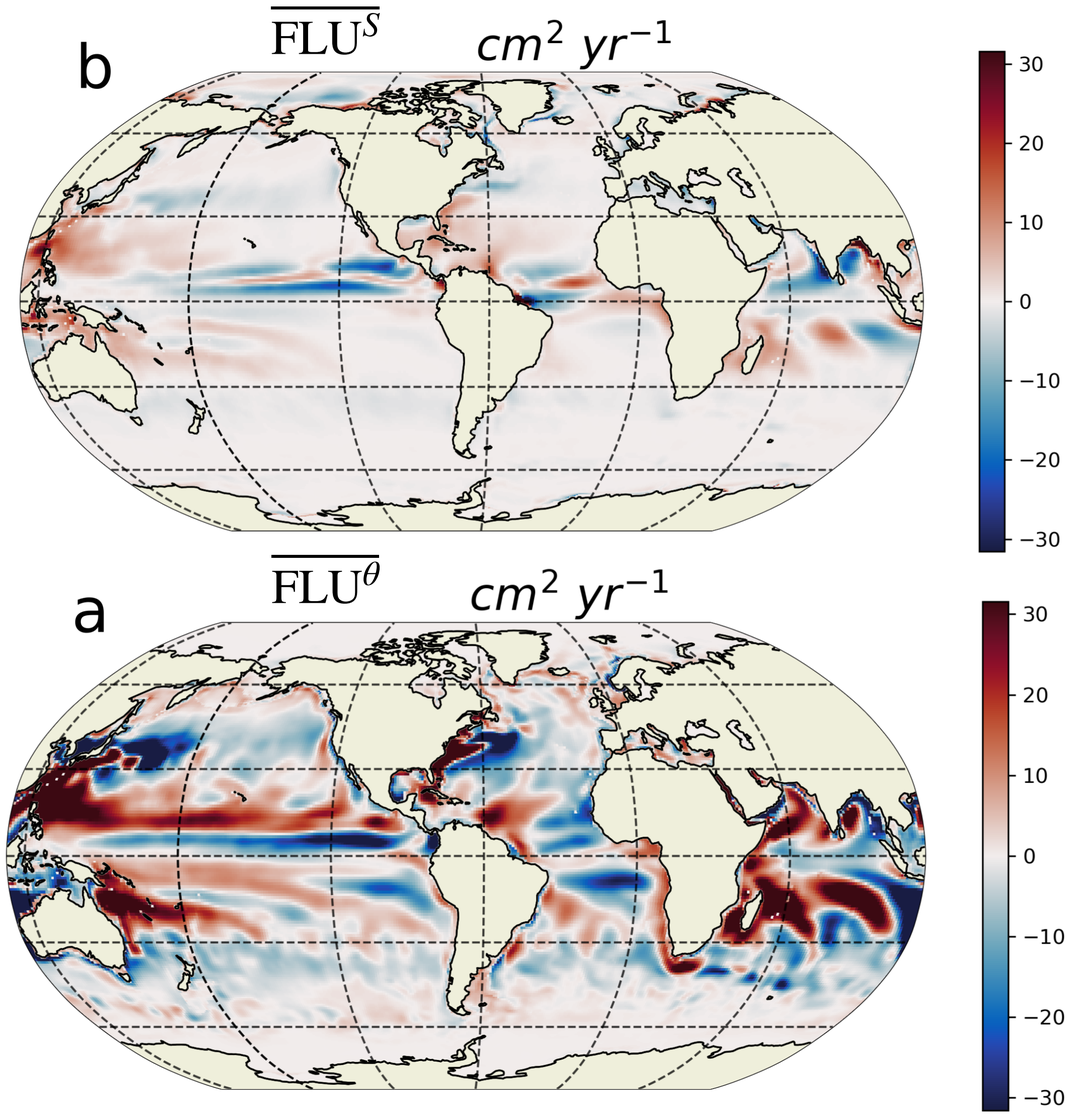
d $\overline{\mathrm{ADV}}$, $cm^2\ yr^{-1}$





$$\overline{\mathrm{ADV}} + \overline{\mathrm{FLU}} \approx 0$$

Buoyancy flux term decomposition



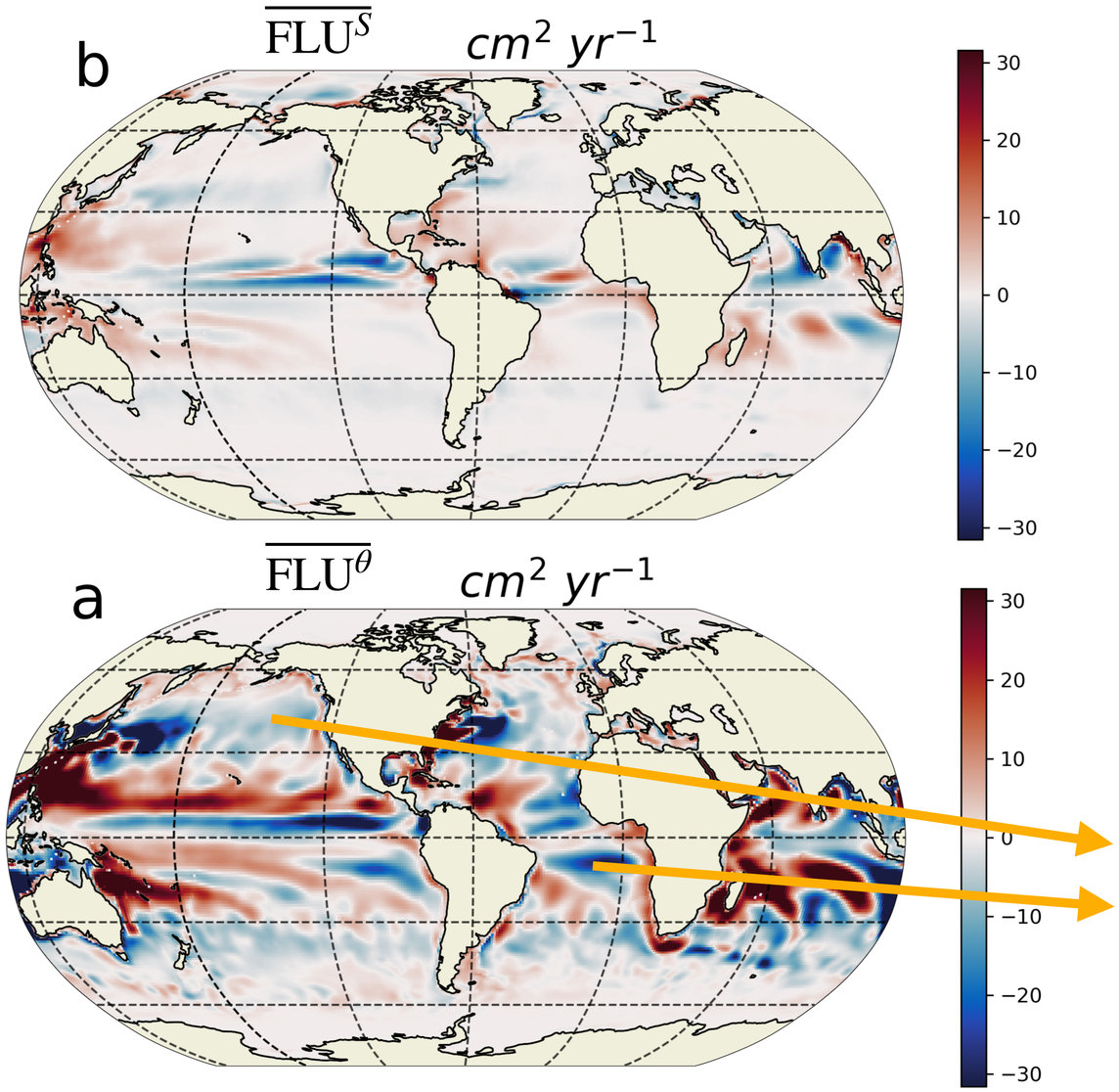
$$\mathrm{FLU} = \mathrm{FLU}^S + \mathrm{FLU}^\theta$$

Freshwater fluxes
P-E+R

Net heat flux

Buoyancy flux term is dominated by the net heat flux

Buoyancy flux term decomposition



$$\mathrm{FLU} = \mathrm{FLU}^S + \mathrm{FLU}^\theta$$

Freshwater fluxes
P-E+R

Net heat flux

Buoyancy flux term is dominated by the net heat flux

How can the seasonal variations of the net heat flux be a sink of SSL variance ?

How can FLU^{θ} be negative in some regions ?

Seasonal SSL

Vertical integral of
Effect of net heat flux on density

$$\mathrm{FLU}^{\theta} = \frac{1}{\rho_0^2} \int_{-H}^{0} \rho \, \mathrm{d}z \int_{-H}^{0} -\frac{\alpha}{C_p} Q \mathrm{d}z \, .$$

$$X_{BT} = \frac{1}{H} \int_{-H}^{0} X \, \mathrm{d}z$$

$$\overline{\mathrm{FLU}^{\theta}} \propto \overline{\rho_{\mathrm{BT}} Q_{BT}}$$

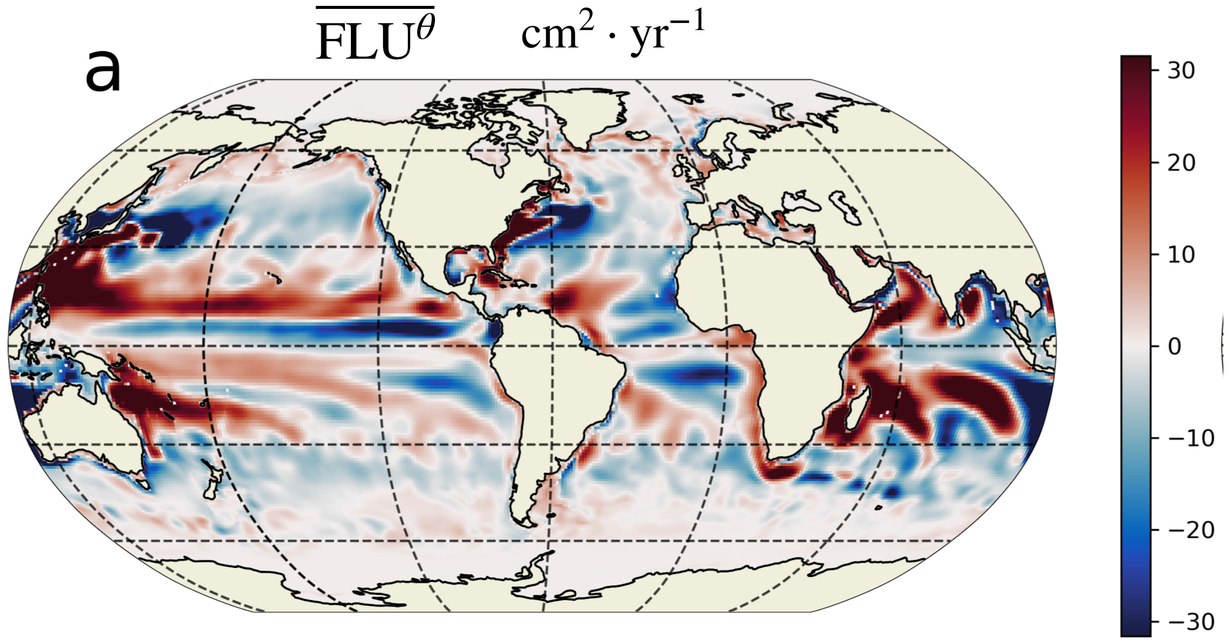
How can FLU^{θ} be negative in some regions ?

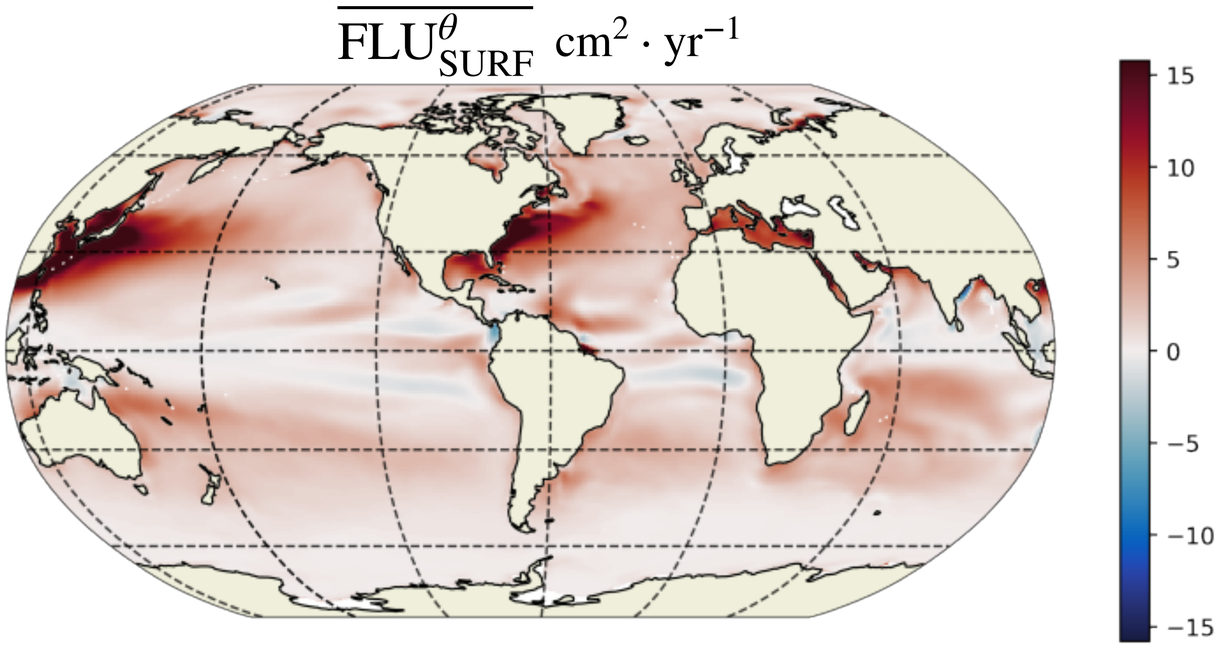
$$\mathrm{FLU}^{\theta} = \frac{H}{\rho_0^2} \int_{-H}^{0} \rho \, \mathrm{d}z Q_{BT} \, .$$

$$\mathrm{FLU}^{\theta}_{\mathrm{SURF}} = \frac{H}{\rho_0^2} \underbrace{\int_{-h}^{0} \rho \, \mathrm{d}z \, Q_{BT} \, .}_{h = 10\,m}$$

First 10m vertical integral

a

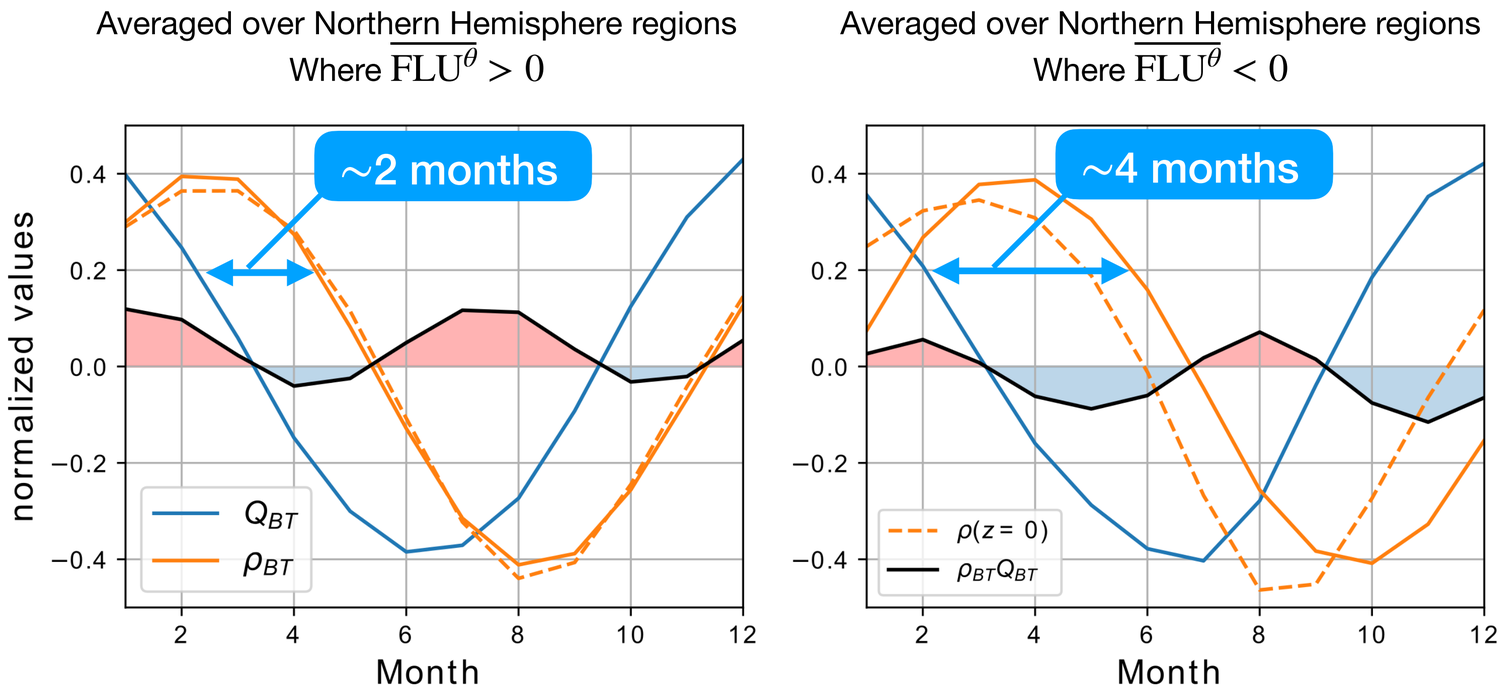




Negative values of $\overline{\mathrm{FLU}^{\theta}}$ are linked with the vertical structure of the density anomalies

How can $\overline{\mathrm{FLU}^{\theta}}$ be negative in some regions ?

$$\overline{\mathrm{FLU}^{\theta}} \propto \overline{\rho_{\mathrm{BT}} Q_{BT}}$$



Larger delay between Q_{BT} and ρ_{BT} in regions where $\overline{\mathrm{FLU}^{\theta}} < 0$

The sign of $\overline{\mathrm{FLU}^{\theta}}$ depends on the vertical propagation of density anomalies

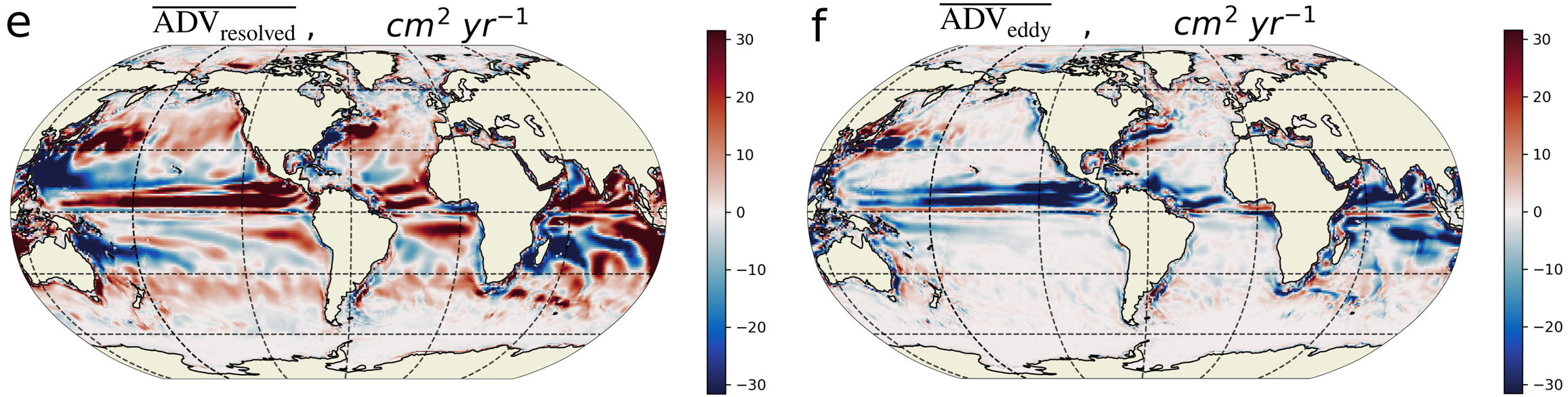
Decomposition of the advective term

$$\mathrm{ADV} = \mathrm{ADV}_{\mathrm{resolved}} + \mathrm{ADV}_{\mathrm{eddy}}$$

Term linked with the resolved advection

Term linked with the GM parametrised eddy fluxes

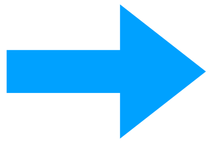
Decomposition of the advective term



GM Parameterized eddy fluxes act as an important sink of seasonal SSL variance

Conclusions

- Mechanisms of the seasonal SSL cycle are more complex than previously hypothesised
- Variance of the seasonal SSL cycle is a result of a balance between the effect of oceanic advection and net heat flux
- At mid latitudes and in the eastern parts of low latitudes regions, net heat flux acts to damp the variance seasonal cycle of SSL
- Eddies locally act as an important sink of seasonal SSL variance



Hochet, A., Llovel, W., Huck, T., & Sévellec, F. (In preparation). Ocean Dynamics control of the Steric Sea Level Seasonal Cycle

Perspectives

- Investigate the mechanisms of SSL variability on different timescales —> Hochet et al. 2023 (JGR.)

- Investigate the role of eddies on SSL variability in eddy-resolving models

- assess the representation of steric sea level mechanisms in climate models.

Why is $\overline{\frac{\partial \eta^2}{\partial t}}$ not (exactly) 0 ?

$$\frac{\partial \eta}{\partial t} = \mathrm{ADV} + \mathrm{DIF} + \mathrm{FLU}\ (1)$$

All terms for the $\theta - S$ budget are given by ECCO as monthly averages

Step 1 Obtain the SSL evolution equation

Detrended Time anomalies

Monthly average over 1993-2014

Step 2 Compute the seasonal cycle on Eq. (1) and η

$$\overline{\eta^{seasonal}\left(\frac{\partial \eta}{\partial t}\right)^{seasonal}}$$

$$\left(\frac{\partial \eta}{\partial t}\right)^{seasonal} \text{ is not exactly equal to } \left(\frac{\partial \eta^{seasonal}}{\partial t}\right)$$

Seasonal steric sea level in ECCO v4r3