Machine-Learned parameterizations of mesoscale eddies in MOM6 ocean model: convolutional neural network and symbolic regression

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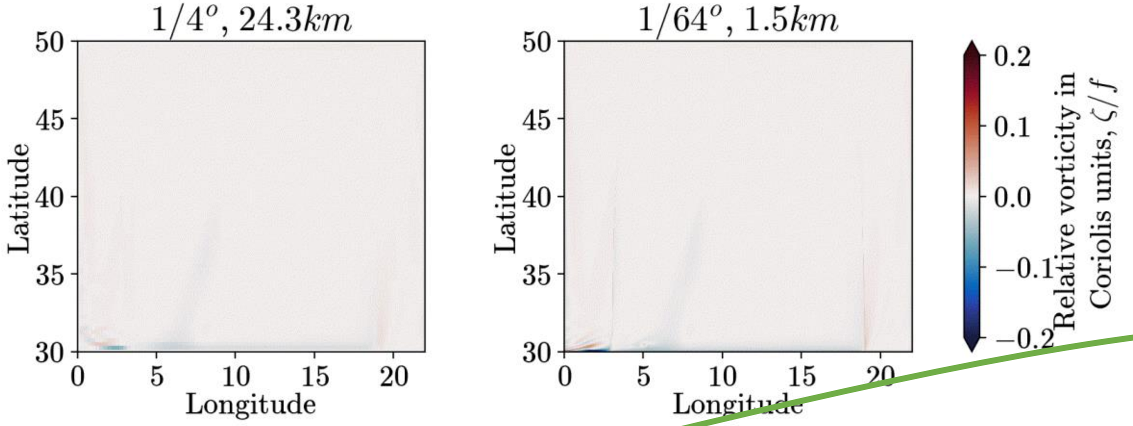
https://m2lines.github.io/

Mesoscale parameterizaion

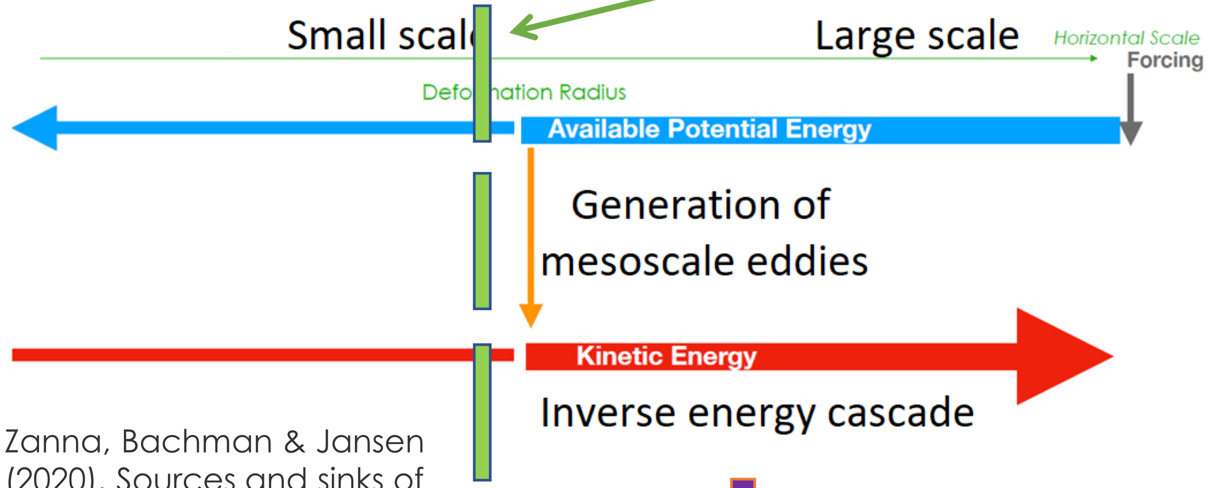


Mesoscale eddies of size (Rossby deformation radius):

$$R_d = \frac{c}{f} \text{ (10-100km)}$$

Gray zone:

$$\Delta x \approx R_d$$



Zanna, Bachman & Jansen (2020). Sources and sinks of ocean mesoscale eddy energy.

Mesoscale parameterization:

- APE removal (buoyancy forcing)
- KE backscatter (momentum forcing)

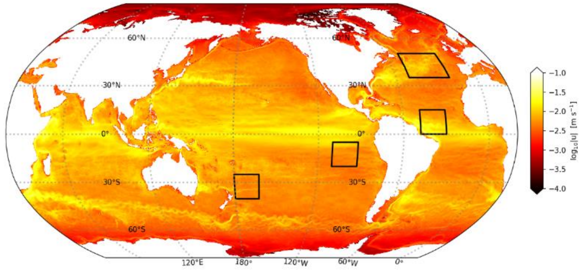
Data-driven mesoscale parameterization

$$\frac{\partial \mathbf{u}_k}{\partial t} + \frac{f+\zeta_k}{h_k}\hat{\mathbf{z}} \times (h_k \mathbf{u}_k) + \nabla K_k + \nabla M_k = \mathbf{F}_k + \mathbf{V}_k \boxed{+ \mathbf{S}_k}$$

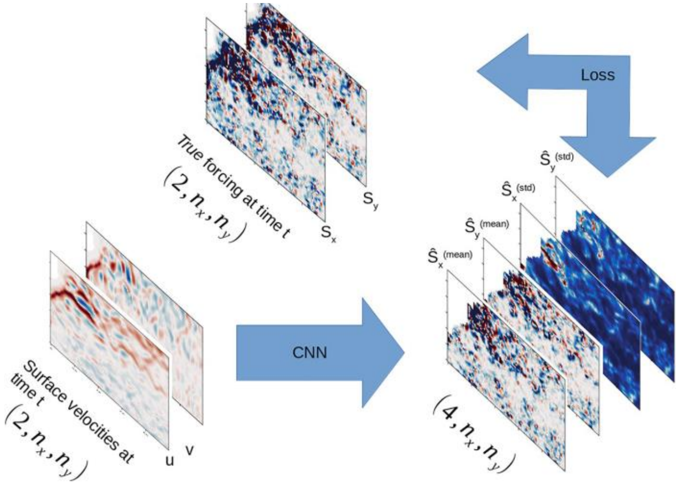
Subgrid momentum forcing

$$\boxed{\mathbf{S} = (\overline{\mathbf{u}} \cdot \overline{\nabla})\overline{\mathbf{u}} - \overline{(\mathbf{u} \cdot \nabla)\mathbf{u}}}$$

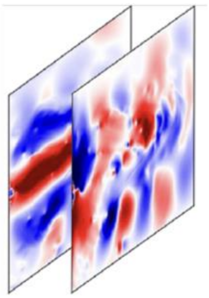
Guillaumin-Zanna-2021:
CNN model



CM2.6 data



MITgcm data



Zanna-Bolton-2020:
Symbolic regression

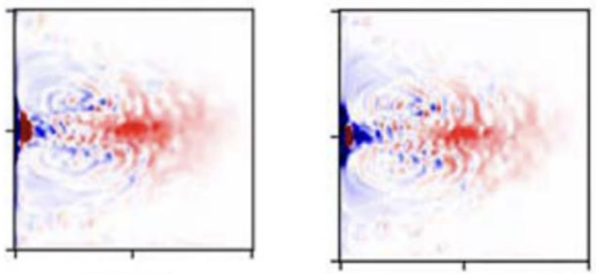
$$\boxed{\begin{aligned} \zeta &= \partial_x v - \partial_y u, \\ \widetilde{D} &= \partial_x u - \partial_y v \\ D &= \partial_y u + \partial_x v \end{aligned}}$$

$$\mathbf{T}(\zeta, D, \widetilde{D}) = \underbrace{\kappa_{BC} \begin{bmatrix} -\zeta D & \zeta \widetilde{D} \\ \zeta \widetilde{D} & \zeta D \end{bmatrix}}_{\text{deviatoric stress}} + \underbrace{\frac{\kappa_{BC}}{2}\left(\zeta^2 + D^2 + \widetilde{D}^2\right)\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}}_{\text{hydrostatic stress}}$$

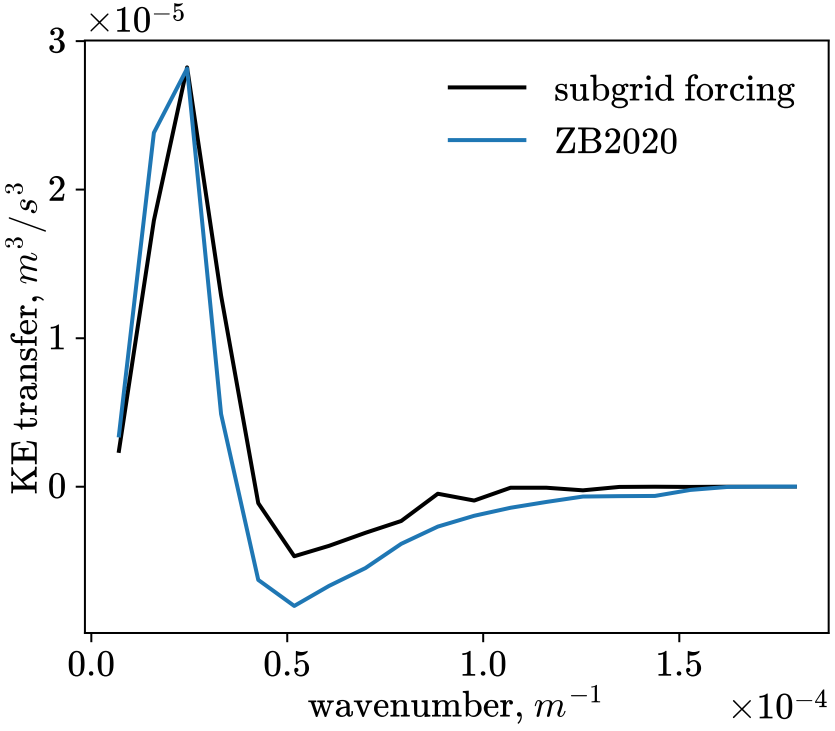
Offline skill of data-driven closures

Subgrid forcing

ZB2020



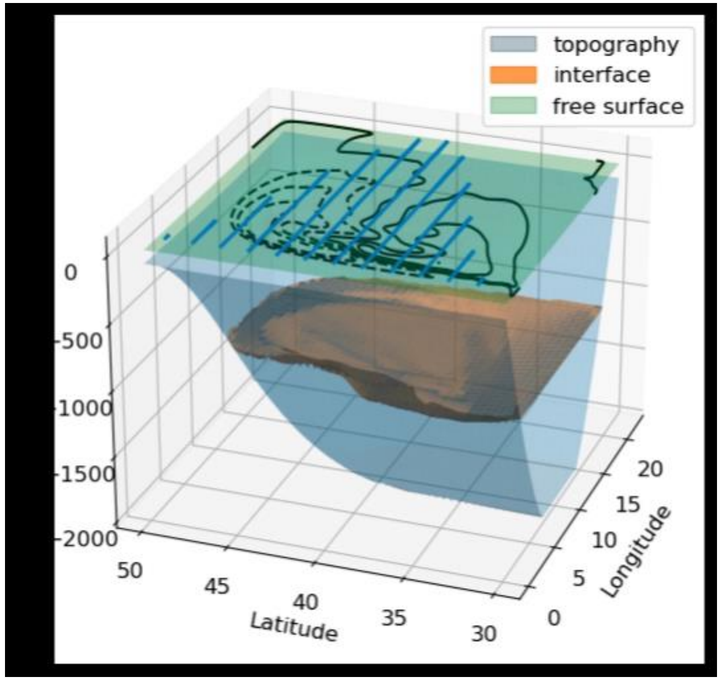
Predicts instantaneous momentum fluxes due to unresolved mesoscale eddies

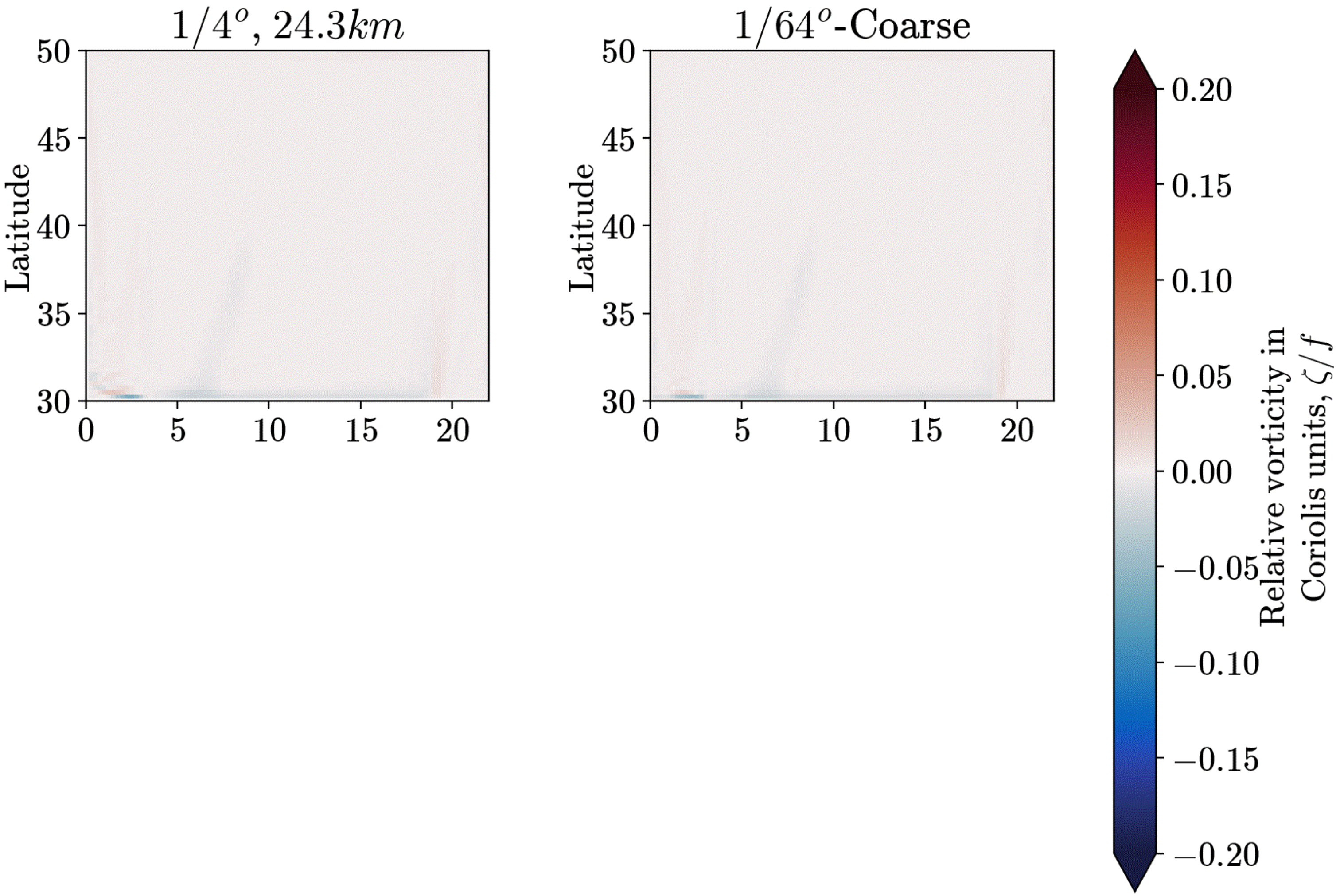


Predicts KE transfer

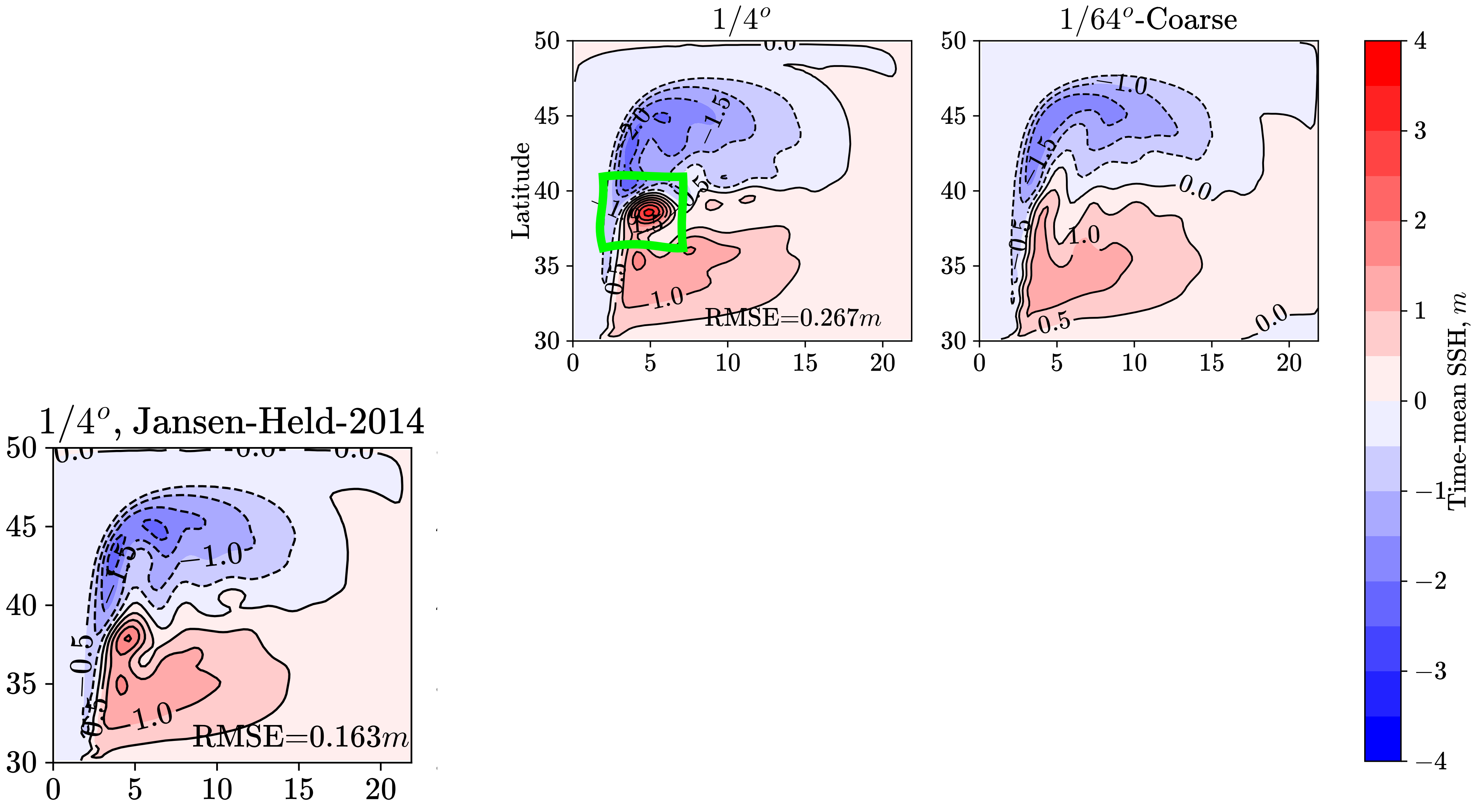
Online skill in realistic ocean models

MOM6 ocean model. Double Gyre.

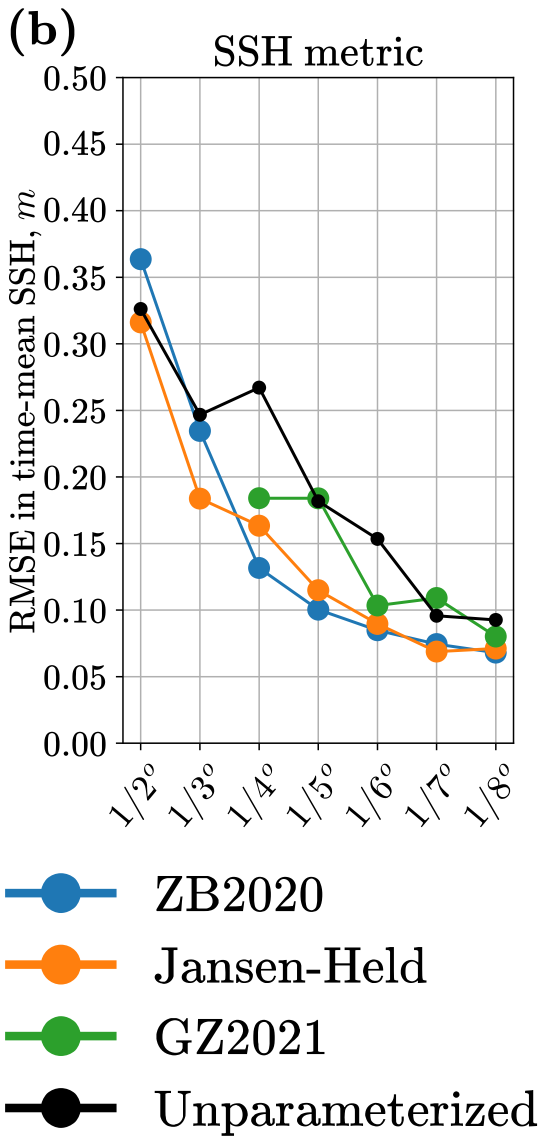


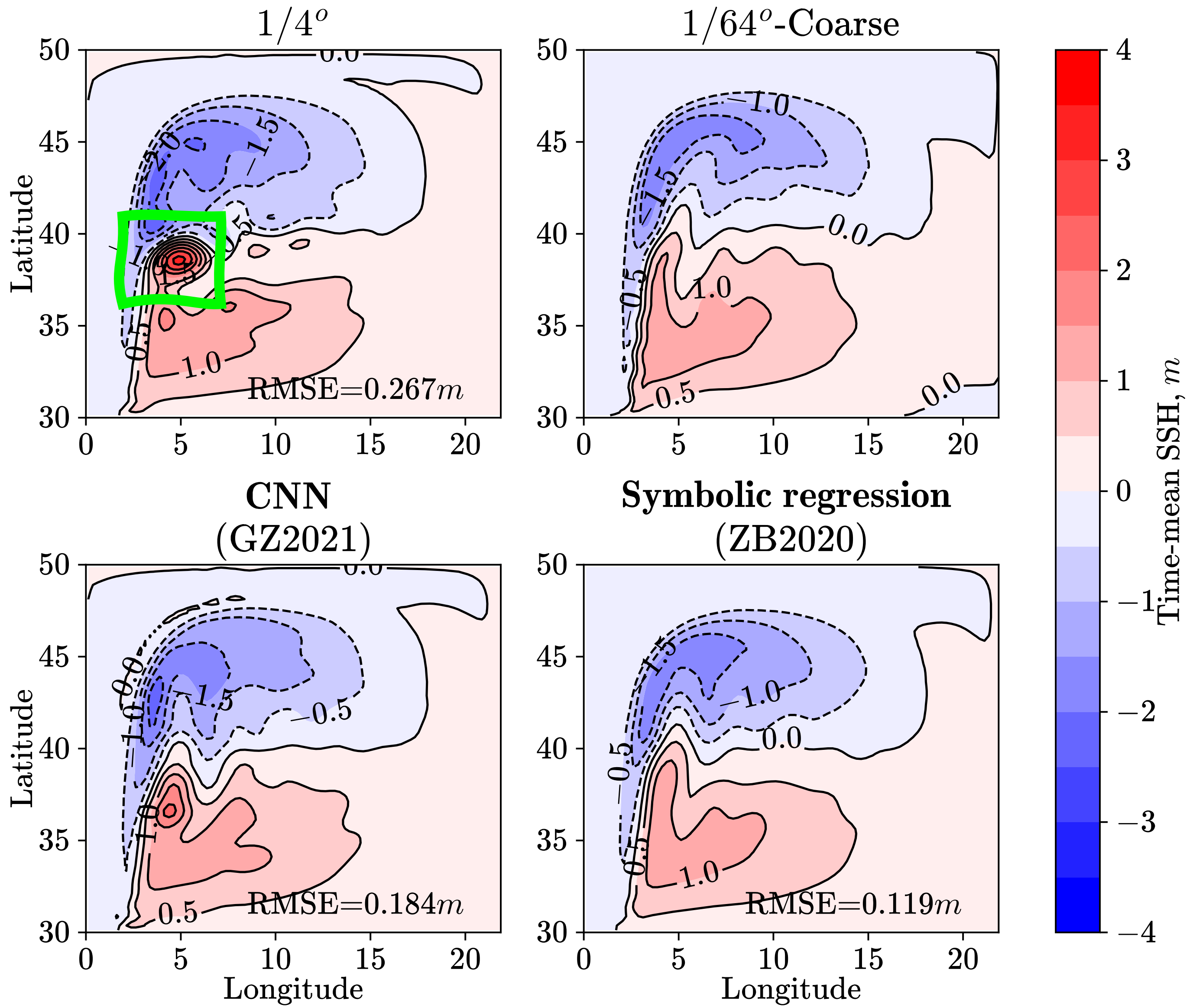


Time-averaged SSH

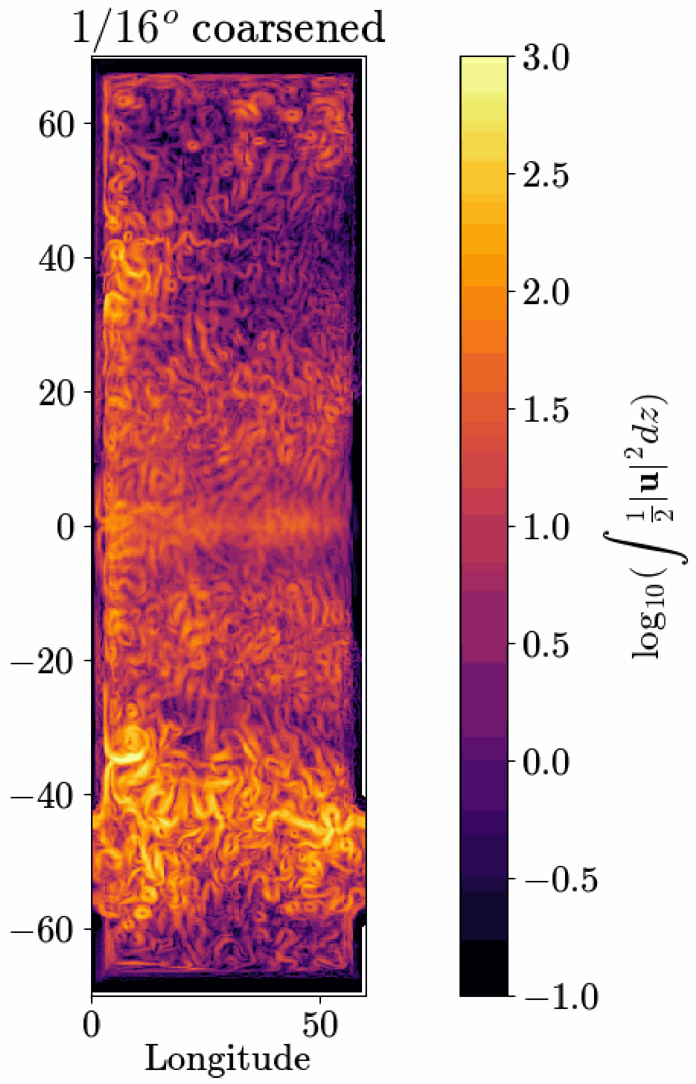


Time-averaged SSH

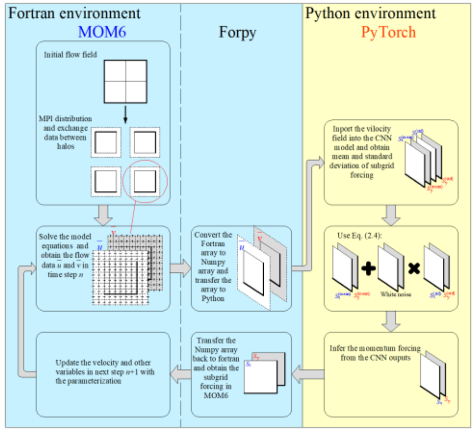




Ongoing research: NewerWorld2 configuration



Challenges



- Implementation:
  - **CNN**: Fortran-Python barried
- A posteriori tuning:
  - **CNN:** vertical profile
  - **Symbolic regression:** additional filters
- Computational cost:
  - **CNN:** requires GPU for affordable runtime
  - **Symbolic regression:** Additional filters increase runtime

Conclusions

- Two **data-driven** mesoscale parameterizations are implemented and evaluated in **MOM6** ocean model
- In some cases they simulate **backscattering** (and improve resolved eddies)
- Both models improve the mean flow (mean SSH)
- Improvement in more realistic configuration (NW2) is more evident by eye
- **Papers:**
  - **CNN:** Zhang2023 submitted
  - **Symbolic regression:** Perezhogin2023 in prep.