Learning non-wave surface divergence from sea surface height using neural networks

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Goal Infer vertical transport from SWOT SSH

- **SWOT is beating expectations, observing true submesoscale** 😺
- Inertia-gravity waves (IGWs) and frontogenetic flows (FG) ⇒ ~~geostrophy~~
- IGWs don't contribute to vertical transport [B18]
- FG flows do contribute to vertical transport [B18, B21]
- Lack dynamics-based model to infer FG flow from SSH
- But if vorticity ζ, strain σ, divergence δ known, JPDFs parse flows into structures [B21]

Use Convolutional Neural Networks (CNN) to learn velocity statistics directly from SSH [X23]

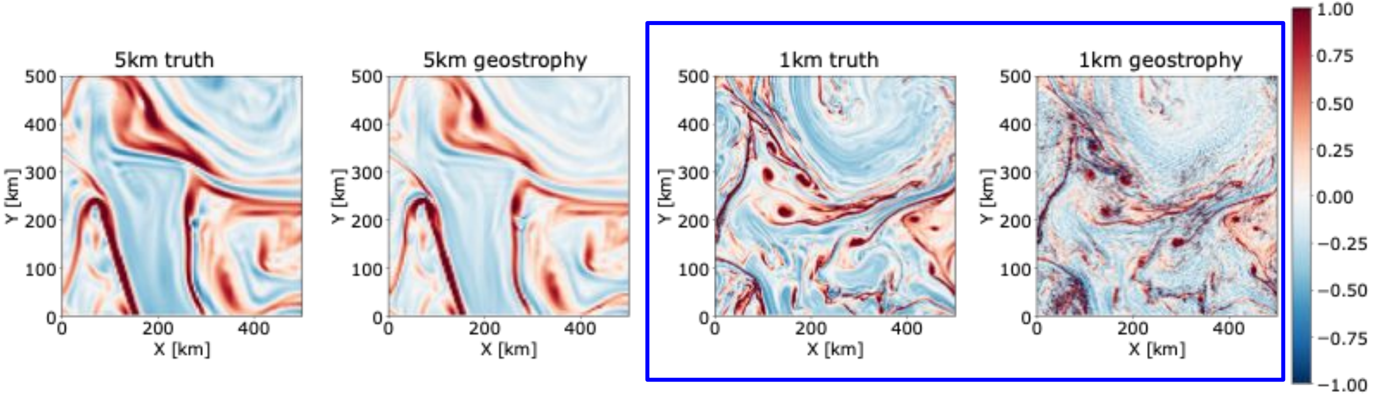
Even non-wavy submesoscales are not geostrophic (enough)

Vorticity/f

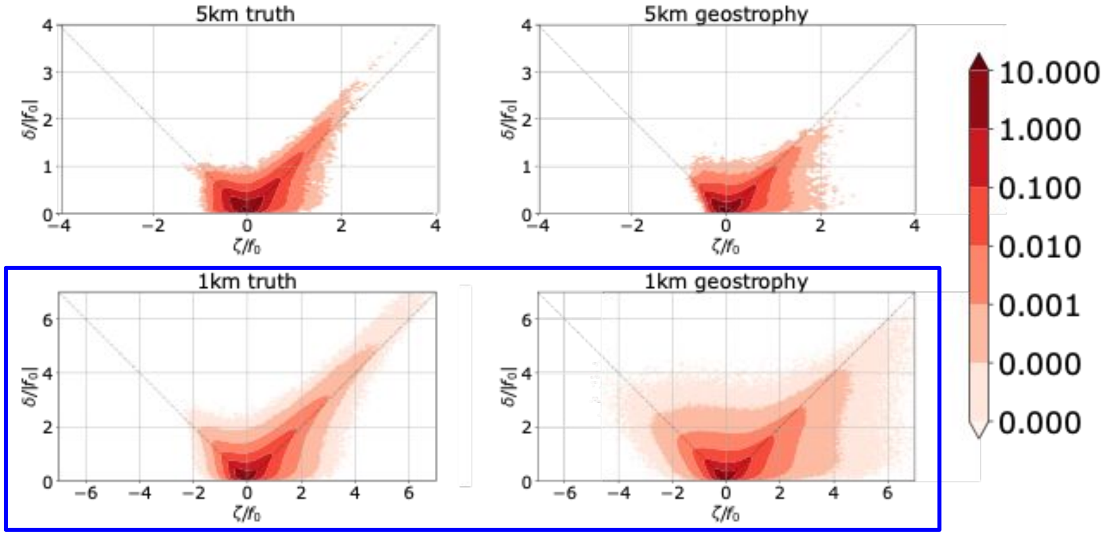
5km & 1km channel sims

Steady wind & T_y

⇒ Not v. wavy

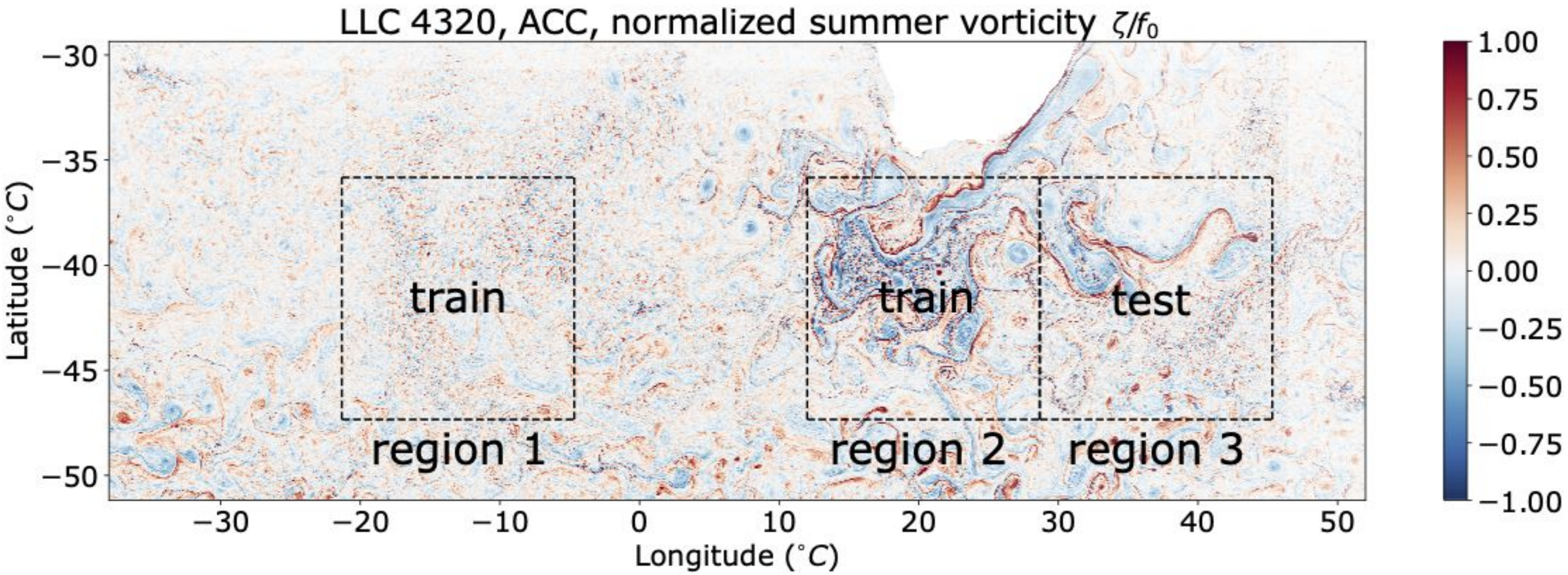


ζ - σ JPDFs tell more than visual norm



[B18, B21, X23]

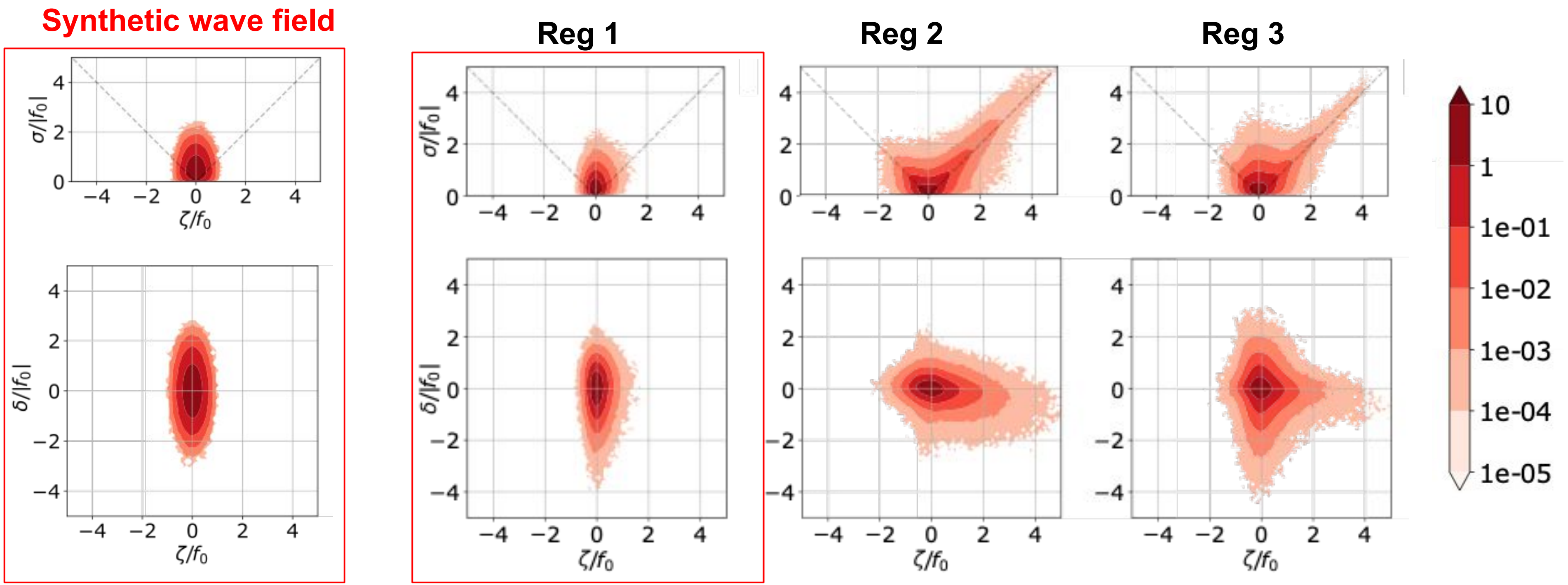
Using NNs to learn LLC4320 (summer vorticity shown)



Train on Reg 1 (wavy) + Reg 2 (submesoscale-y) SSH

⇨ Learn Reg 3 (mixed) vorticity ζ, strain σ & divergence δ

Flow types in regions 1, 2, 3 seen through ζ, σ & δ JPDFs



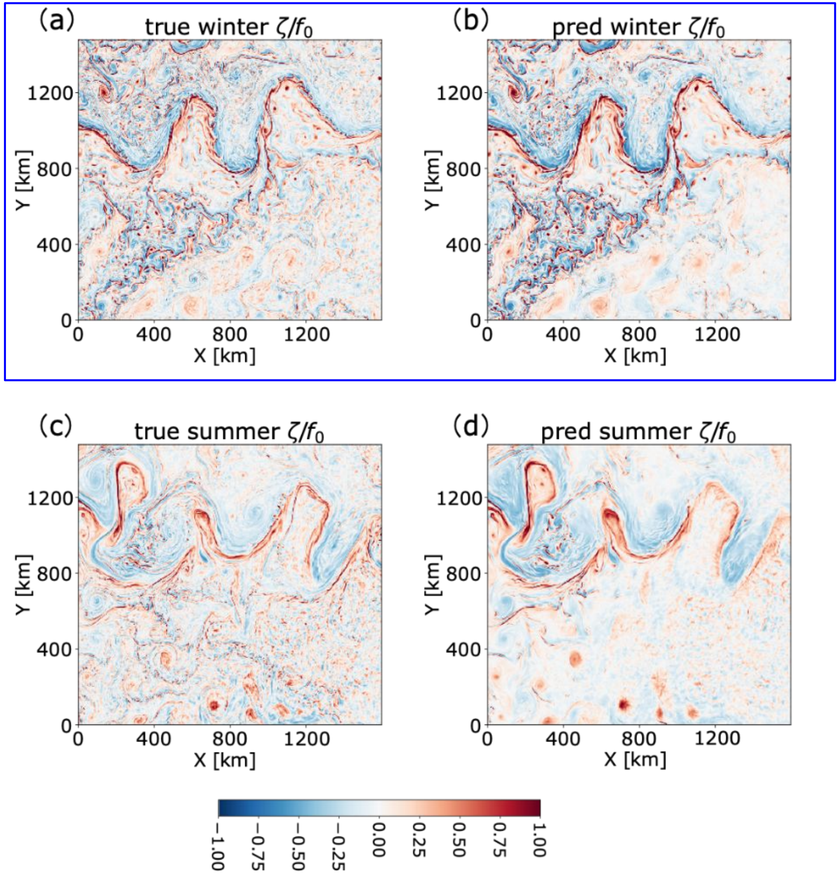
Reg 1 looks like waves

Reg 2 looks like typical submesoscale [B21]

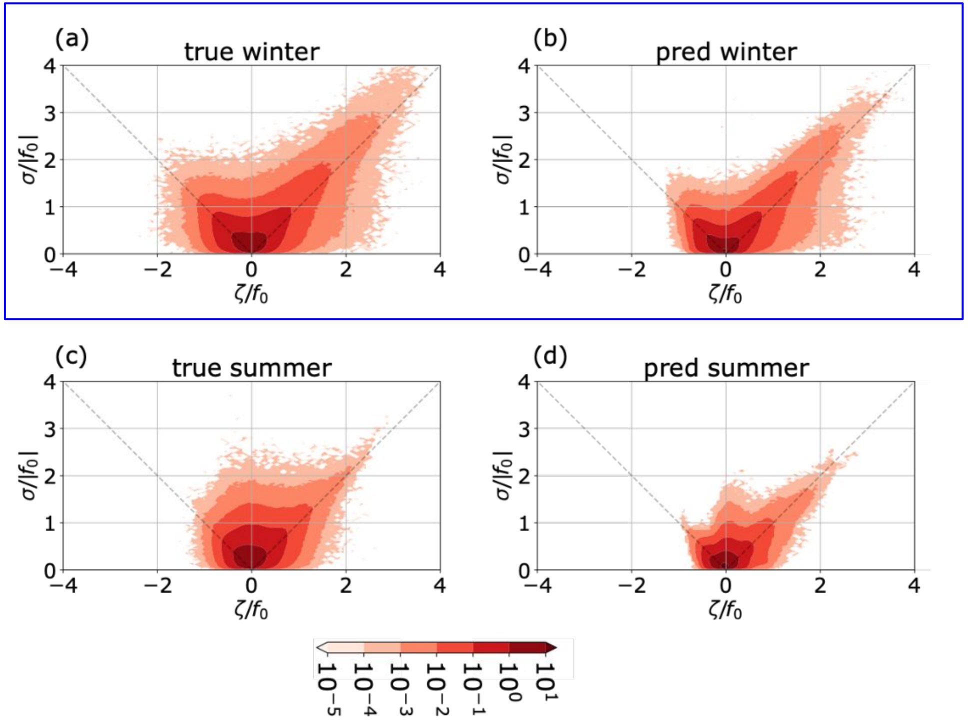
Reg 3 has **both**

True and predicted, summer and winter in region 3

Vorticity/f

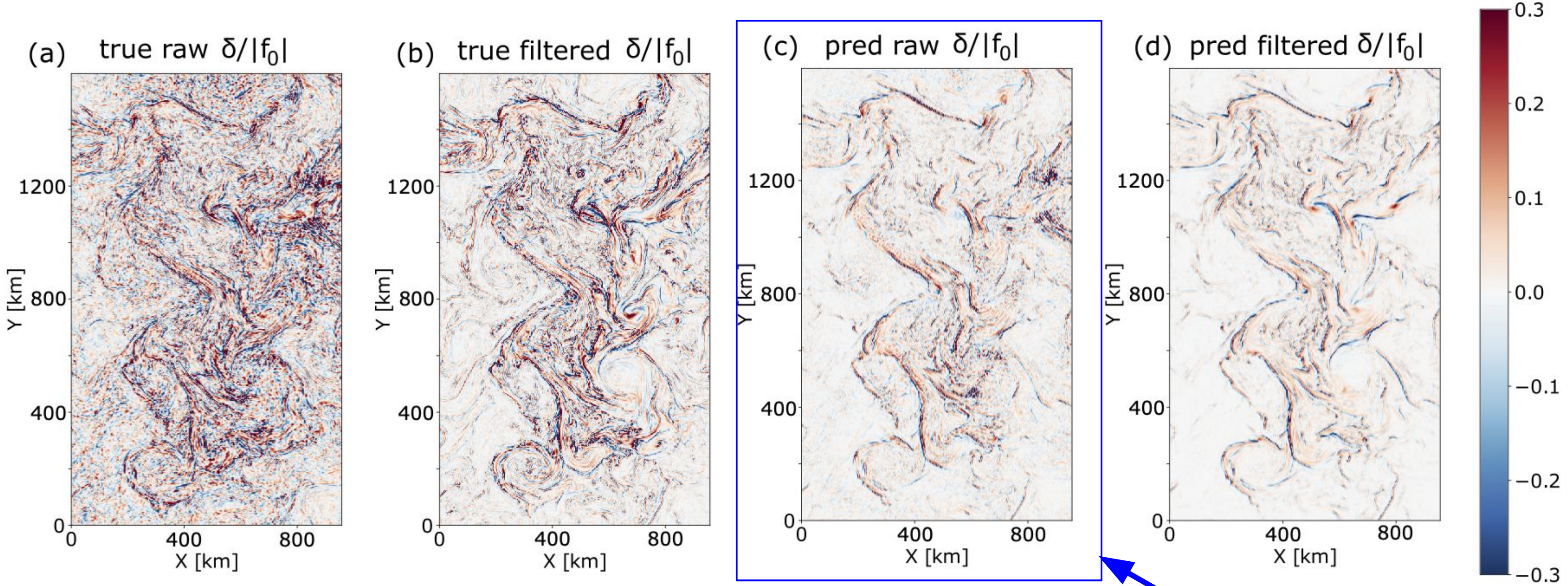


Corresponding ζ-σ JPDFs. Winter prediction better



Learned divergence “naturally” omits IGW divergence 😺

True and predicted **divergence** in **winter ****, using both raw input and Lagrangian-IGW-filtered velocities ([J23] and Spencer’s poster!)



indeterminate sign +/- frequency branches

$$\delta = -\frac{\omega m^2}{N^2}\hat{p}\sin\left(kx + ly + mz - \omega t\right)$$

Even **without pre-filtering waves**, UNET learns nearly IGW-free divergence field

Plans for using SWOT data

- Retrain CNN on LLC4320 region that coincides with a cross-over spot
- Use SWOT-simulator before training
- {many tweaks to method in the works.. cost function, physics-informed, etc}
- With collaborators 👀: Use trained model on SWOT cross-over data to identify fronts
- Cross check with SST and other observational data that might be available
- Take advantage of ability to time-average with 1-day repeat cycle data

References

[X23] Xiao, Q., D. Balwada, S. Jones, M. Herrero-Gonzalez, S. Smith, R. Abernathey, 2023: "Reconstruction of Surface Kinematics from Sea Surface Height Using Neural Networks". Accepted for *JAMES*.

[J23] Jones, S., Q. Xiao, R. Abernathey, and S. Smith, 2023: Using Lagrangian filtering to remove waves from the ocean surface velocity field. *JAMES*, **15**

[B21] Balwada, D., Q. Xiao, S. Smith, R. Abernathey and A. Gray, 2021: Vertical fluxes conditioned on vorticity and strain reveal submesoscale ventilation. *J. Phys. Oceanogr.*, **51**, 2883-2901

[B18] Balwada, D., S. Smith, and R. Abernathey, 2018: Submesoscale vertical velocities enhance tracer subduction in an idealized Antarctic Circumpolar Current. *Geophys. Res. Lett.*, **45**