NASA SWOT Science Team Meeting 2022

USING MACHINE LEARNING TO INTERPOLATE SSH

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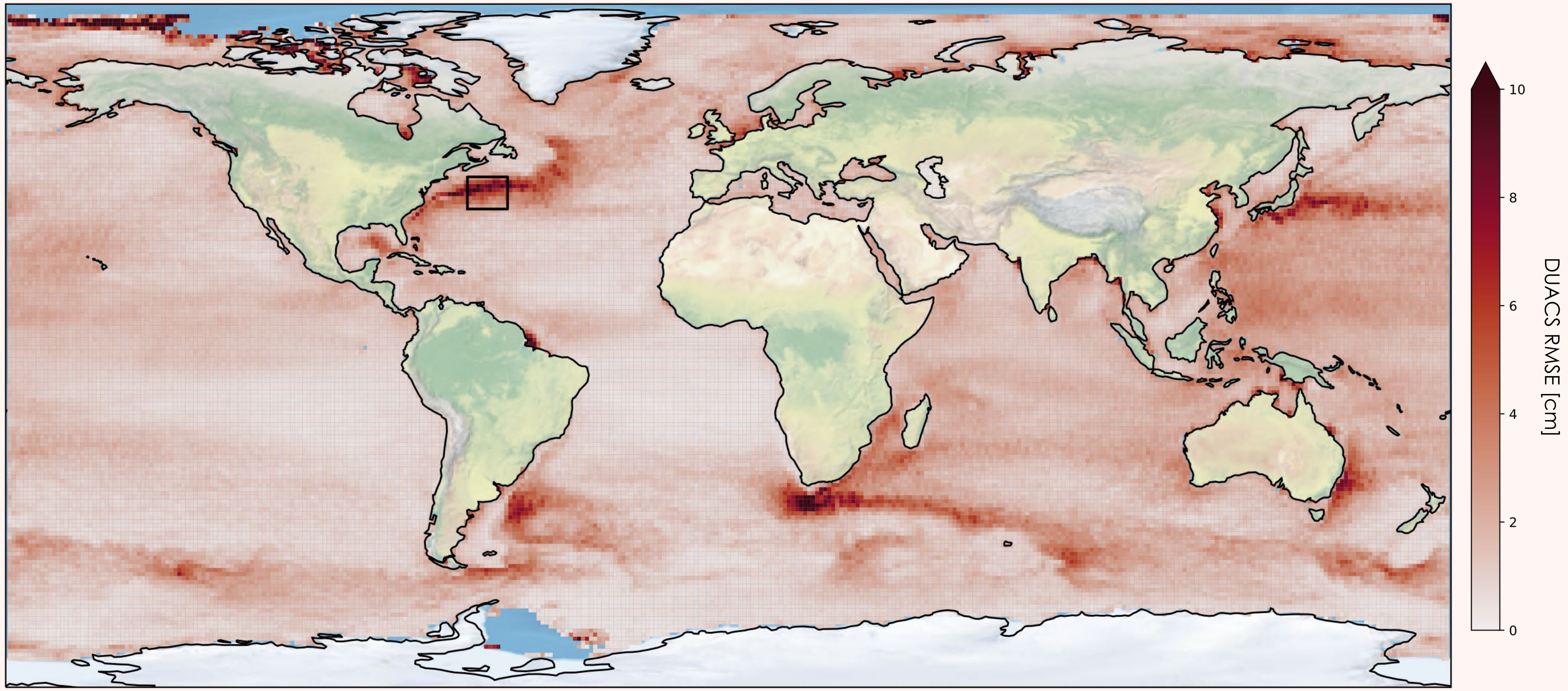
With thanks to Patrice Klein & Steve Brunton

MOTIVATION

SSH interpolation

- **Nadir altimeters only sample SSH along 1D tracks which are widely spaced**
- **DUACS product uses ‘optimal interpolation’ to reconstruct 2D SSH field, leading to large errors in regions with energetic mesoscale turbulence:**



RMSE = root mean square error

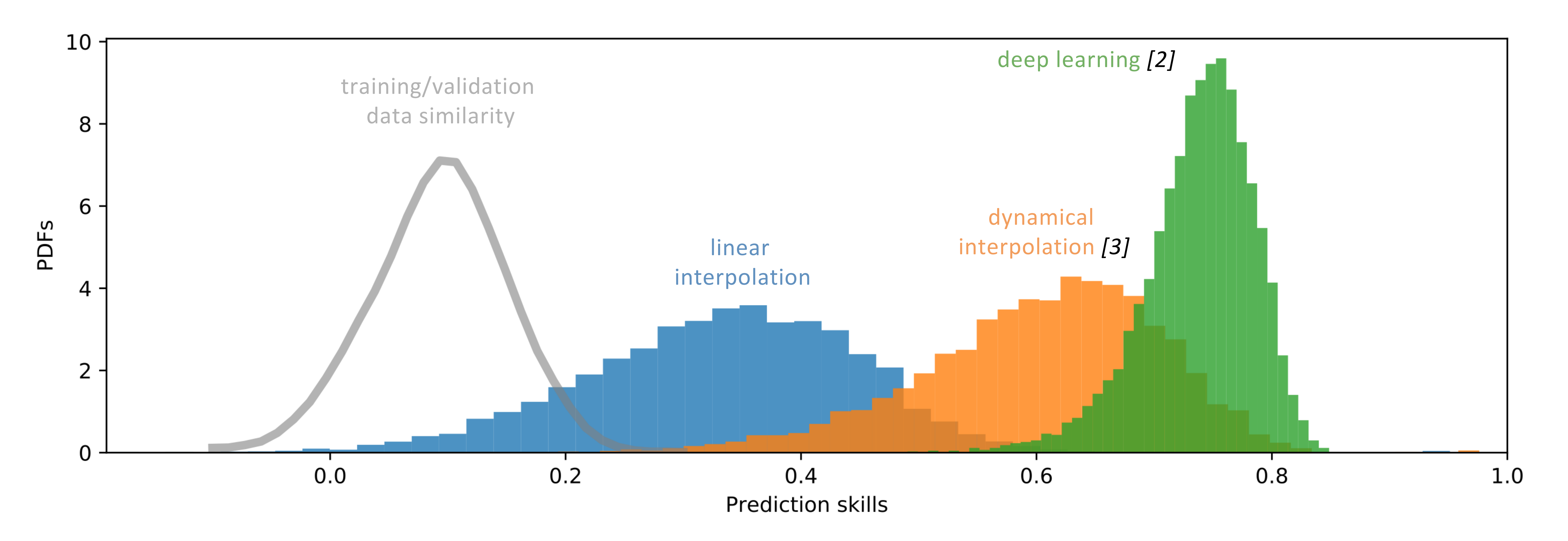
DUACS RMSE against withheld Cryosat-2 observations (2015-2019) [1]

[1] Pujol, M., 2022, personal communication.

MOTIVATION

Why use machine learning (ML)?

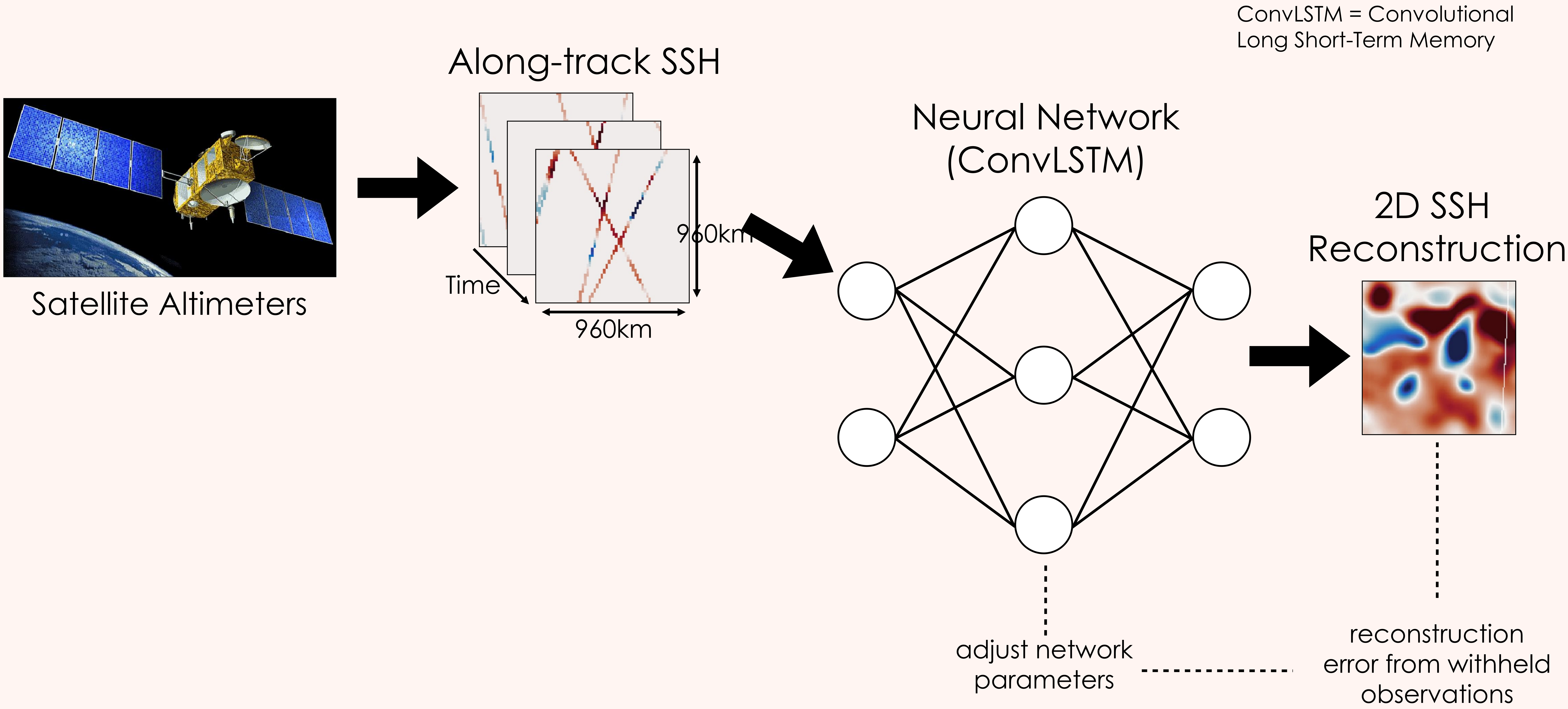
- **Deep learning neural networks can learn non-linear mappings from inputs to outputs**
- **A neural network could be trained to learn the dynamics governing SSH evolution**
- **Previous work *[2]* showed a neural network could accurately interpolate SSH from a 2 layer QG model of ocean turbulence:**



SSH prediction skill in QG turbulence for a deep learning, linear, and dynamical interpolation [2]

[2] Manucharyan, G., et al., 2021, Journal of Advances in Modeling Earth Systems.
[3] Ubelmann, C., et al., 2015, J. Atmos. Ocean. Tech.

METHODS

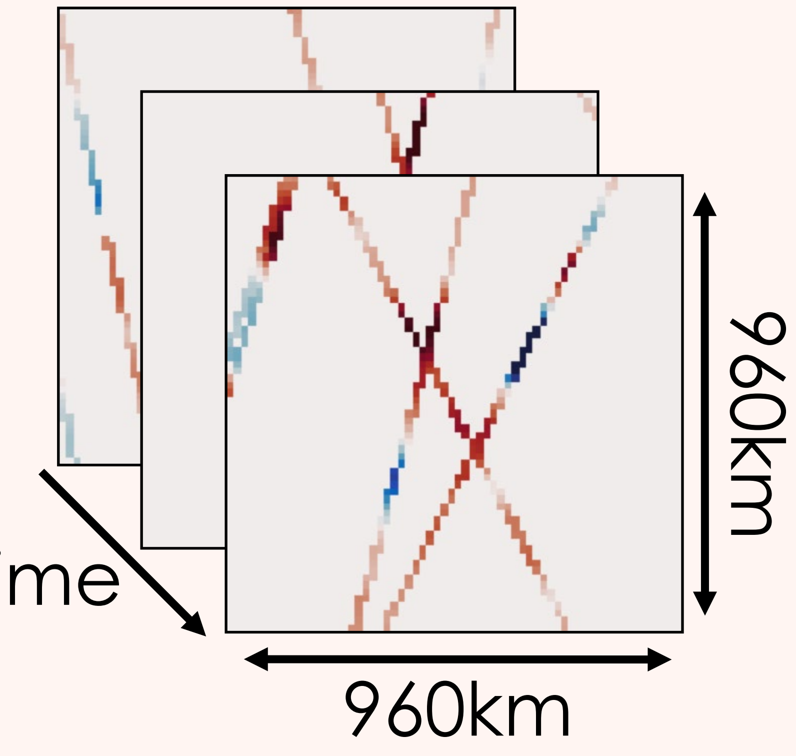

ConvLSTM = Convolutional Long Short-Term Memory
Along-track SSH
Satellite Altimeters
Time
960km
960km
Neural Network (ConvLSTM)
2D SSH Reconstruction
adjust network parameters
reconstruction error from withheld observations

METHODS

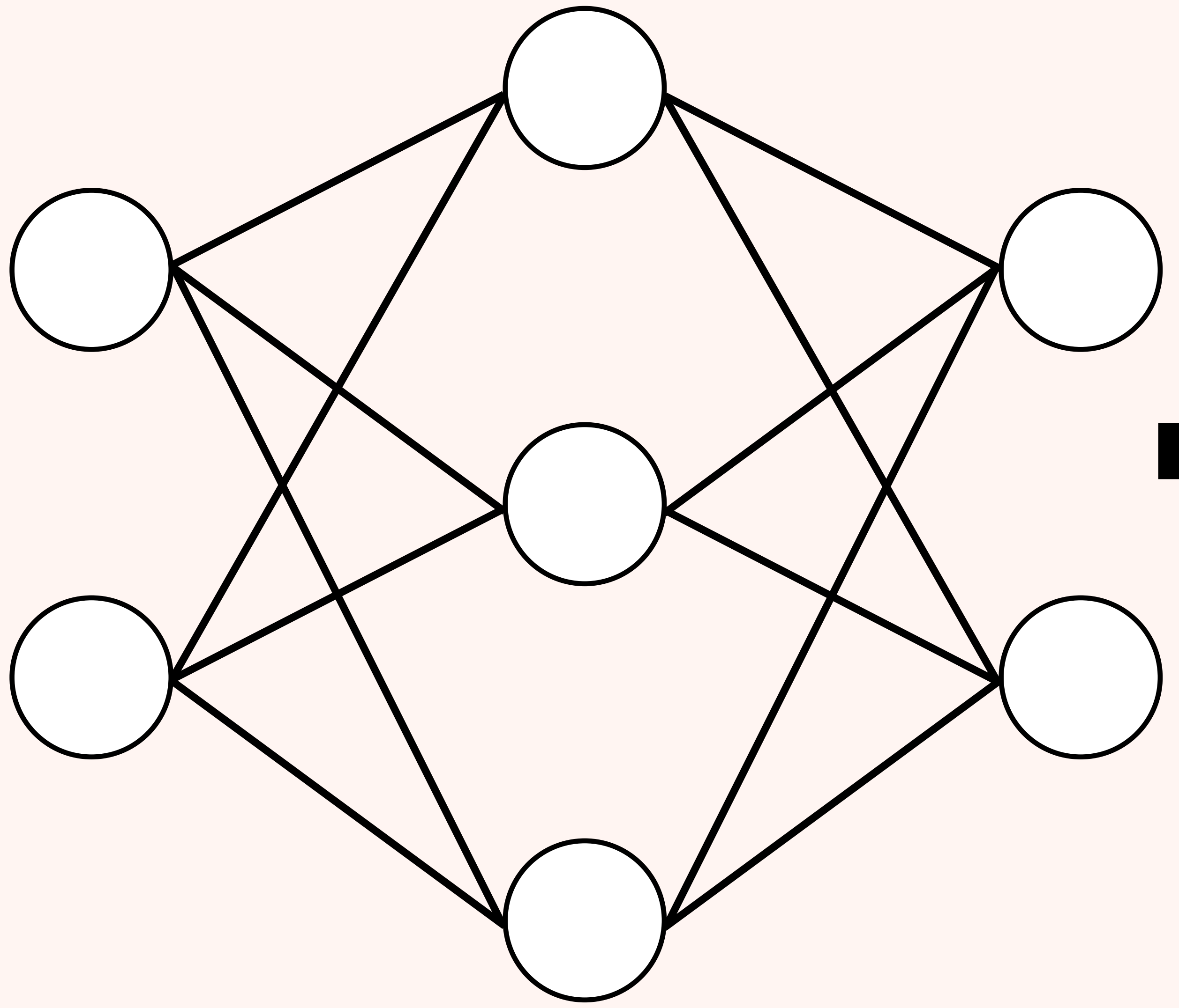
ConvLSTM = Convolutional Long Short-Term Memory

Satellite Altimeters

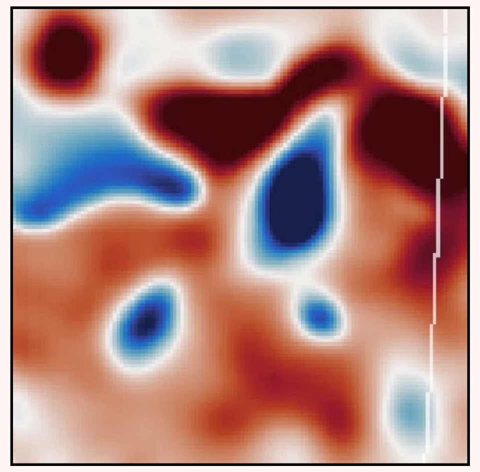
Along-track SSH



Neural Network (ConvLSTM)



2D SSH Reconstruction



adjust network parameters

reconstruction error from withheld observations

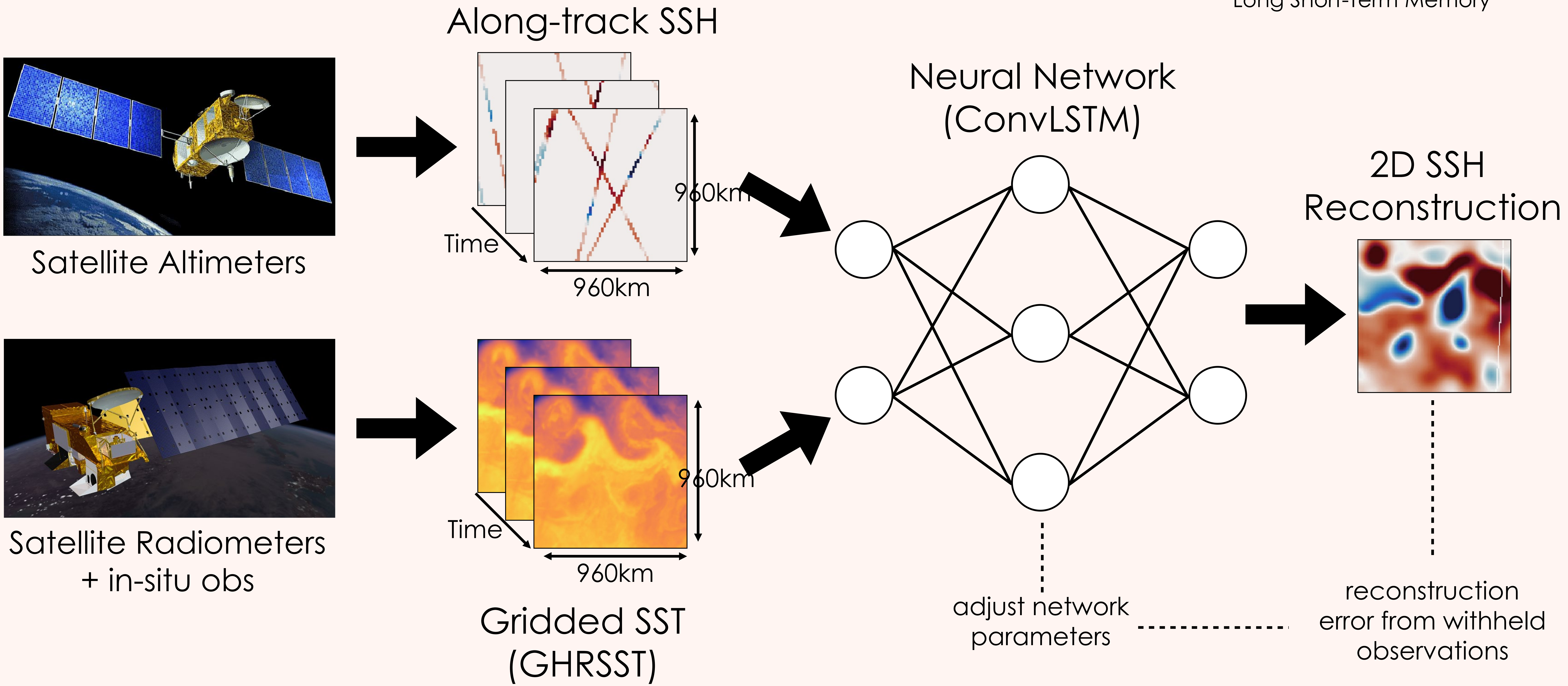
<u>From SQG dynamics:</u>
Surface geostrophic currents (and hence SSH) are related to surface buoyancy (and hence SST). *[4]*

So, SST observations could be used to help inform SSH reconstruction. *[5]*

[4] Lapeyre, G., 2017, Fluids.
[5] Isern-Fontanet, J., et al., 2006, Geophysical Research Letters.

METHODS

ConvLSTM = Convolutional
Long Short-Term Memory



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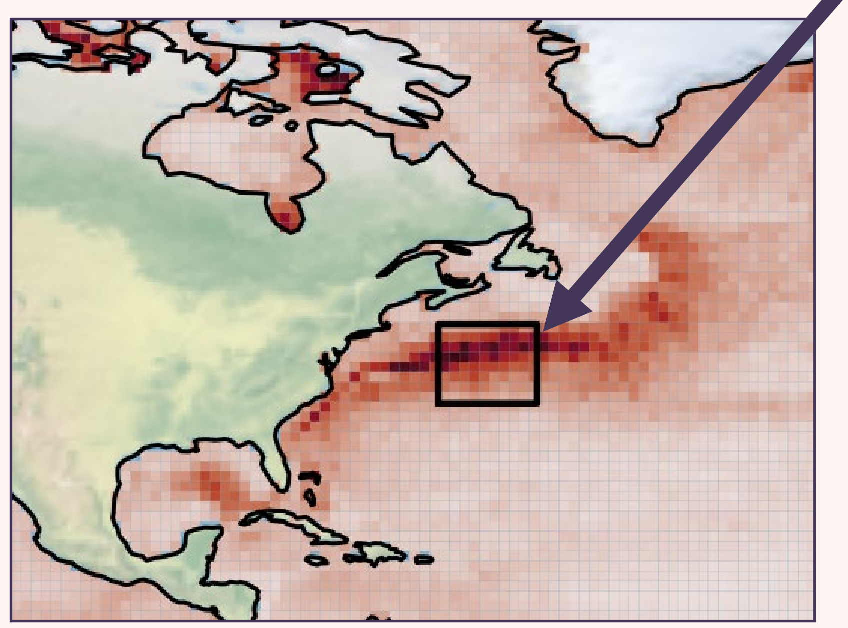
RESULTS

Root mean square error

- We tested our reconstruction's accuracy against independent altimeter observations in a region of the Gulf Stream (55-65°W, 34-42°N) and compared to other methods using data from *[6]*:



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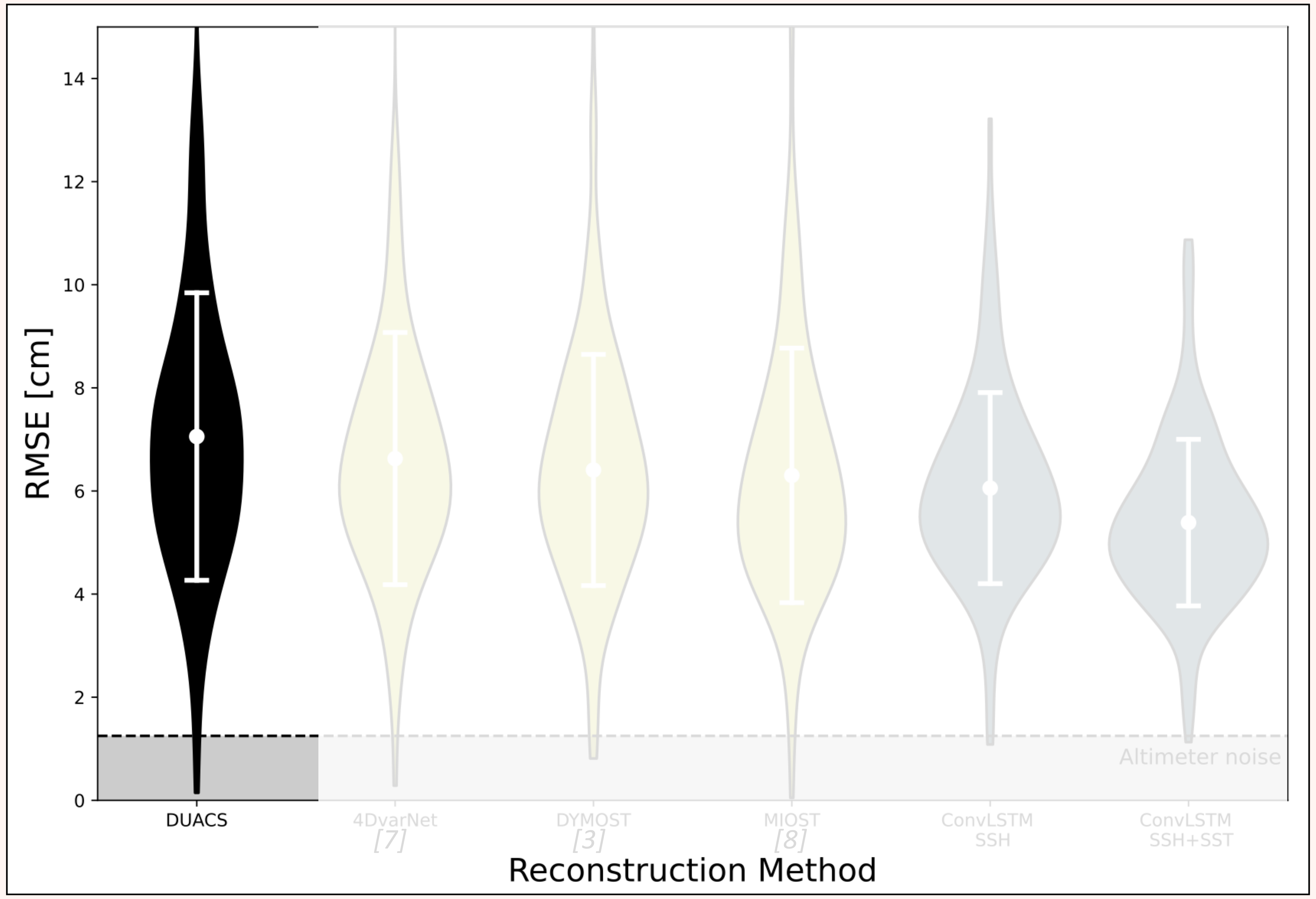

[3] Ubelmann, C., et al., 2015, J. Atmos. Ocean. Tech.
[6] https://github.com/ocean-data-challenges/2021a_SSH_mapping_OSE.
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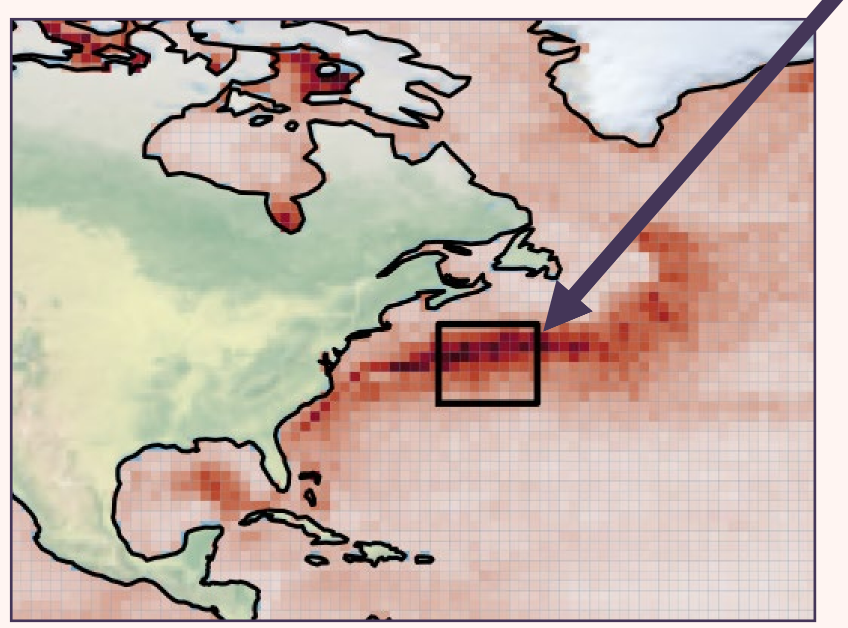
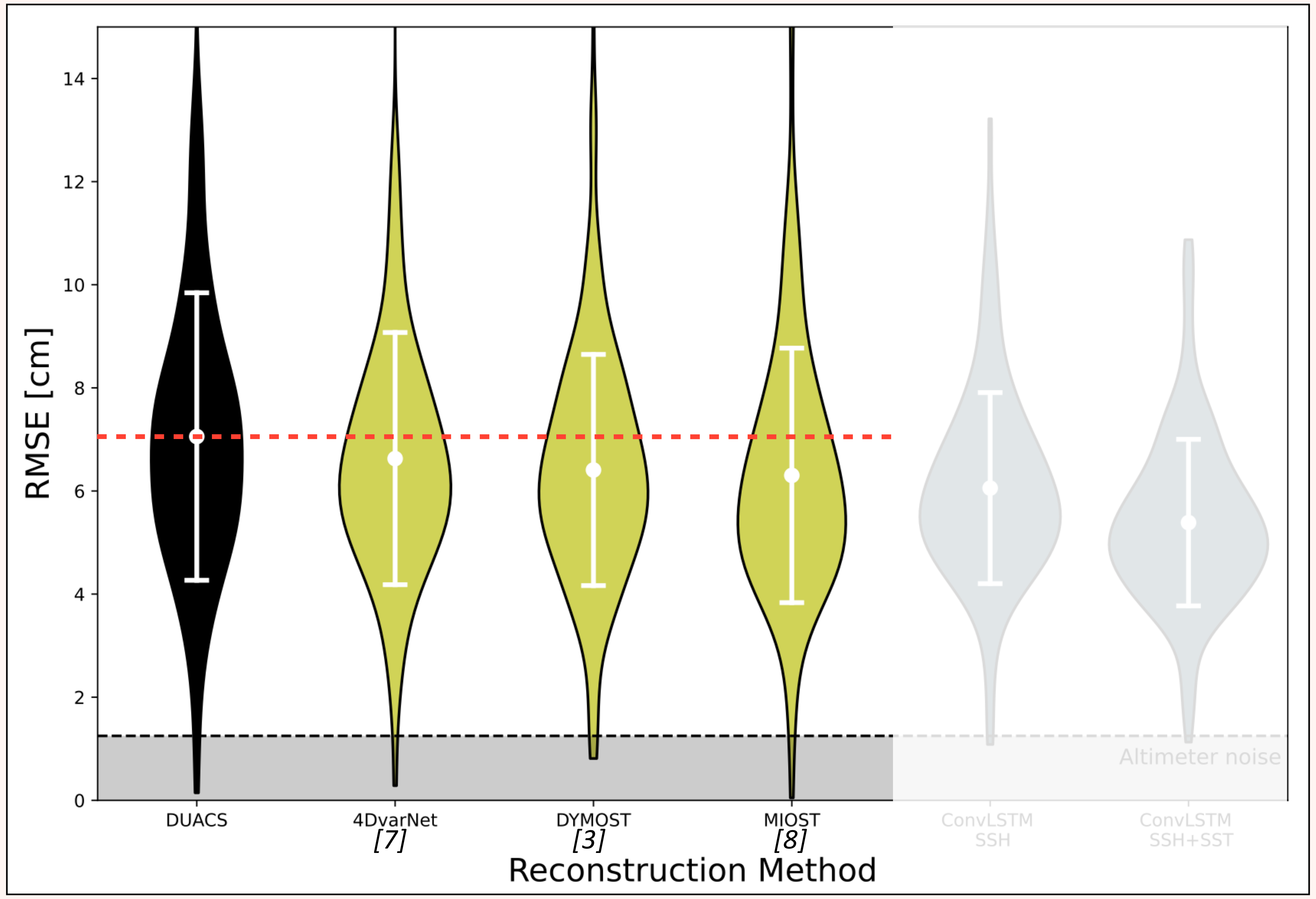


EXISTING METHOD

RECENTLY PROPOSED METHODS



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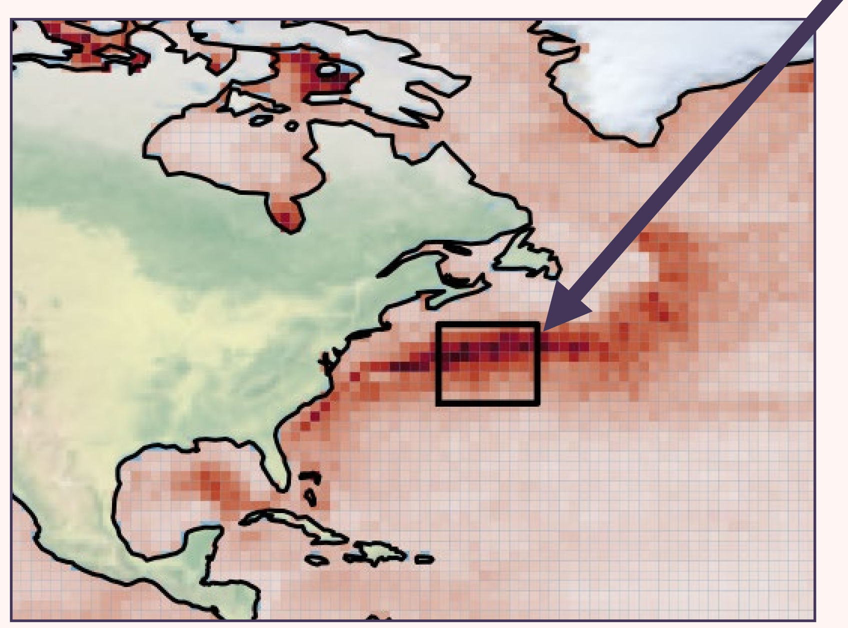

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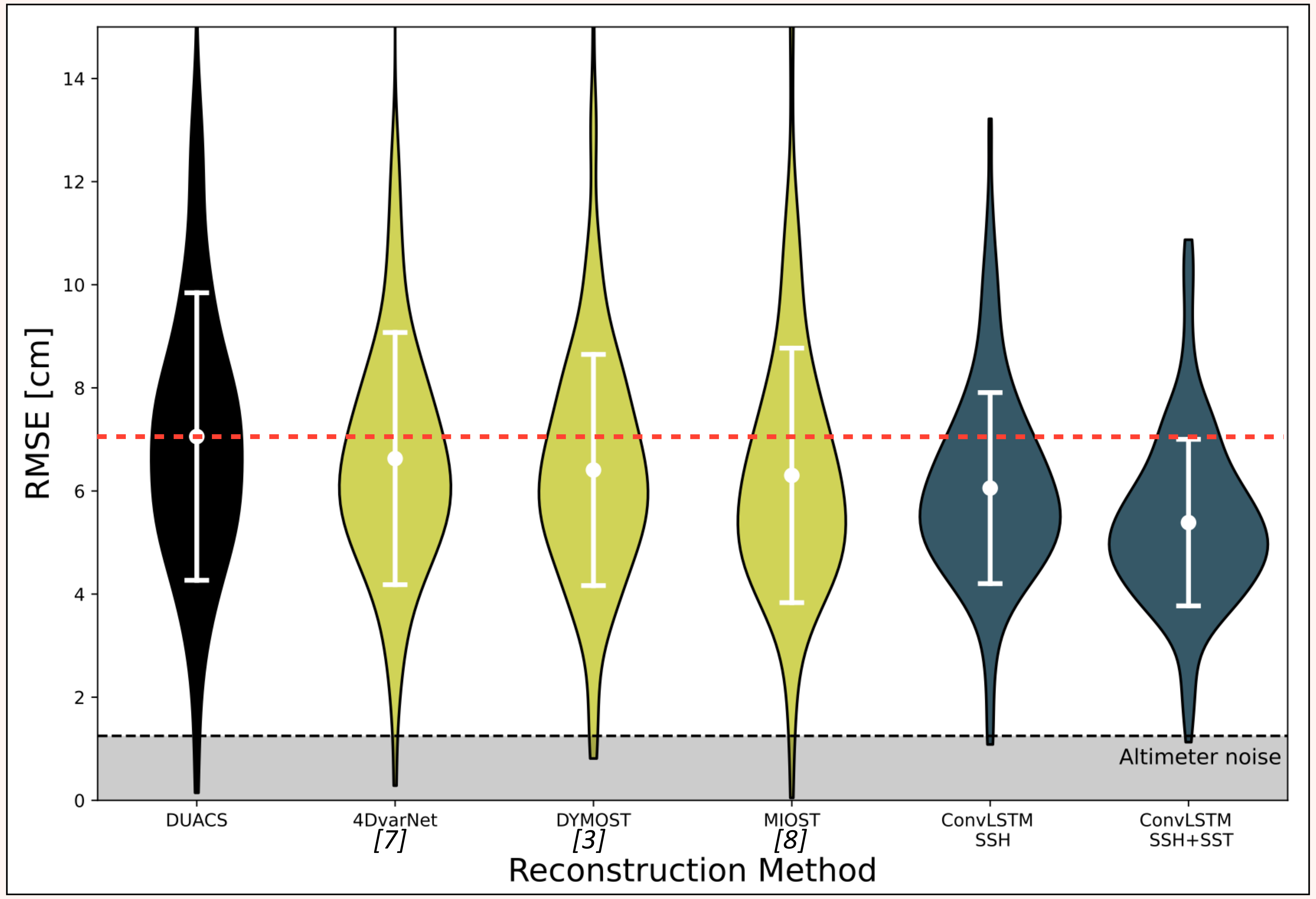
OUR METHOD



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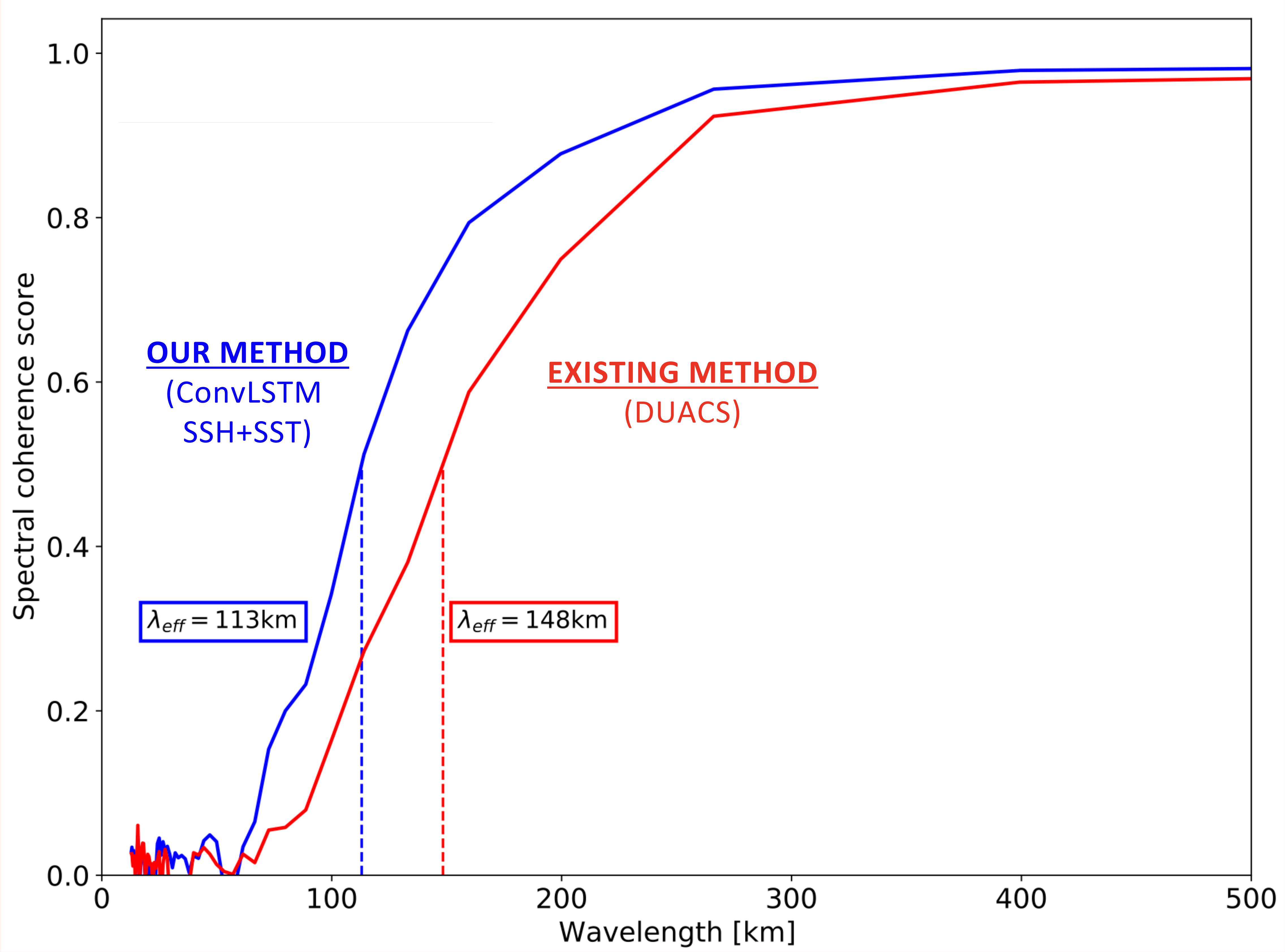
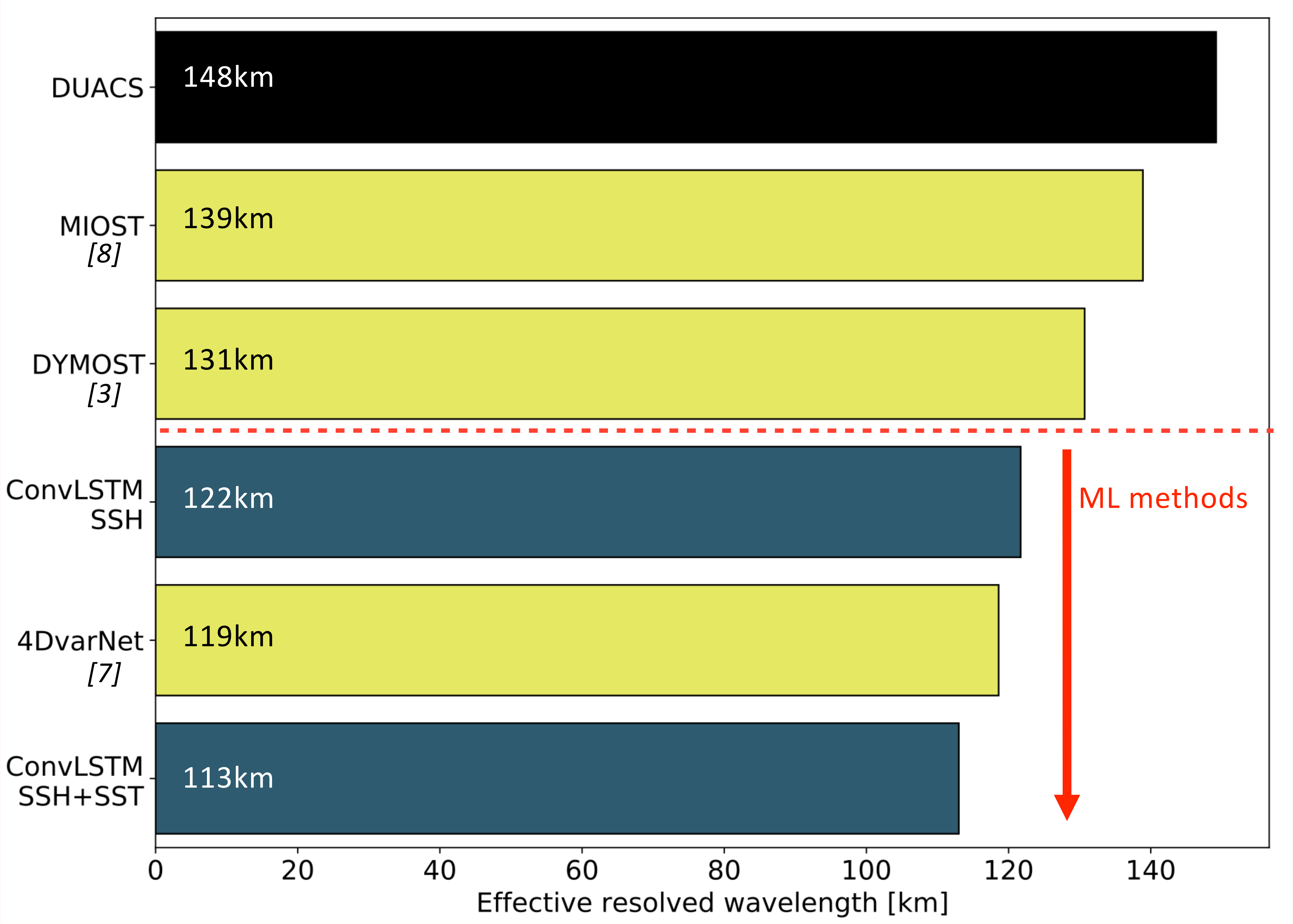
RESULTS

Effective resolution

- **Our method accurately resolves smaller scale SSH features:**

$$\text{Spectral coherence score} = 1 - \frac{\text{PSD}(\text{reconstruction} - \text{observations})}{\text{PSD}(\text{observations})}$$





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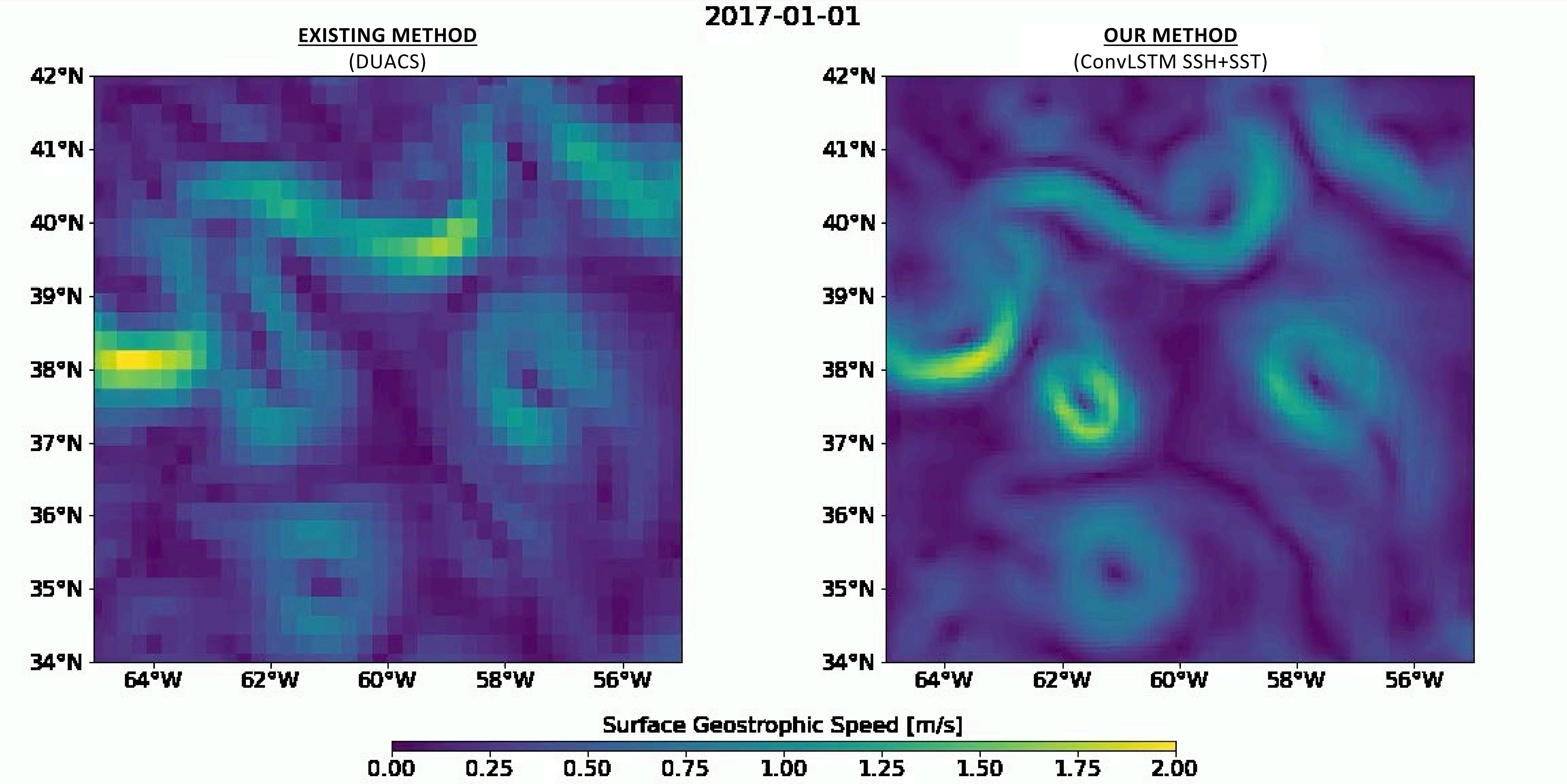
RESULTS

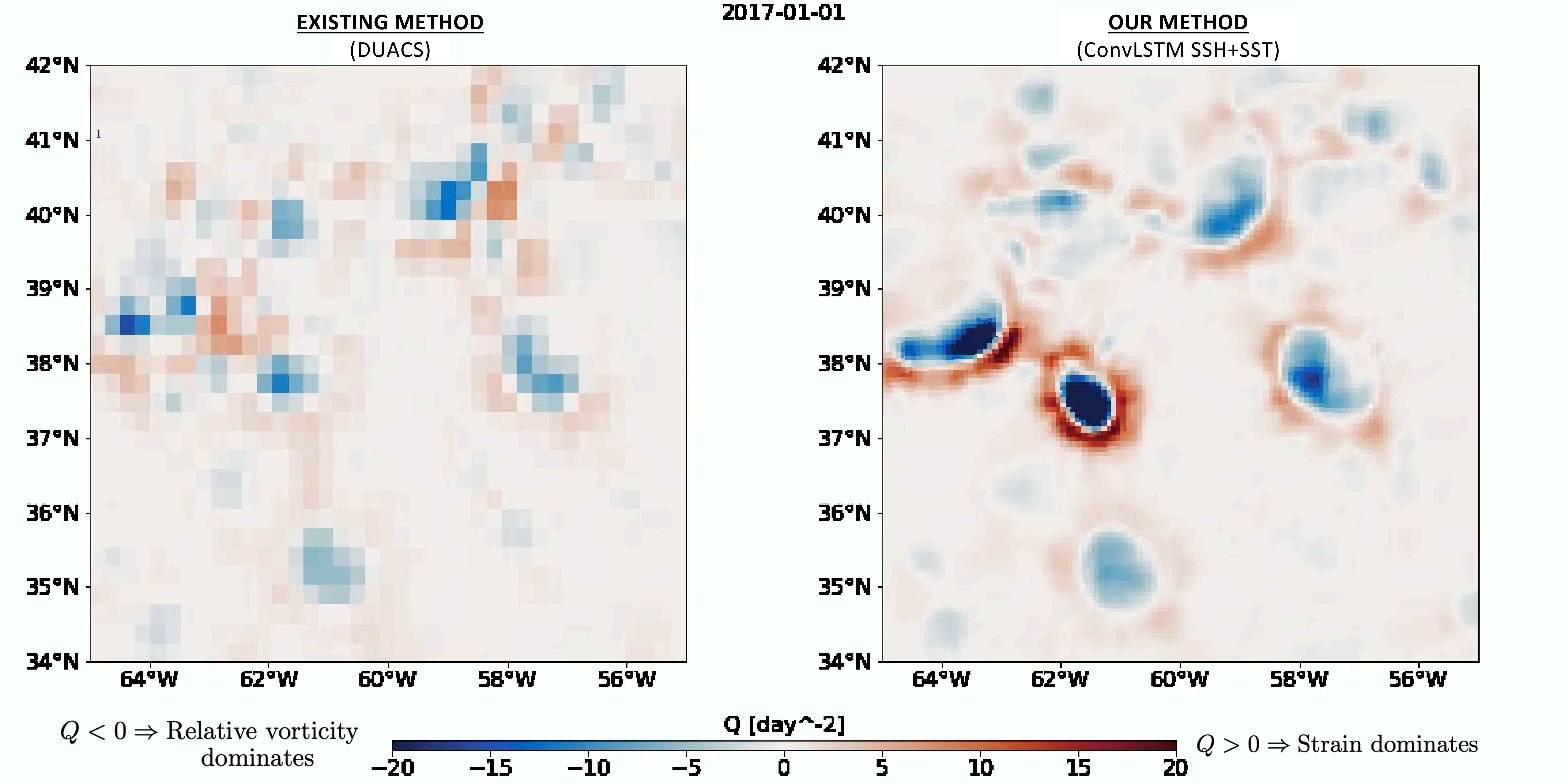
Surface geostrophic current speed



RESULTS

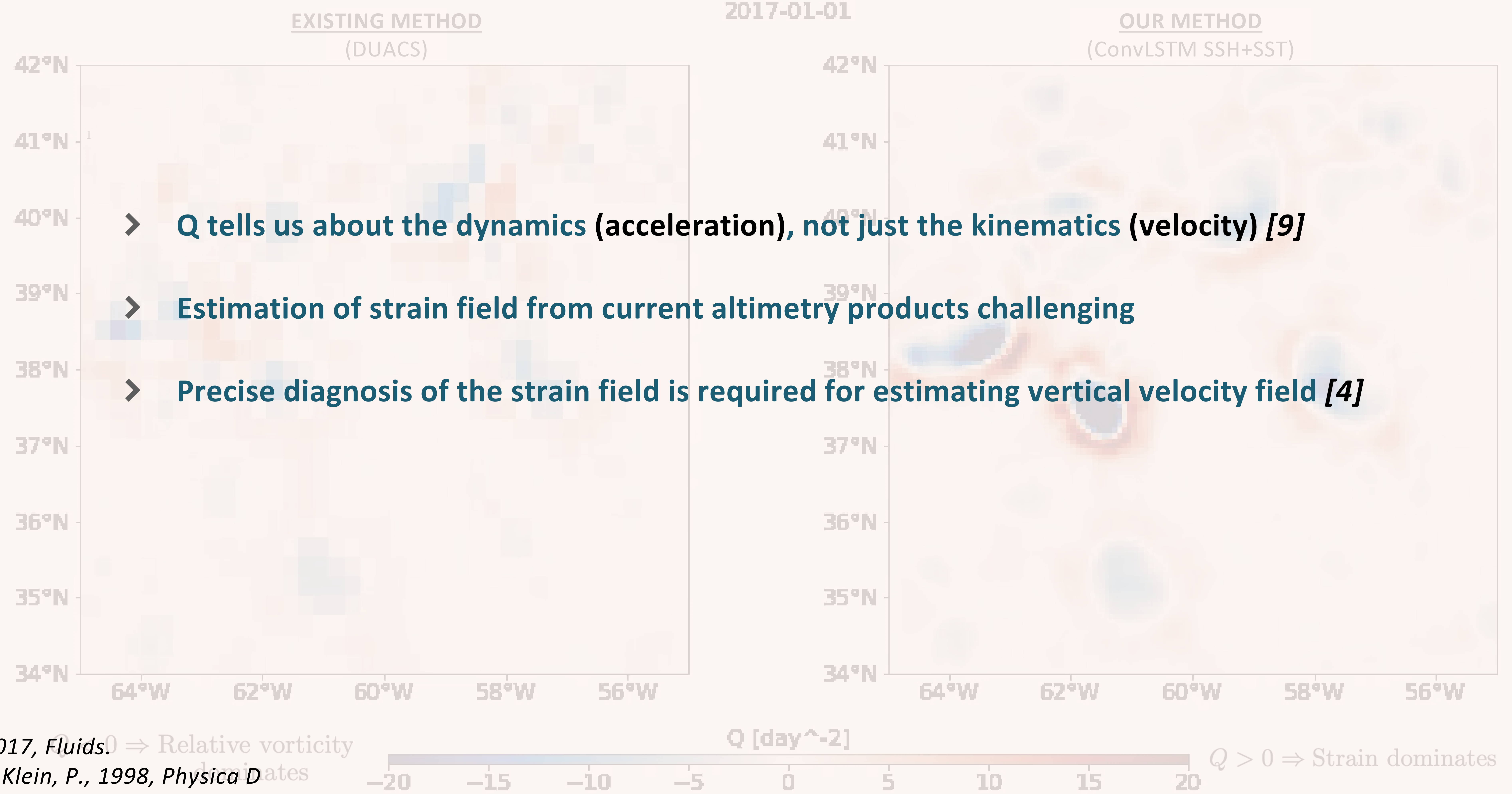
Okubo-Weiss Parameter (Q)

$$Q = \gamma^2 - \omega^2 = \underbrace{\left(\frac{\partial u}{\partial x} - \frac{\partial v}{\partial y}\right)^2 + \left(\frac{\partial v}{\partial x} + \frac{\partial u}{\partial y}\right)^2}_{\text{strain rate}} - \underbrace{\left(\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}\right)^2}_{\text{relative vorticity}}$$



WHY DO WE NEED TO ACCESS THE OKUBO-WEISS PARAMETER?

$$Q = \gamma^2 - \omega^2 = \underbrace{\left(\frac{\partial u}{\partial x} - \frac{\partial v}{\partial y}\right)^2 + \left(\frac{\partial v}{\partial x} + \frac{\partial u}{\partial y}\right)^2}_{\text{strain rate}} - \underbrace{\left(\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}\right)^2}_{\text{relative vorticity}}$$



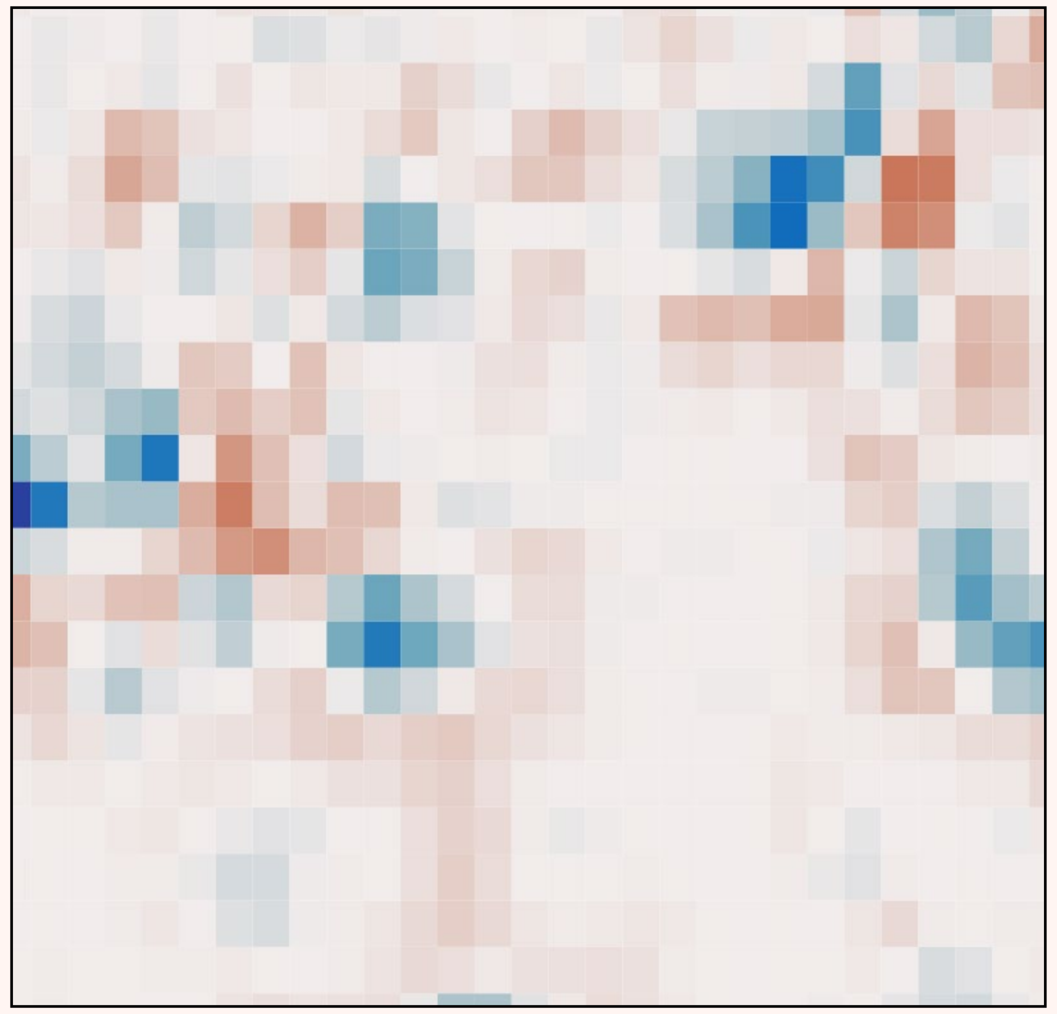
- **Q tells us about the dynamics** (acceleration), **not just the kinematics** (velocity) *[9]*
- **Estimation of strain field from current altimetry products challenging**
- **Precise diagnosis of the strain field is required for estimating vertical velocity field** ***[4]***

[4] Lapeyre, G., 2017, Fluids.
[9] Hua, B.L., and Klein, P., 1998, Physica D

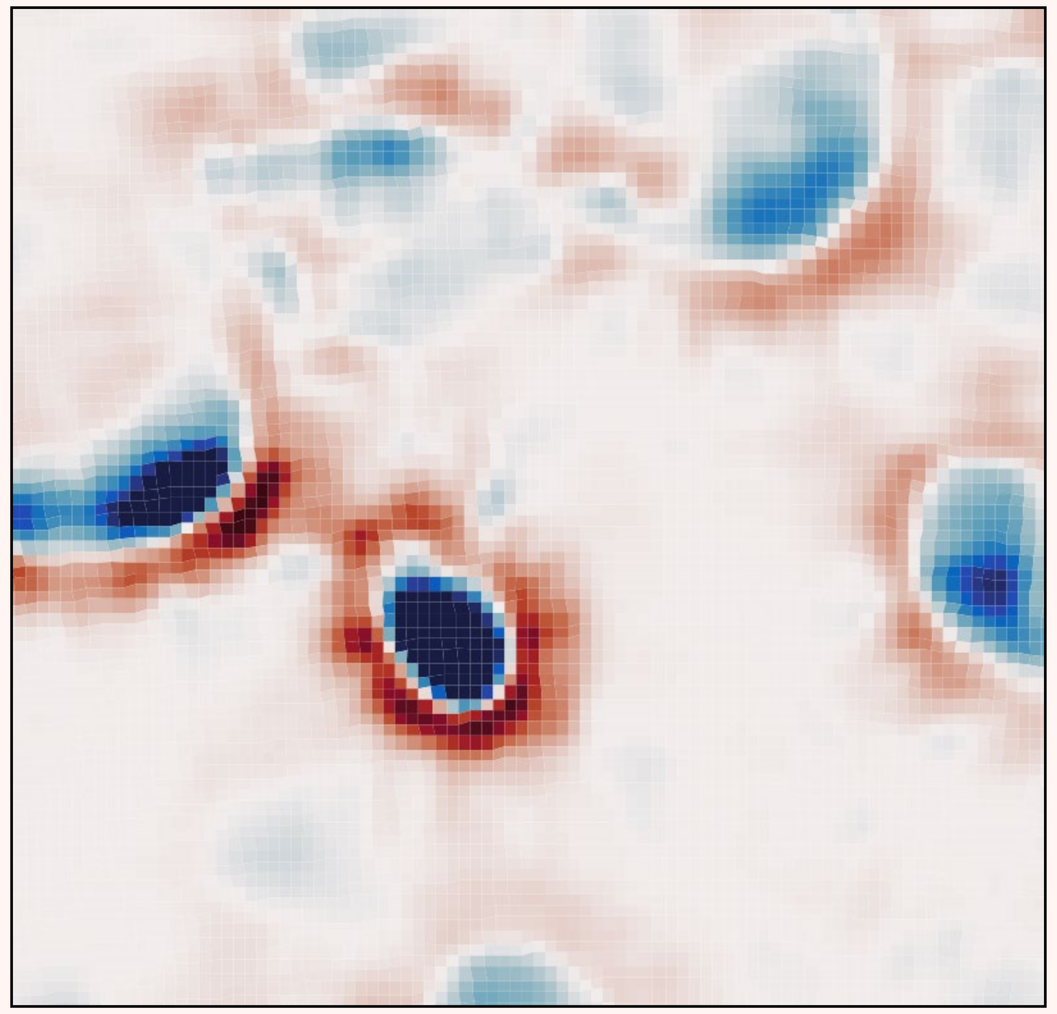
NEXT STEPS

- Scale up to whole world - publish an improved global mesoscale SSH dataset from nadir altimeters and SST

EXISTING METHOD
(DUACS)



OUR METHOD
(ConvLSTM SSH+SST)



This work was funded as part of the NASA Ocean Surface Topography Science Team

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- Explore using high resolution ocean models for training via transfer learning

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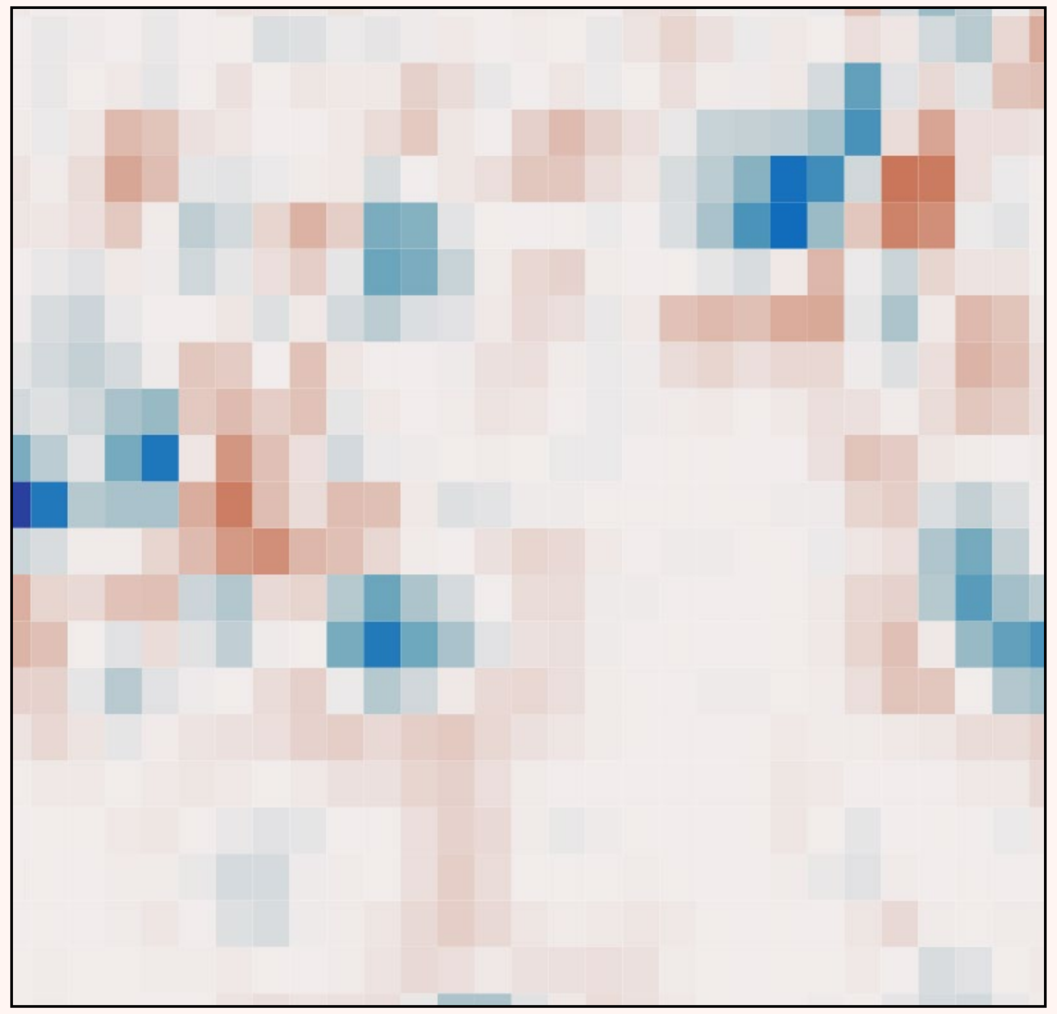

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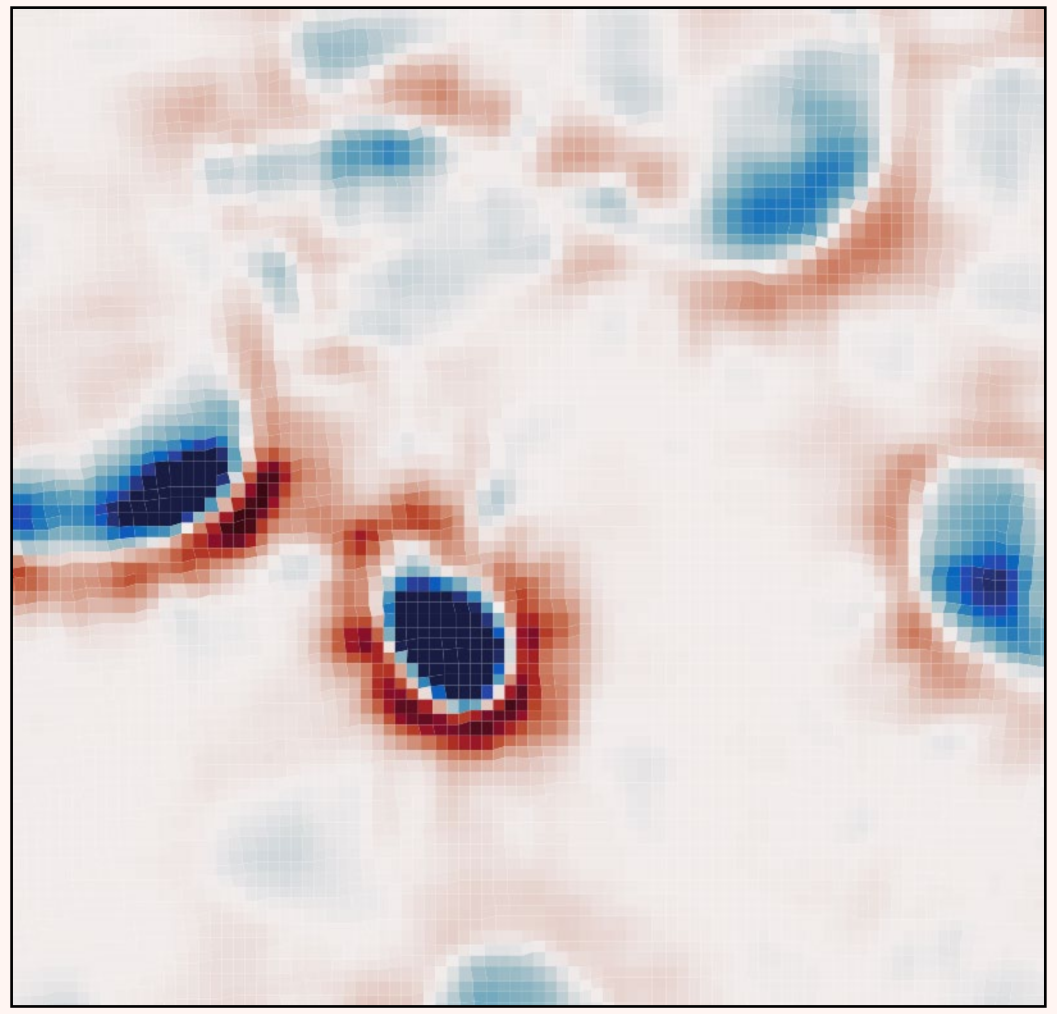

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- Explore using high resolution ocean models for training via transfer learning
- Opportunities and challenges for incorporating SWOT data:
  - High spatial resolution but low time resolution
  - Fast sampling phase offers unique opportunities for training ML interpolators

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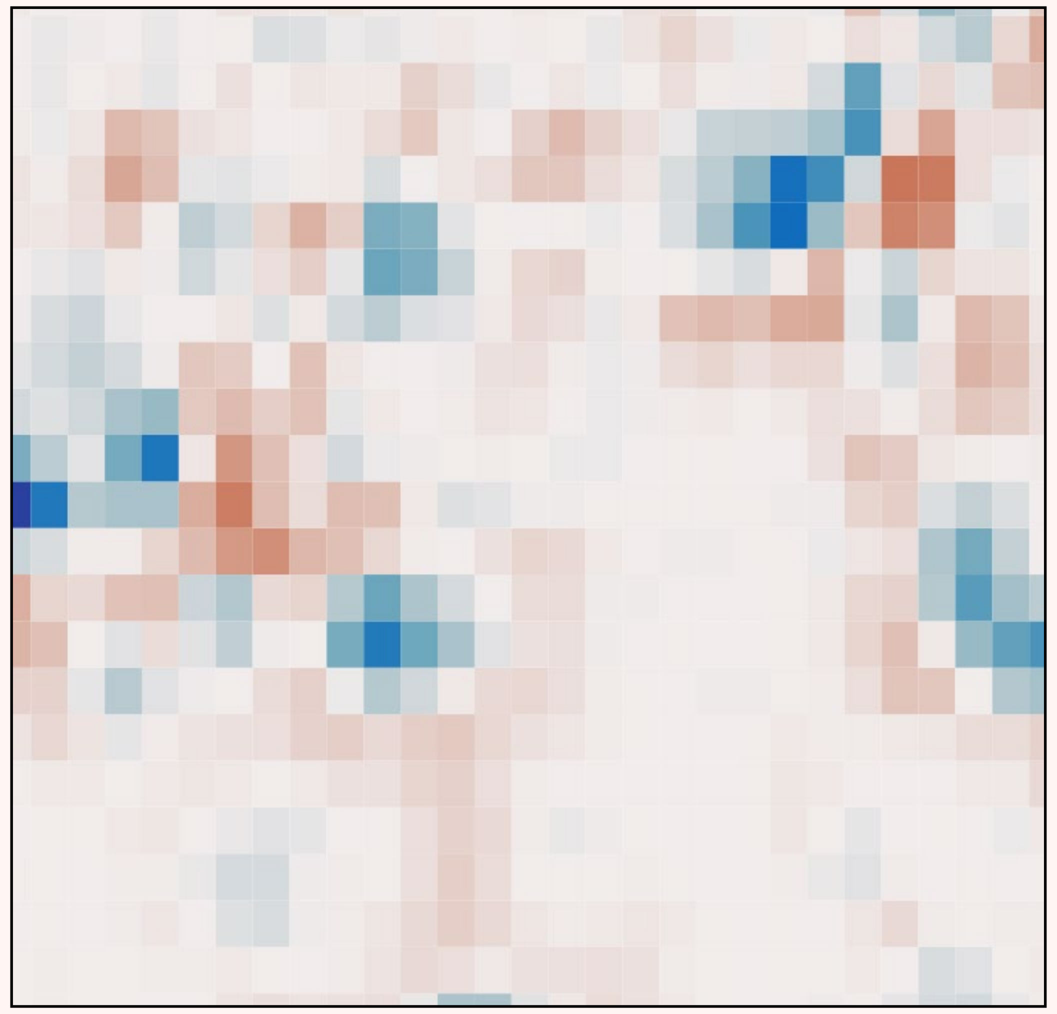

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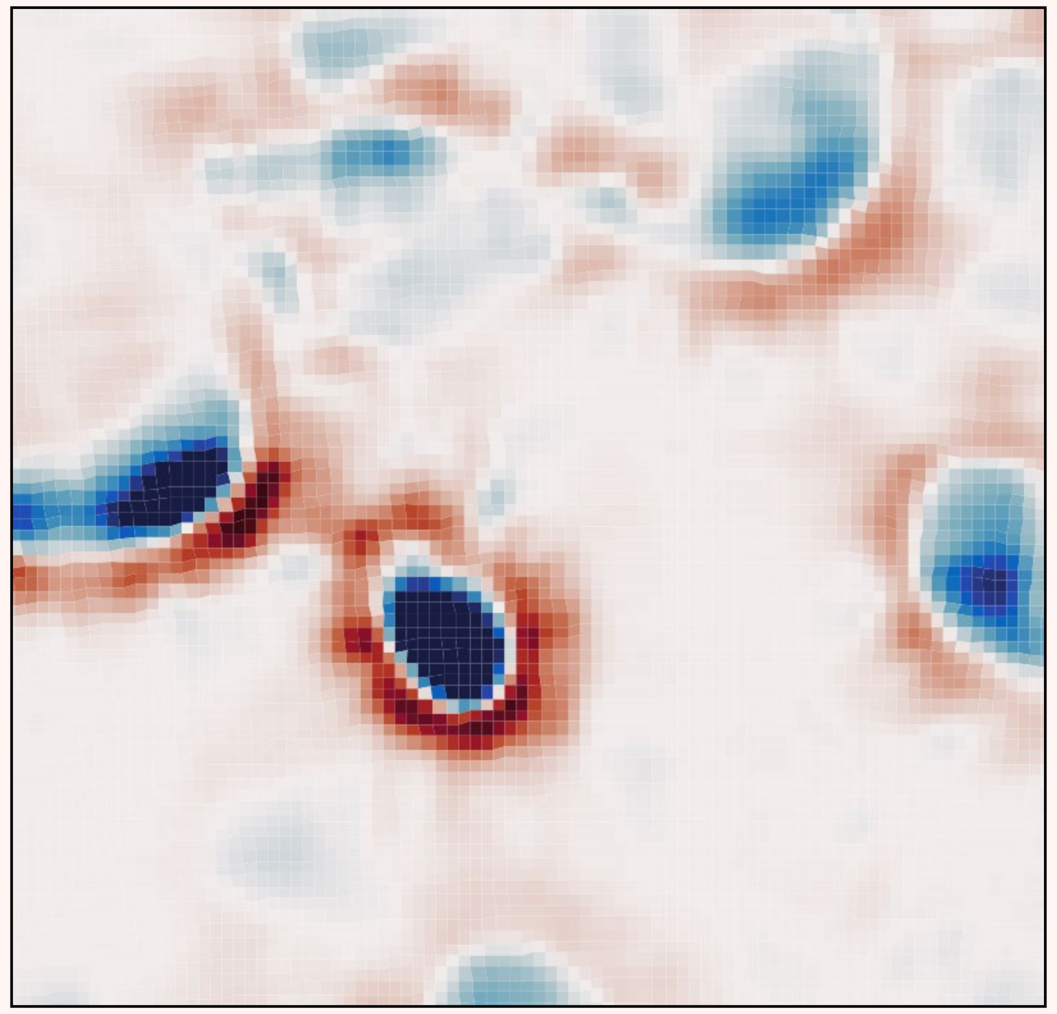

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