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Deep learning for accurate SSH reconstruction from altimetry and SST observations

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Background

Two-dimensional sea surface height (SSH) reconstructions from satellite altimeter observations are an important dataset for studying upper ocean dynamics. Satellites currently only provide along-track SSH observations, leaving large areas of the ocean requiring interpolation. Commonly-used interpolation methods (e.g. the DUACS product) perform poorly in regions of high eddy kinetic energy, where there are many mesoscale eddies.

Preliminary work showed that a deep learning model can learn the non-linear dynamics governing SSH evolution, and hence more accurately reconstruct the unobserved SSH in idealised 2-layer quasi-geostrophic turbulence *[1]*. Here, we train a neural network to more skillfully reconstruct the mesoscale SSH field from real-world satellite observations *(Methods, [2])*.

The SSH field is closely dynamically related to the SST field, which is better observed by satellites. Thus, we supplement SSH observations with SST observations to help improve the SSH mapping.

KEY POINTS

> We developed a deep learning framework for mapping SSH from altimetry and SST observations

> ConvLSTM SSH+SST resolves SSH down to length scales **30%** smaller than DUACS and has **17%** lower SSH RMSE

> Including SST improved both RMSE and effective resolution of ConvLSTM reconstruction

> Our SSH map results in **25%** higher eddy kinetic energy than DUACS in Gulf Stream test region

> Our new SSH reconstruction leads to stronger geostrophic strain and vorticity fields than DUACS

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REFERENCES

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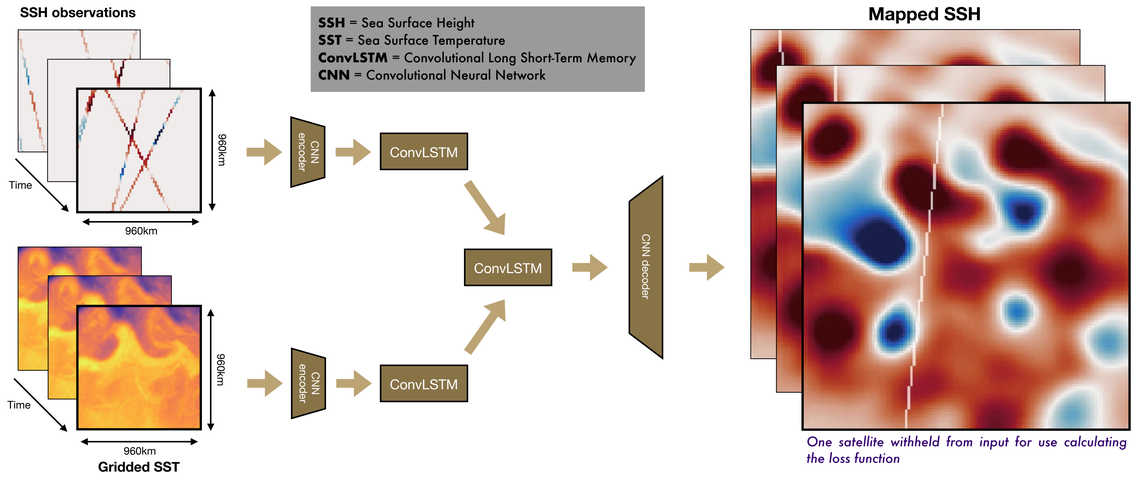
Global altimetry data are made available by the Copernicus Marine Environment Monitoring Service (CMEMS). Global SST data are made available by the Group For High Resolution Sea Surface Temperature (GHRSST). The Ocean Data Challenge data used for testing in this study were developed and validated by CLS and MEOM Team from IGE (CNRS-UGA-IRD-G-INP), France and distributed by Aviso+.

Methods: deep learning framework *[2]*



One satellite withheld from input for use calculating the loss function

Results: accuracy of mapped SSH

> We trained our neural network using observations of the Gulf Stream Extension (GSE) from 2010-17 & 2018-20.
> We tested our method using independent satellite altimeter observations throughout 2017 in a region of the GSE with active mesoscale turbulence (55-65°W, 34-42°N) using the data distributed in *[3]*.
> We find that ConvLSTM outperforms DUACS and other recently proposed reconstruction methods *(Fig. 1)*.
> We find that including SST observations significantly improves the accuracy and resolution *(Fig. 2)* of our SSH reconstruction.

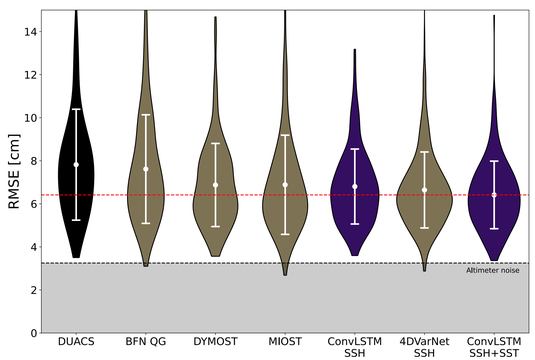


Figure 1: Root mean square error (RMSE) distributions for different SSH reconstruction methods when evaluated against independent satellite altimeter observations throughout 2017 using data from *[3]*. The white error bars indicate the mean and standard deviation of the RMSE distributions. The DUACS product is in black, other recently proposed methods *[4-7]* are in gold, and our neural network is in purple. The estimated instrument noise for the altimeter observations is shaded.

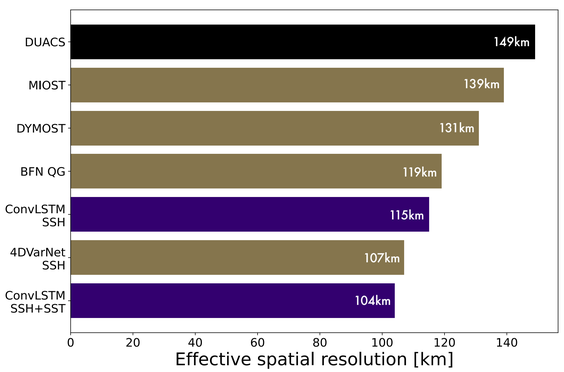


Figure 2: Smallest wavelengths of SSH signals effectively resolved by each method, calculated using the method described in *[8]*.

Results: geostrophic currents

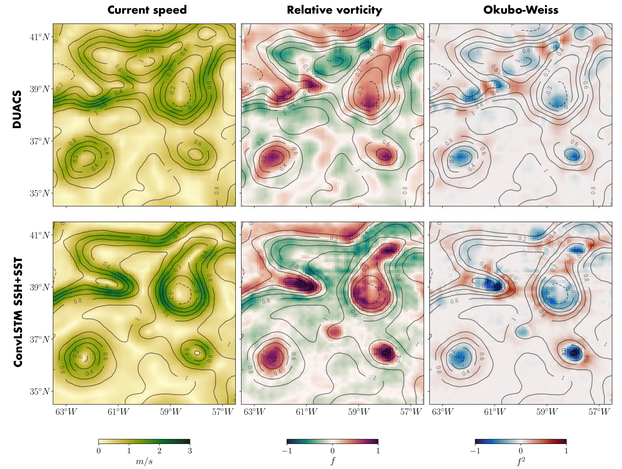


Figure 3: Surface geostrophic currents calculated from the SSH maps produced using DUACS and our method (ConvLSTM SSH+SST) are shown in the top and bottom row respectively. Current speed, relative vorticity, and the Okubo-Weiss quantity are shown in the left, middle, and right columns respectively. SSH contours spaced every 0.2m are overlaid.

(SCAN QR CODE FOR VIDEO)

> Our SSH map results in a clearer separation between the Gulf Stream and nearby eddies, as can be seen in the surface current speed, relative vorticity, and Okubo-Weiss fields *(Fig. 3)*.
> Our map's currents are stronger, resulting in higher eddy kinetic energy *(Fig. 4)*.

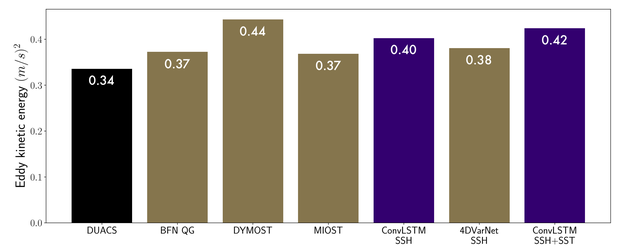


Figure 4: Domain- and time-averaged eddy kinetic energy for surface geostrophic currents calculated from each method's mapped SSH field.

FUTURE WORK

> Develop and validate a global SSH product using similar method to that outlined here

> Revisit key ocean surface dynamics problems in light of improved mesoscale SSH field