Temperature, salinity and mixed-layer depth in the Gulf Stream reconstructed by bridging remote-sensing and in situ observations with neural networks

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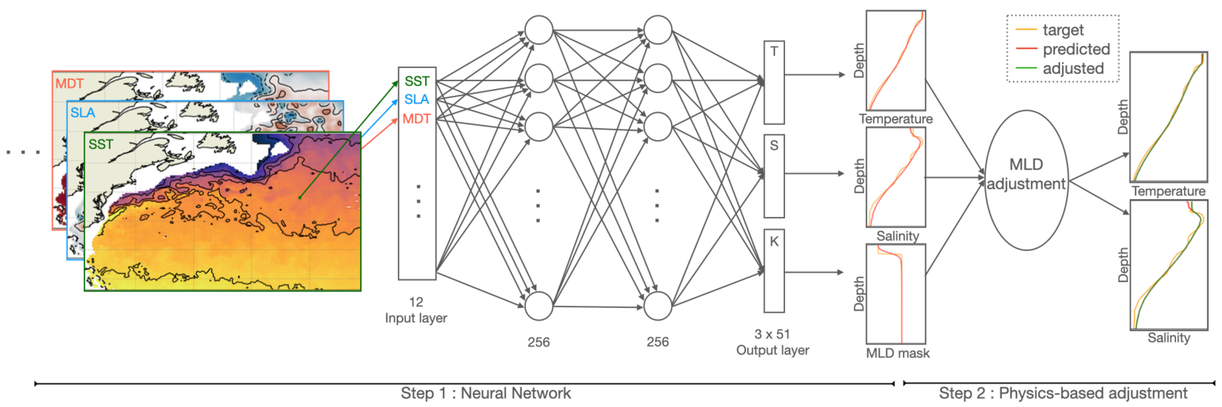
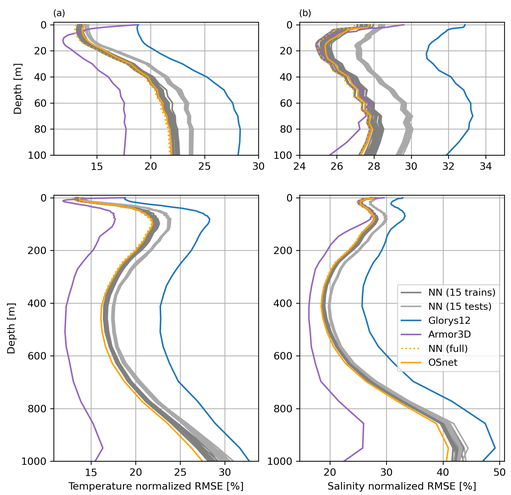
—> We introduce OSnet (Ocean Stratification network), a new ocean reconstruction system aimed at providing a physically consistent analysis of the upper ocean stratification.

—> The proposed scheme is a bootstrapped multilayer perceptron trained to predict simultaneously temperature and salinity (T–S) profiles down to 1000 m and the mixed-layer depth (MLD) from surface data covering 1993 to 2019.

—> The MLD prediction is used to adjust a posteriori the vertical gradients of predicted T–S profiles, thus increasing the accuracy of the solution and removing vertical density inversions.



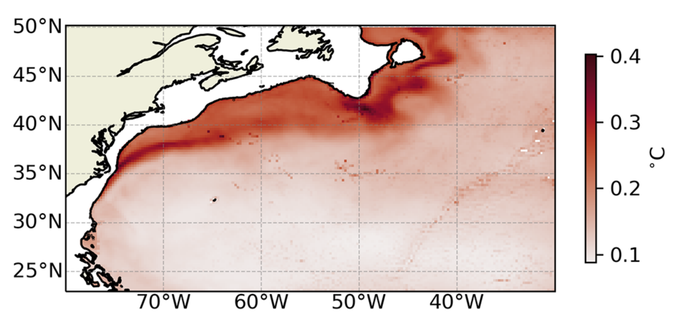
Schematic of OSnet formed of a neural network (NN) with two hidden layers and a mixed-layer (MLD) depth adjustment. The NN uses 12 surface inputs to predict profiles of temperature (T), salinity (S) and MLD mask (K).



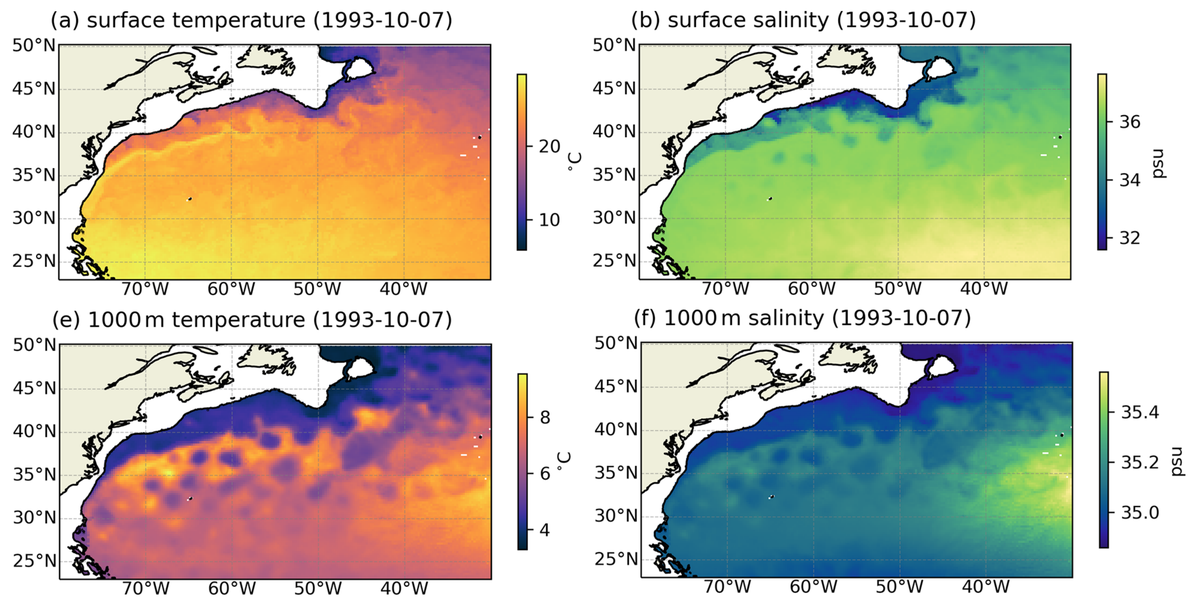
Normalized root mean square error (nRMSE) between temperature (a) and salinity (b) observed (CORA) and predicted profiles (Glorys12, Armor3D, NN and OSnet). The normalization is done with the standard deviation of the observed temperature and salinity by depth.

—> OSnet profiles have root mean square error comparable with the observation-based Armor3D weekly product and the physics-based ocean re- analysis Glorys12.

—> The lowest confidence in the prediction is located north of the Gulf Stream, between the shelf and the current, where the thermohaline variability is large.



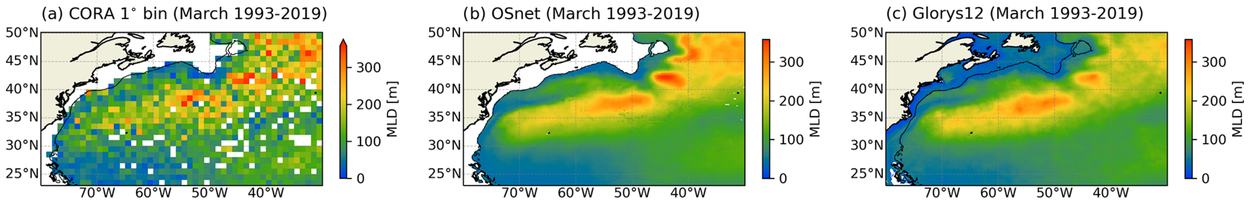
Surface time average maps of the confidence intervals temperature i.e., the standard deviation of the 15 bootstrapped models.



OSnet temperature and salinity maps for 7 January 1993 at the surface and 1000 m, available here : https://doi.org/10.5281/zenodo.6011144.

—> The prediction is generalized on a 1/4° daily grid, producing four-dimensional fields of temperature and salinity, with their associated confidence interval issued from the bootstrap.

—> OSnet reconstructed field is coherent even in the pre-Argo years, demonstrating the good generalization properties of the network. It reproduces the warming trend of surface temperature, the seasonal cycle of surface salinity and mesoscale structures of temperature, salinity and MLD.



Maps of the March mean of the MLD defined with a density threshold of 0.03 kg m⁻³ for (a) CORA T–S profiles averaged by bins of 1° (b) OSnet and (c) Glorys12. The maximum of the color bar is set by the maximum of OSnet. The shelf break is traced in black with the bathymetry contour of 1000 m.

Conclusions

While OSnet delivers an accurate interpolation of the ocean stratification, it is also a tool to study how the ocean stratification relates to surface data. See the code to make your own predictions : https://github.com/euroargodev/OSnet-GulfStream

Our results demonstrate the potential of machine learning methods to improve predictions of ocean interior properties from observations of the ocean surface.

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—> Lellouche, et al. "The Copernicus global 1/12 oceanic and sea ice GLORYS12 reanalysis." *Frontiers in Earth Science* 9 (2021): 698876.
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—> Szekely, et al. "The CORA 5.2 dataset for global in situ temperature and salinity measurements: data description and validation." *Ocean Science* 15.6 (2019): 1601-1614.

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