Reconstructing Global Ocean Deoxygenation Over a Century with Deep Learning

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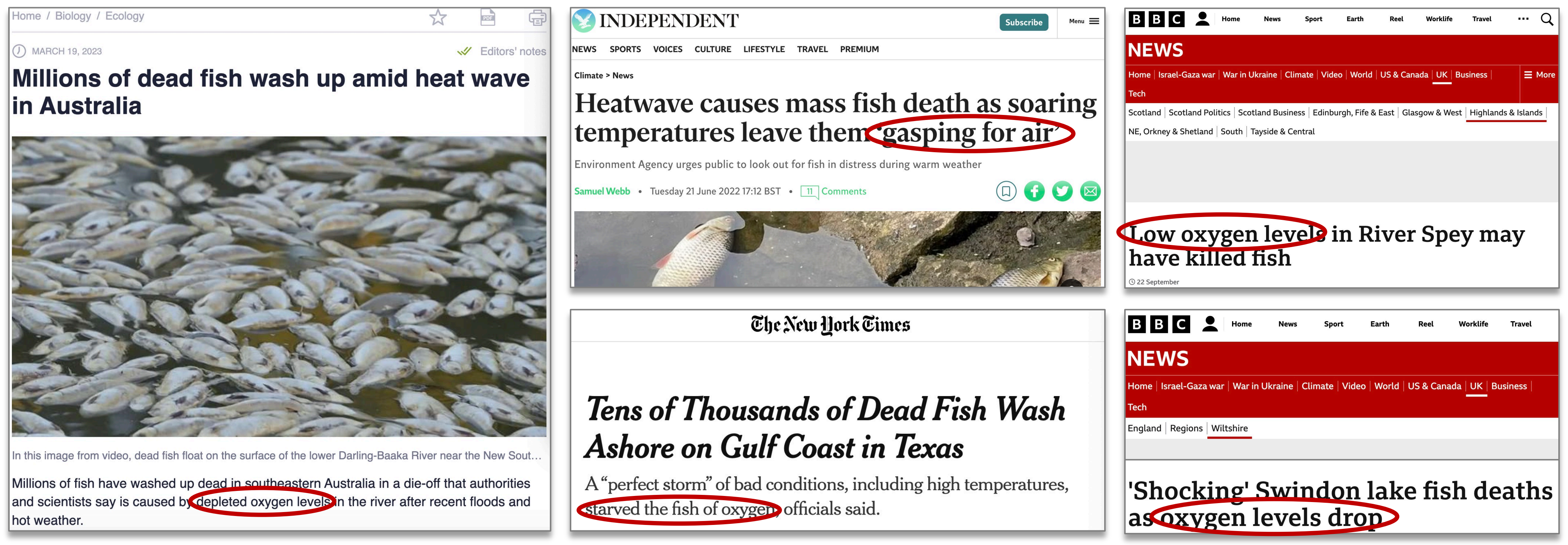
Background & Introduction

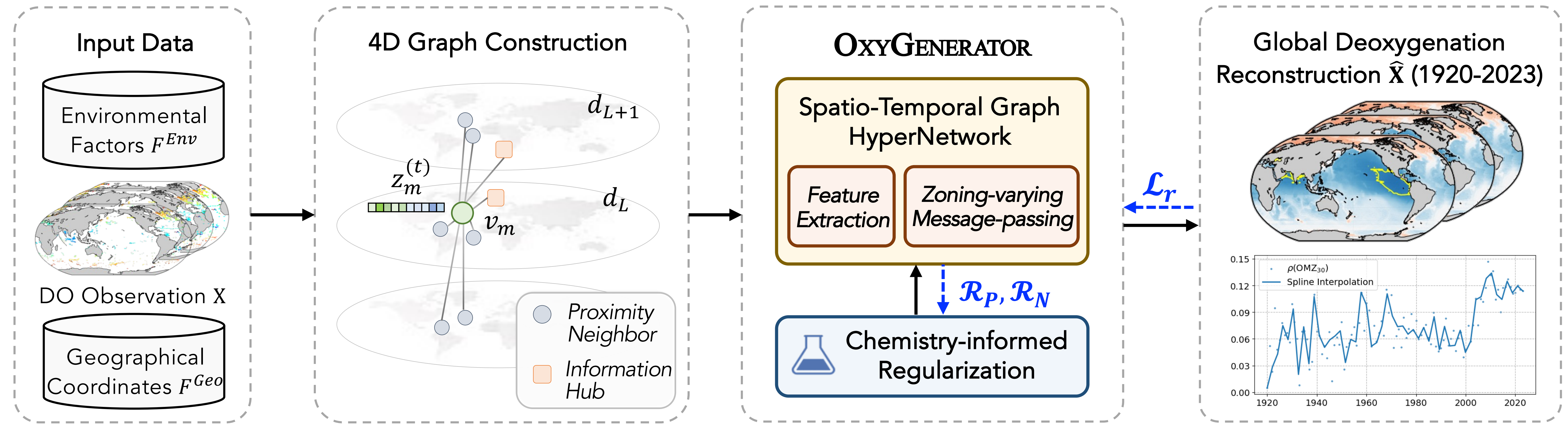
- Oxygen is fundamentally essential for all life. Unfortunately, dissolved oxygen (DO) in the ocean has been **steadily decreasing** over the past 50 years, indicating the acceleration of global ocean deoxygenation.
- To quantitatively understand the **long-term trend of global ocean deoxygenation**, oceanographers simulate the DO concentration based on **numerical simulations**, e.g., CMIP6, without utilizing in-situ DO observations.
- However, these models are unable to adjust for DO simulation biases caused by global warming and human activities, leading to error propagation and showing large discrepancies with in-situ observations.



Proposed Method: OxyGenerator

- Graph-based Modeling: Connect both local and remote observations in irregular four-dimension space.
- Spatio-Temporal Graph HyperNetwork: Inspired by the zoning strategy in oceanography, we propose zoning-varying message-passing to capture the heterogeneity.
- Chemistry-informed regularization: To fuse the knowledge of physical-biogeochemical properties.

$$(CH_2O)_{106}(NH_3)_{16}H_3PO_4 + 138O_2 \rightarrow 106CO_2 + 122H_2O + 16HNO_3 + H_3PO_4$$

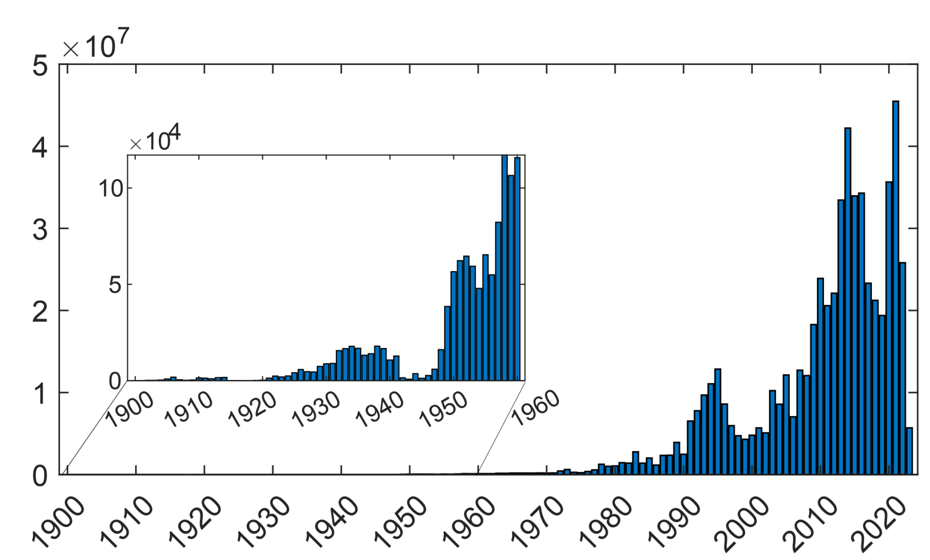


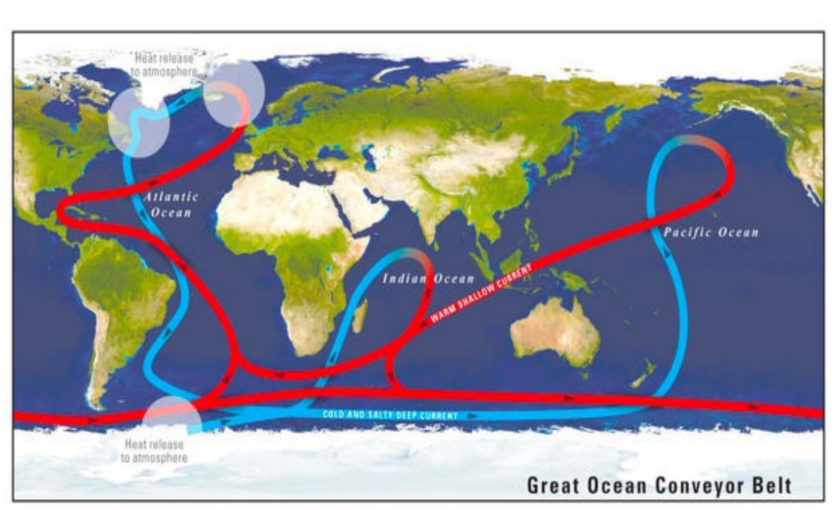
Technical Challenges

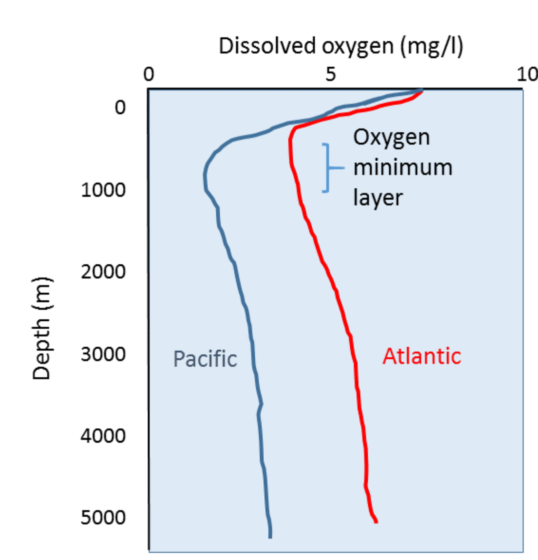
① **Historical dissolved oxygen observation is severely sparse.**
- ➢ According to World Ocean Database (WOD), more than 96.26% dissolved oxygen observation are missing in the past 100 years, especially in early years.

② **Global ocean shows irregular 4D spatio-temporal heterogeneity.**
- ➢ After data gridding, we denote each grid as a 4D coordinate of [longitude, latitude, depth, time].
- ➢ Due to ocean currents, global warming, etc., the ST-correlations in different regions are heterogeneous.

③ **Dissolved oxygen is influenced by coupled physical-biogeochemical properties.**
- ➢ The solubility of oxygen is related to physical processes such as temperature, salinity, and pressure.
- ➢ Active oxygen also participates in chemical reactions and biological activities in seawater.

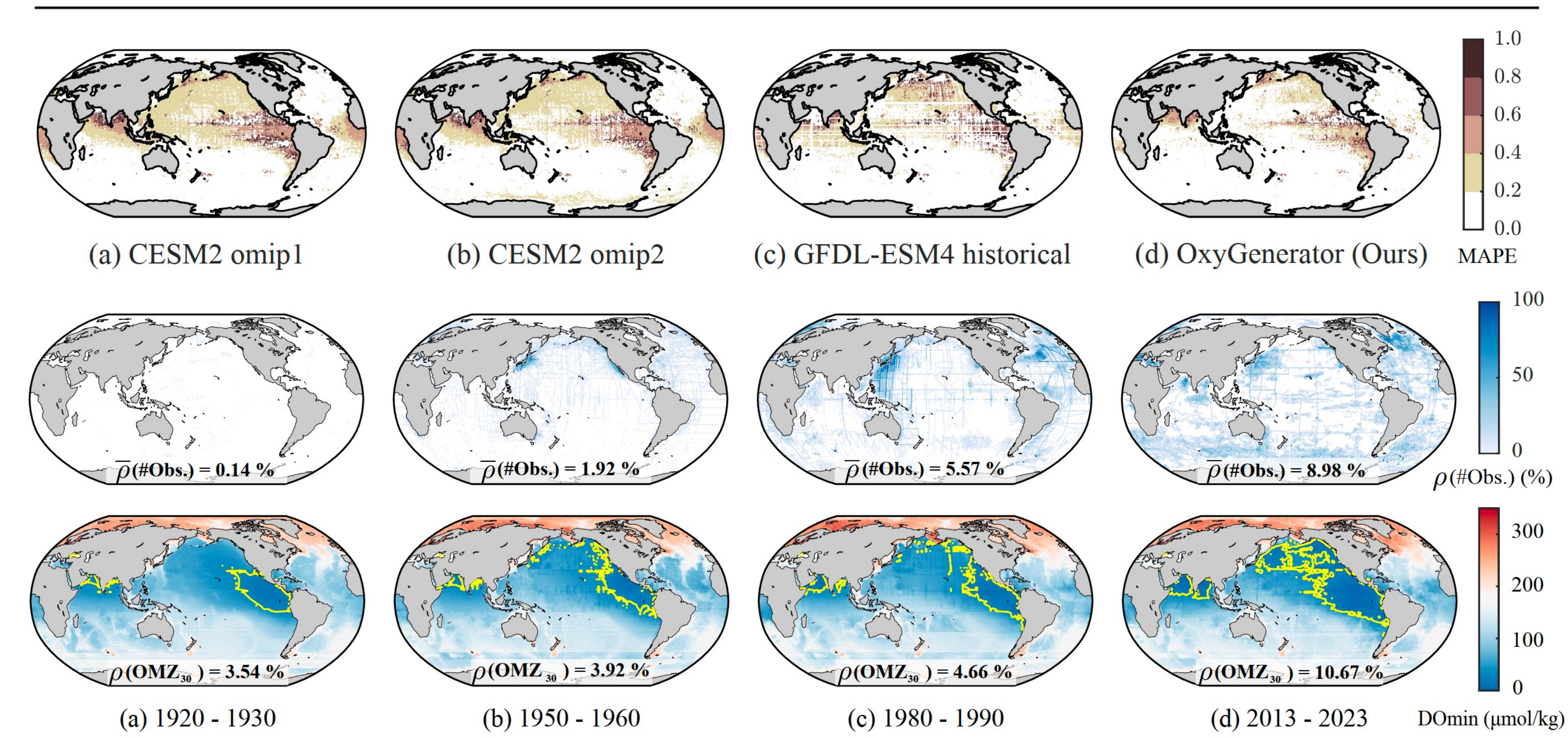


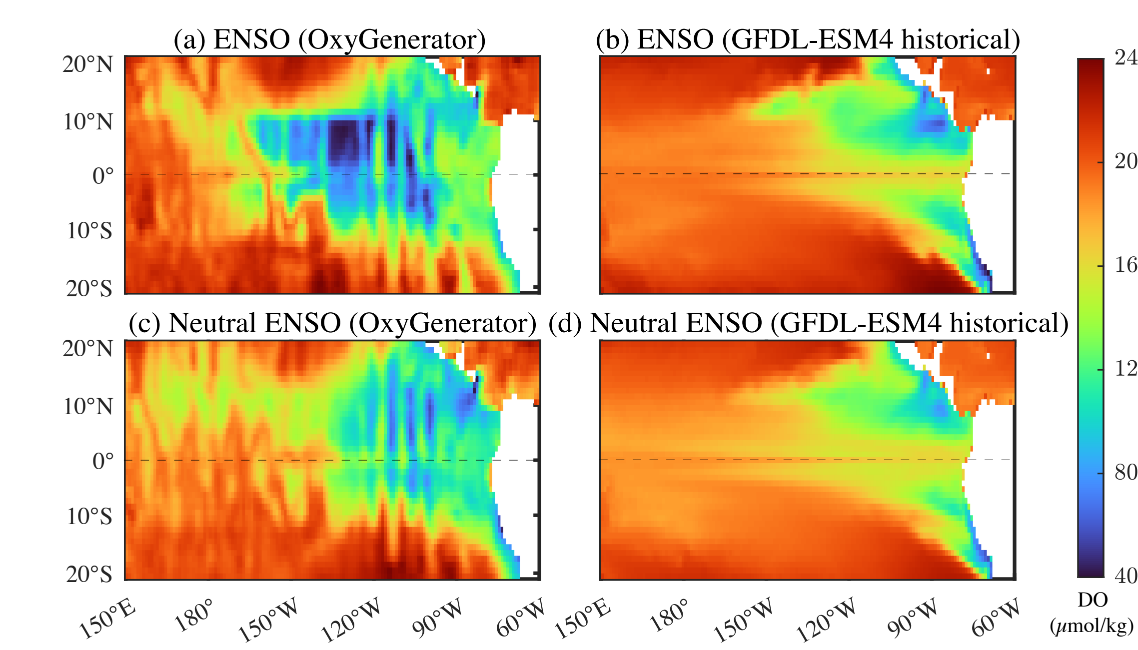




Experiment Results & Model Analysis

Benchmark	$k=1$	$k=2$	$k=3$	$k=4$	Average Performance			
	MAPE	MAPE	MAPE	MAPE	MAPE	R2	RMSE	MAE
CESM2 omip1	23.63	23.15	<u>23.67</u>	<u>22.87</u>	<u>23.32±0.38</u>	0.7966±0.0064	37.37±0.34	25.98±0.31
CESM2 omip2	<u>23.62</u>	<u>23.00</u>	24.60	23.13	23.58±0.72	0.7947±0.0096	38.22±0.55	27.12±0.32
GFDL-ESM4 historical	26.13	24.01	26.68	24.33	25.28±1.31	<u>0.8228±0.0051</u>	<u>35.45±0.65</u>	<u>23.69±0.38</u>
OxyGenerator (Ours)	**14.72**	**13.48**	**15.72**	**13.20**	**14.28±1.16**	**0.9026±0.0072**	**26.31±1.23**	**17.57±1.10**
Improvement	37.67%	41.38%	33.59%	42.28%	38.77%	9.70%	25.78%	25.83%





Comparison of reconstruction results in the surface of the Tropical Pacific during ENSO and neutral ENSO.

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