LangYa: A Large AI model for Global Ocean Forecasting

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Abstract

Accurate high-resolution forecasting of the global ocean state is fundamental to understanding ocean dynamics and supporting marine environmental services. However, existing artificial-intelligence-based ocean forecasting systems are commonly constrained by autoregressive error accumulation, insufficient representation of dynamic atmosphere–ocean interactions, unstable training at high spatial resolutions, and limited capability in reproducing sharp vertical structures such as the thermocline. Here, we present **LangYa**, a global ocean foundation model designed for cross-spatiotemporal forecasting of multiple ocean state variables at a horizontal resolution of 1/12°. Instead of recursively propagating forecasts from one lead time to the next, LangYa explicitly incorporates forecast time as prior information, enabling a single model to directly generate ocean forecasts at different lead times from 1 to 7 days.

LangYa integrates four key methodological innovations. First, an LLM-inspired time-embedding module maps forecast lead time into a high-dimensional representation and introduces temporal information directly into feature learning, substantially reducing dependence on autoregressive forecasting. Second, an atmospheric forcing module based on asynchronous cross-iterative random sampling is introduced to represent the dynamic influence of the atmosphere on ocean evolution. Third, scaled cosine attention together with residual post-normalization is employed to improve optimization stability and convergence for high-resolution global modeling, while a high-resolution reconstruction module suppresses grid-like artifacts in forecast fields. Finally, a thermocline-adaptive loss function incorporates vertical-gradient information to enhance the representation of rapidly varying subsurface temperature structures. LangYa is trained using global GLORYS12 ocean reanalysis together with ERA5 atmospheric information and provides unified forecasts of temperature, salinity, and three-dimensional ocean currents.

Comprehensive evaluations demonstrate that LangYa achieves competitive or superior forecasting skill compared with representative operational numerical ocean forecasting systems. In particular, its temperature and salinity forecasts outperform the compared numerical systems across the evaluated 1–7-day lead times, while its ocean-current forecasts also show advantages over representative high-resolution numerical forecasts. Case studies over dynamically active regions, including the Kuroshio, Gulf Stream, and Agulhas Current, further demonstrate

robust cross-region generalization in reproducing current direction and velocity structures. When operational numerical forecasts are used as model inputs, LangYa maintains stable forecasting performance and can produce high-resolution forecasts with approximately one-second inference response. These results demonstrate the potential of a non-autoregressive, atmosphere-driven ocean foundation model for efficient global ocean forecasting and provide a foundation for extending LangYa toward multimodal ocean phenomena forecasting, regional marine services, and operational applications.