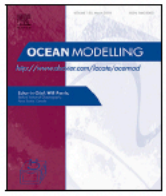
Ocean Modelling 200 (2026) 102678

Contents lists available at ScienceDirect

Ocean Modelling

journal homepage: www.elsevier.com/locate/ocemod



Review

Machine learning in ocean data assimilation: Advances, gaps and the road to operations

Davide Grande [a,b,c,*], Roberto Buizza [b], Andrea Storto [c,d]

[a] University School for Advanced Studies IUSS, Pavia, 27100, Italy
[b] Interdisciplinary Centre on Sustainability and Climate, Sant'Anna School of Advanced Studies, Pisa, 56127, Italy
[c] National Research Council of Italy (CNR), Institute of Marine Sciences (ISMAR), Rome, 00133, Italy
[d] National Research Center for High Performance Computing, Big Data and Quantum Computing (ICSC), Italy

ARTICLE INFO

Keywords:
Machine learning
Ocean data assimilation
Ocean modeling
Artificial intelligence
Operational oceanography

ABSTRACT

This review examines recent advances in the application of machine learning to ocean data assimilation, covering contributions published between 2020 and 2025. We identify emerging trends, recurring limitations, and critical open questions, structuring the discussion around four scientific challenges: observation integration, boundary treatment, fine-scale process representation, and physical consistency. While convolutional neural networks remain widely used, particularly in bias correction and super-resolution tasks, recent studies increasingly employ multilayer perceptrons, long short-term memories, transformers and neural operators for error estimation, sequential bias correction, and latent-space assimilation. Despite this architectural diversity, most contributions remain confined to idealized configurations or offline modules, with limited evidence of generalization and integration into operational pipelines. We conclude that hybrid systems combining embedded physical knowledge with systematic validation across different oceanic regimes will be essential to unlock the full potential of machine learning-enhanced ocean data assimilation.