Deep Learning Framework for Automated Detection and Parameter Estimation of Internal Solitary Waves from Sentinel-1 SAR Imagery in the Lombok Strait, Indonesia

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Abstract:

Internal solitary waves (ISWs) are nonlinear internal waves that exert significant influence on subsurface ocean mixing, sediment resuspension, and coastal current dynamics. Their occurrence and variability have critical implications for navigation safety, offshore infrastructure, and climate-related energy redistribution in the upper ocean. Traditional studies of ISWs using synthetic aperture radar (SAR) imagery have primarily relied on manual interpretation to estimate parameters such as soliton count, wavelength, and propagation direction. While effective in specific case studies, manual approaches are labor-intensive, subjective, and challenging to scale for large, multi-year satellite archives. This study introduces an artificial intelligence framework for automated detection and parameter estimation of ISWs using Sentinel-1 SAR imagery. The approach integrates convolutional neural networks (CNNs) for spatial feature extraction, long short-term memory (LSTM) modules for sequence learning, and a self-attention mechanism to emphasize wave-relevant features. Sentinel-1 SAR imagery was preprocessed through radiometric calibration, speckle filtering, terrain correction, and patch-based extraction. A dataset of 128 × 128 patches containing visible internal wave signatures was compiled, with annotations including wavefront masks, soliton count, wavelength, and orientation. Results demonstrate that the hybrid CNN–LSTM–attention model can delineate ISW wavefronts, estimate soliton count with a mean absolute error below one soliton, and achieve wavelength predictions within ±10 pixels of ground truth. Ablation experiments indicate progressive performance improvements when sequential and attention mechanisms are included. The study highlights the feasibility of applying AI for large-scale, automated monitoring of ISWs, offering pathways toward more systematic investigation of internal wave dynamics in the Indonesian seas and globally.

Keywords: Deep learning, internal solitary waves, oceanography, remote sensing, Sentinel-1