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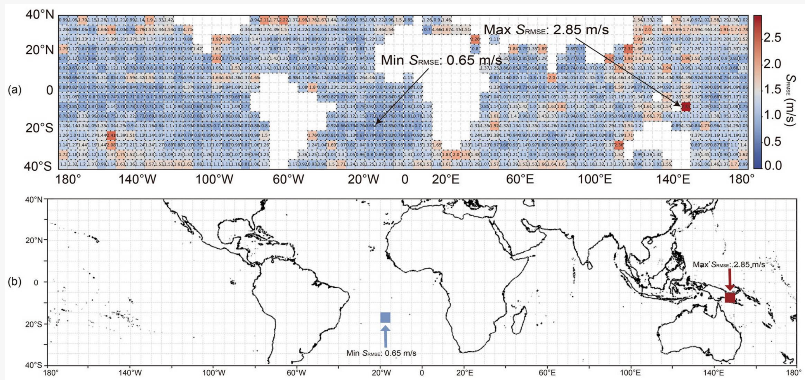
Smarter satellite winds: AI model boosts ocean weather forecasting

GA, UNITED STATES, July 7, 2025 /EINPresswire.com/ -- Accurate monitoring of ocean surface winds is critical for predicting storms, ensuring maritime safety, and understanding climate dynamics. Yet traditional sensing techniques often fall short in coverage and efficiency. Now, a team of scientists has developed Convolutional Neural Network (CNN)-Squeeze-and-Excitation Network (SENet)—a new deep learning model that leverages satellite-based Global Navigation Satellite System-Reflectometry (GNSS-R) data to vastly improve wind speed retrieval. By integrating a specialized attention mechanism known as SENet into a convolutional neural network, the model hones in on the most relevant features, accelerating training and boosting accuracy. In tests across more than one million data points, CNN-SENet significantly outperformed conventional models in both speed and precision, opening new avenues for real-time, global ocean wind monitoring.



Spatial performance of the CNN-SENet model. The subfigure a depicts RMSE of grid cells in the research area and subfigure b depicts land distribution within the research area.

Monitoring wind over the ocean is not just about data—it's about survival. Ships, offshore platforms, and coastal cities depend on timely wind forecasts, particularly during extreme weather events. Traditionally, wind speeds have been measured using buoys, ships, and specialized satellites, but these approaches are expensive and offer limited spatial or temporal reach. Global Navigation Satellite System-Reflectometry (GNSS-R), which repurposes satellite navigation signals reflected off the sea surface, offers a more scalable and cost-effective alternative. Its ability to operate under all weather conditions and deploy on microsatellites makes it ideal for global applications. Yet despite its promise, extracting accurate wind data from GNSS-R signals remains a technical hurdle. Due to these challenges, there is a pressing need to develop advanced models capable of precise, efficient retrieval.

Addressing this challenge, researchers from Nanjing Tech University and the Chinese Academy of Sciences have introduced a novel model called CNN-SENet. The study (DOI: 10.1186/s43020-024-

00157-2) was published in Satellite Navigation in June 2025. This model blends convolutional neural networks (CNNs) with the Squeeze-and-Excitation Network (SENet) attention mechanism to enhance feature extraction from GNSS-R Delay Doppler Maps. Trained on more than one million data points from NASA's CYGNSS satellite and ERA5 reanalysis datasets, CNN-SENet aims to deliver more accurate and computationally efficient wind speed retrievals across global oceans.

CNN-SENet elevates traditional CNN architecture by embedding SENet modules between convolutional layers. These attention modules dynamically emphasize the most informative parts of the input, enabling the model to learn more effectively while cutting training iterations. The model was tested across a broad dataset compiled from CYGNSS satellite observations and ERA5 reanalysis wind speeds, spanning wind conditions from calm seas to 40 m/s gales.

The results were striking. CNN-SENet achieved a root mean square error (RMSE) of 1.29 m/s and an R^2 of 62.4%, outperforming the standard CNN (RMSE: 1.43 m/s) and the widely used Geophysical Model Function (GMF) method (RMSE: 1.91 m/s). Even under high wind conditions, where retrieval is most difficult, CNN-SENet maintained superior performance, with an RMSE of just 3.01 m/s—substantially lower than its counterparts.

The model also showed faster training efficiency, completing its learning in half the time of standard CNNs across various hardware configurations. Spatially, it performed best over open ocean regions, with 82% of analyzed areas achieving RMSE below 1.5 m/s. Temporal tests across different months confirmed the model's consistency, indicating robust generalization over time. Together, these results highlight CNN-SENet as a promising tool for global, high-resolution ocean wind monitoring.

"Our aim was to create a smarter, faster model that can adapt to real-world variability in ocean environments," said Dr. Dongliang Guan, co-author of the study. "By integrating SENet into the CNN framework, we've empowered the system to focus on what matters most—improving both efficiency and accuracy. This is especially critical for monitoring extreme weather systems like typhoons, where every minute counts." The researchers believe this advancement will contribute significantly to building more agile, data-driven marine forecasting networks.

The practical implications of CNN-SENet extend far beyond academic performance. Its lightweight design and computational efficiency make it ideal for deployment on microsatellite constellations, offering the potential for near real-time global wind field monitoring. Such capabilities are vital for marine weather forecasting, disaster preparedness, and climate modeling. Looking ahead, the team plans to enhance the model by integrating additional environmental parameters—such as wave height and sea state—and refining the architecture for even faster processing. With continued innovation, CNN-SENet could become a core component in next-generation satellite observation systems, delivering smarter and more scalable solutions for ocean monitoring worldwide.

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