# Ocean warming patterns key to accurate tropical cyclone climate projections

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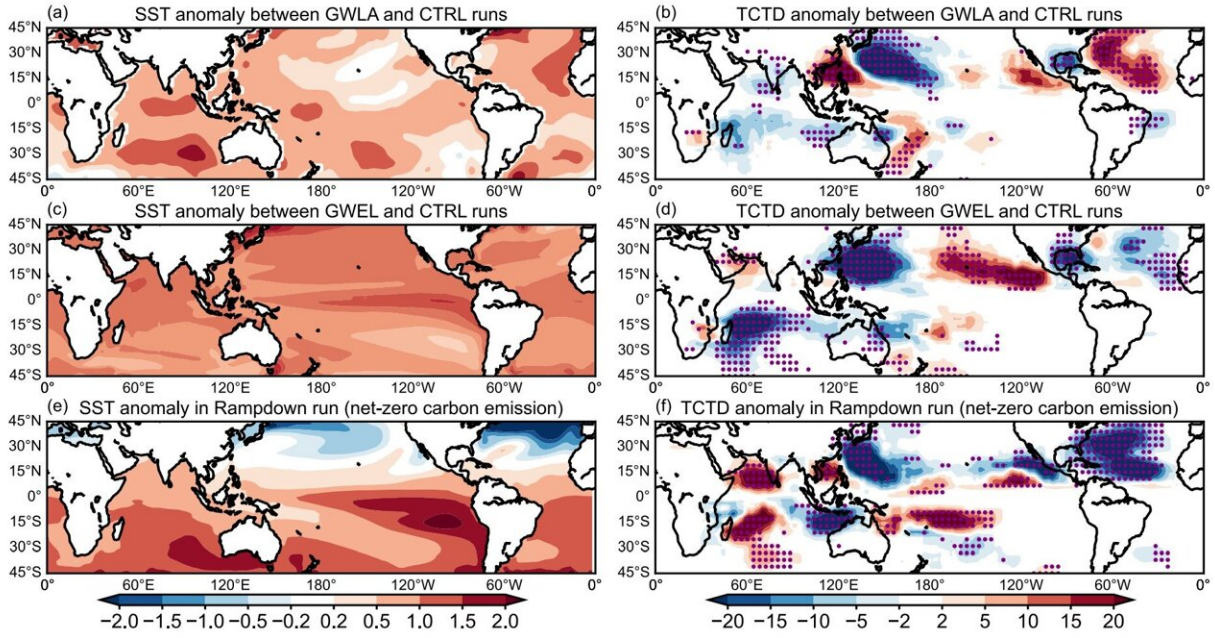


Simulated TC track density differences (TCTD, right column) under different warming scenarios (left column): (a, b) La Niña-like warming (GWLA) vs. control; (c, d) El Niño-like warming (GWEL) vs. control; (e, f) Ramp-down (net-zero emissions) vs. control. Purple dots indicate statistically significant areas (90% confidence, Student's t-test). [From Zhao et al. (2020a), except for (c) from Liu et al. (2024)]. Credit: *Advances in Atmospheric Sciences* (2025). DOI: 10.1007/s00376-025-5114-1

A new review published in *Advances in Atmospheric Sciences* sheds light

on one of climate science's enduring puzzles: how the patterns of tropical ocean warming influence the behavior of tropical cyclones (TCs) in a warming world. An international team of scientists synthesizes decades of observational evidence and climate modeling advances to chart a path forward for more reliable TC projections.

Tropical cyclones rank among the costliest and deadliest weather phenomena globally, yet our ability to project future changes in their activity remains limited. The team recently determined that a key challenge lies in the complex influence of tropical sea surface temperature (SST) warming patterns on TC behavior.

Observations since the 1950s consistently show a La Niña-like warming pattern—featuring cooling or weaker warming in the eastern tropical Pacific—while over 80% of CMIP6 climate models project the opposite: an El Niño-like pattern with enhanced warming in the eastern Pacific.

"These discrepancies, stemming from biases in cloud feedbacks, ocean dynamics, and large-scale atmospheric circulation, have profound implications. Because tropical SST patterns modulate TC genesis, intensity, and spatial distribution, inaccurate SST projections cascade into large uncertainties in climate projections of cyclone activity," said Yuqing Wang, lead author of the review and professor at the University of Hawaii at Manoa, Honolulu, U.S.

The research team set out to clarify why models diverge from observations and how different warming patterns influence TCs. More importantly, they argue that reliable TC projections must account for realistic warming patterns.

"'Pattern-conditioned' approaches using convection-permitting high-resolution models offer a promising way to reduce uncertainty," Prof.

Wang said.

Unlike traditional coarse-resolution models, these storm-resolving models can directly simulate TCs and their response to warming, offering insights into processes like rapid intensification and structural evolution.

The team also underscores the role of inter-basin interactions—warming in the Indian and Atlantic oceans, for instance, can reinforce La Niña-like conditions in the Pacific, in turn altering global TC distributions. Therefore, assessing TCs requires a truly global view of SST dynamics and their feedback.

The research team calls for a coordinated effort to integrate storm-resolving global models, bias-corrected SST pattern scenarios, and physics-informed diagnostics into the next generation of tropical cyclone projection frameworks. This means not only resolving the fine-scale structure of storms, but also ensuring that the underlying SST forcing is credible.

Future research should prioritize ensemble simulations across a range of warming patterns, incorporate time-evolving SST anomalies, and evaluate model performance against observed tropical variability. These steps will help clarify how cyclone activity may evolve under different climate pathways—critical information for long-term risk assessment, infrastructure planning, and climate adaptation.

In an era of intensifying extreme weather, this review offers a clear message: to better project the future of tropical cyclones in a warmer climate, we must first understand the patterns of the warming seas.

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Shanghai, China; Associate professor Jiuwei Zhao from Nanjing University of Information Science & Technology (NUIST), Nanjing, China; Professor Shang-Ping Xie from University of California San Diego, La Jolla, U.S..

The invited review is included in a special issue to commemorate the 40th Anniversary of *Advances in Atmospheric Sciences* and the Centenary of the Chinese Meteorological Society.

**More information:** Yuqing Wang et al, Tropical Sea Surface Warming Patterns and Tropical Cyclone Activity: A Review, *Advances in Atmospheric Sciences* (2025). DOI: 10.1007/s00376-025-5114-1