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GFDL BULLETIN

Research Highlights from the Geophysical Fluid Dynamics Laboratory Community

Advancing the Modeling, Understanding, and Prediction of Weather and Climate

Crucial role of sea surface temperature warming patterns in near-term high-impact weather and climate projection

npj Climate and Atmospheric Science *Ming Zhao[1], Thomas Knutson[1]*

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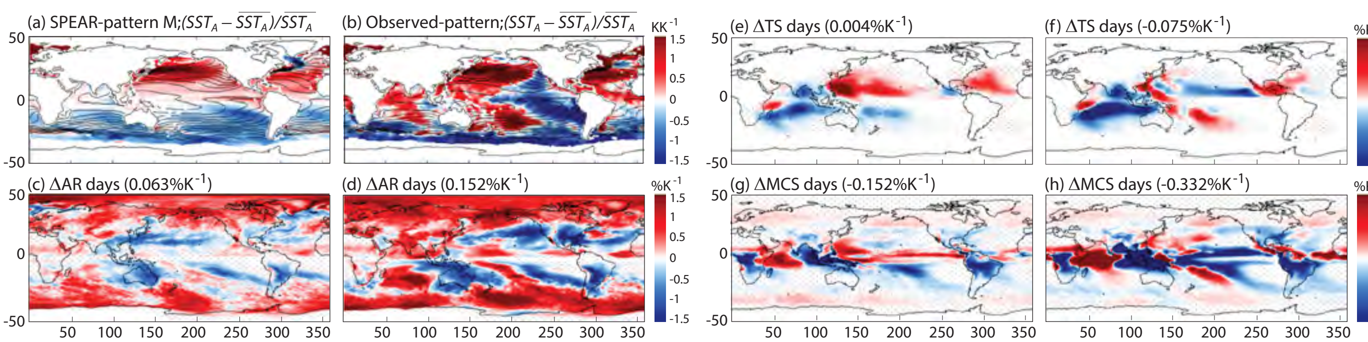
Recent studies indicate that global climate models (GCMs), including those used in the Coupled Model Intercomparison Project Phase 6 (CMIP6) for the latest Intergovernmental Panel on Climate Change (IPCC) assessments, have faced challenges in accurately simulating observed sea surface temperature (SST) trend patterns over the past four decades. While GCMs have typically predicted enhanced warming in the Eastern Equatorial Pacific (EPAC) and the Southern Ocean (SO), real-world observations have shown intensified warming in the Indo-Pacific Warm Pool (IPWP) and slight cooling in both the EPAC and SO. In this study, Zhao et al. demonstrate these biases in SST trend patterns have notable implications for near-term climate projections, including (a) the behavior of high-impact storms like atmospheric rivers (ARs), tropical storms (TSs), and mesoscale convective systems (MCSs), and (b) changes in global precipitation patterns and the Earth's surface warming response to increased carbon dioxide (CO_2) levels, viz., climate sensitivity.

Utilizing GFDL's high-resolution global atmospheric model (C192AM4) and the Seamless System for Prediction and Earth System Analysis and Research (SPEAR) prediction system, the study explores how these biases in SST trends affect the understanding of these crucial climate phenomena. The authors suggest that if future SST warming patterns continue to align with recent historical trends, the frequency of high-impact storms, hydroclimate impacts, and global warming could diverge significantly from current model projections. For example, the study indicates that projected global warming could be lower than expected due to stronger negative feedbacks and reduced climate sensitivity. The roles of SST trends in specific regions, such as the EPAC and the North Atlantic tropical cyclone Main Development Region (AMDR), are particularly crucial for modeling future changes in AR and MCS frequency, while SST trends in the IPWP and AMDR play a central role in future changes in TS frequency.

This research represents the first comprehensive study of how SST warming patterns influence the global distribution and frequency of ARs, TSs, and MCSs, and the global hydrological sensitivity. Addressing the climate model biases in SST trend simulations is essential for improving future projections of high-impact weather events, regional precipitation patterns, and overall global warming. As advancements in high-resolution atmospheric modeling continue to enhance the realism of weather and climate simulations, the ability to study the impact of SST trends on high-impact storms and climate will become increasingly important for more accurate predictions.

OAR Goals: Make Forecasts Better

Sea Surface Temperature (SST) warming patterns and their impact on high-impact storm frequencies



The figure compares sea surface temperature (SST) warming patterns and their impact on the modeled frequencies of atmospheric rivers (ARs), tropical storms (TSs), and mesoscale convective systems (MCSs) between simulations based on the Seamless System for Prediction and Earth System Research (SPEAR) model and observed SST trends for the period 1979–2020. Red shading indicates regions with increased frequencies of high-impact events, while blue shading represents regions with decreased frequencies.

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Skillful seasonal prediction of wind energy resources in the contiguous United States

Communications Earth & Environment *Xiaosong Yang[1], Thomas L. Delworth[1], Liwei Jia[1], Nathaniel C. Johnson[1], Feiyu Lu[1,2], and Colleen McHugh[3]*

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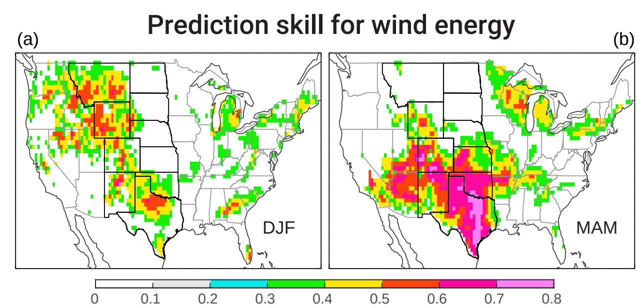
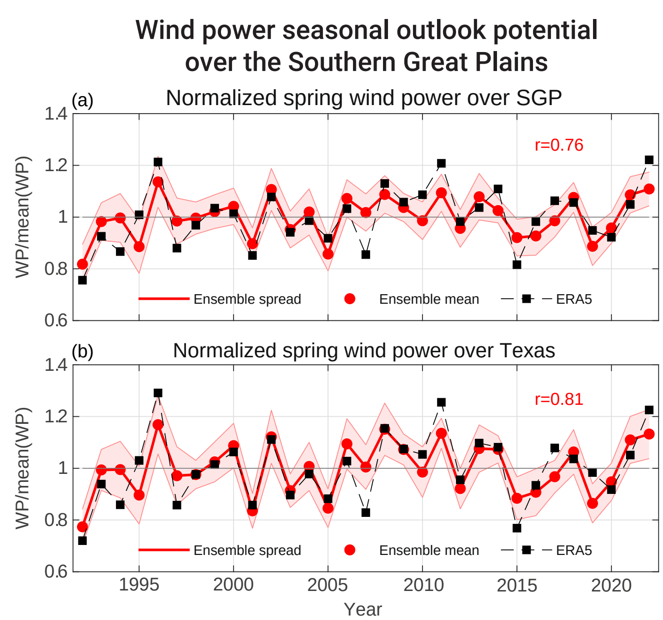
As the demand for wind energy in the United States continues to grow, electricity generated from wind is projected to rival traditional sources such as coal and nuclear power during peak seasons. However, the inherent variability in wind patterns, driven by atmospheric conditions on seasonal and interannual timescales, presents challenges for reliable energy production. Yang et al. focus on the need for skillful seasonal wind energy predictions, which are crucial for optimizing energy production and grid management.

Utilizing GFDL's Seamless System for Prediction and Earth System Research (SPEAR) model, the authors examine year-to-year wind energy variations across the contiguous United States. The results demonstrate that SPEAR performs exceptionally well during peak wind energy seasons, particularly in spring and winter, with a high accuracy in predicting wind energy over the Southern Great Plains, a region that holds much of the U.S. wind energy capacity. The study highlights the role of the El Niño-Southern Oscillation (ENSO) in influencing large-scale wind patterns and storm tracks which, in turn, affect wind energy resources. In addition, SPEAR shows strong skill in state-level wind energy predictions. For example, spring wind energy output in Texas, which accounts for nearly a quarter of the nation's wind capacity, was forecast with high accuracy, achieving a correlation of 0.8 between predicted and observed values. These reliable forecasts, available months in advance, provide valuable tools for energy planners and grid operators to better manage wind energy production during peak seasons.

The study emphasizes the potential of SPEAR to significantly improve seasonal wind energy predictions, offering insights into the link between climate variability and renewable energy output. This advancement has the potential to enhance the integration of wind energy into the grid, and assist decision-makers in optimizing resource planning for stable and sustainable energy supplies.



Prediction skill analysis of wind energy based on the anomaly correlation coefficient (ACC) between GFDL's Seamless System for Prediction and Earth System Research (SPEAR) Seasonal Retrospective Forecasts (SRF) at a one-month lead and the European Centre for Medium-Range Weather Forecasts (ECMWF) Reanalysis version 5 (ERA5) for (a) December-January-February (DJF) and (b) March-May (MAM). ACC values with p-values greater than 0.05 are not shown. The SRF is initialized on November 1st and February 1st for DJF and MAM, respectively, during the period of 1991–2022. Black outlines indicate the states in the U.S. Great Plains.



Time series of normalized observations (black squares), ensemble mean (red dots) and spread (shading) from GFDL's Seamless System for Prediction and Earth System Research (SPEAR) Seasonal Retrospective Forecasts (SRF). (a) Averaged over the Southern Great Plains (30°-40°N, 95°-107°W) for spring (March-April-May, MAM) wind power (WP) during 1992–2022. (b) The same as (a) for spring wind power averaged over Texas. Observations and model results are normalized by their 1992–2022 mean. SPEAR's SRF is initialized on March 1st each year.

OAR Goals: Make Forecasts Better

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Causes and multiyear predictability of the rapid acceleration of U.S. Southeast Sea level rise after 2010

npj Climate and Atmospheric Science *Liping Zhang[1,2], Thomas L. Delworth[1], Xiaosong Yang[1], Fanrong Zeng[1], Qinxue Gu[1,3], and Shouwei Li[1,3]*

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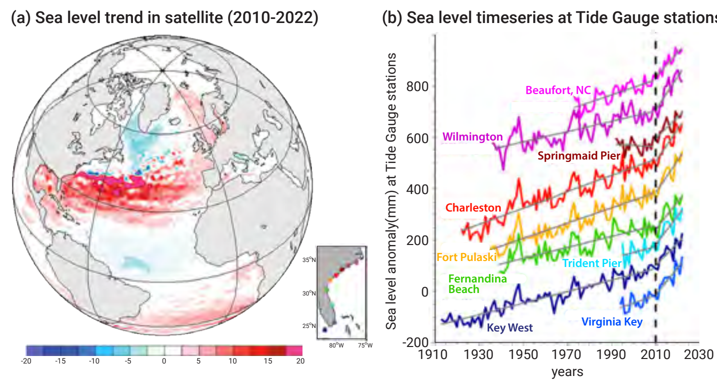
Sea level rise (SLR) is one of the most severe consequences of a warming climate, posing a significant threat to coastal communities through dangerous flooding and damage to critical infrastructure. In recent years, the U.S. Southeast Coast (USSEC) has emerged as a "hot spot" for rapid sea level rise in the North Atlantic Ocean. Observations between 2010 and 2023 reveal a striking increase, with rates of rise averaging 10.8 mm per year—three to four times higher than the rates recorded between 1920 and 2009.

While global sea level rise is accelerated by anthropogenic radiative forcing, regional variations are strongly influenced by internal climate variability. Through a combination of observational data and climate models, the authors identify two key contributors to the rapid increase in sea level along the USSEC post-2010: *multidecadal buoyancy-driven variations in the Atlantic Meridional Overturning Circulation (AMOC) and changes in heat transport driven by wind-induced ocean circulation.* Notably, the research demonstrates that decadal prediction systems can provide skillful forecasts of these variations, with AMOC-driven sea level changes being predictable up to five years in advance and wind-driven changes up to two years in advance. The findings suggest that predicting coastal sea level rise and its associated flooding risk along the USSEC is potentially feasible on multiyear timescales.

Observations in rapid acceleration of sea level rise along the U.S. Southeast Coast after 2010



(a) The linear trend of sea level rise (mm/year) from 2010 to 2022 based on satellite observations.

(b) Time series of annual mean sea level anomalies (mm) with respective to long term mean at various Tide Gauge (TG) stations along the U.S. Southeast Coast. Rainbow dots in the bottom-left subplot indicate the locations of the TG stations. The solid grey lines in (b) represent the linear sea level trends before and after 2010 at each Tide Gauge station. Constant values have been added to the time series in (b) to visually offset the data for clarity. The offsets, applied from south to north, are (in mm): 0, 0, 200, 200, 300, 400, 600, 650, and 800.

This study marks the first attempt to link coastal sea level variability and predictability to both buoyancy-driven AMOC changes and wind-driven North Atlantic tripolar modes. The rapid sea level rise along the USSEC is driven by the cumulative effects of long-term global warming, AMOC variations, and wind-driven ocean responses to the North Atlantic Oscillation (NAO), highlighting the complex interplay of these factors in contrast to solely internal variability. However, accurately distinguishing the forced signal from internal variability remains a challenge in both observations and models. It is also important to recognize the limitations of the models used in this study. The Seamless System for Prediction and Earth System Analysis and Research (SPEAR) model, for instance, has low ocean resolution and does not account for non-climate factors such as vertical land movement, nor does it include tides or land ice components. These limitations need to be addressed with improved models and as more data becomes available. Nonetheless, the study represents a significant advance in understanding the predictability of sea level rise and the potential to develop multiyear forecasts for regions like the USSEC, which face heightened risks from rapid sea level rise.

OAR Goals: Detect Changes in the Ocean & Atmosphere, Make Forecasts Better

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A predicted pause in the rapid warming of the Northwest Atlantic Shelf in the coming decade

Geophysical Research Letters *Vimal Koul[1], Andrew C. Ross[2], Charles Stock[2], Liping Zhang[2], Thomas Delworth[2], Andrew Wittenberg[2]*

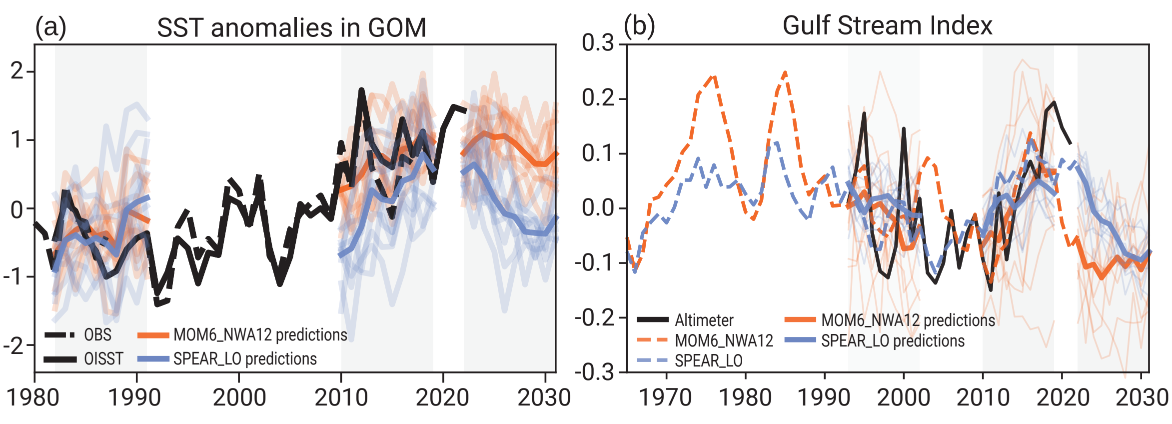
DOI: 10.1029/2024GL110946

The Northwest Atlantic Shelf has seen some of the fastest ocean warming rates globally, raising concerns about the long-term impact of the warming on marine ecosystems and coastal communities. The Koul et al. study, using a high-resolution decadal prediction system suggests a temporary pause in this rapid warming trend over the next decade. To address the unique challenges of predicting regional ocean variability, the authors developed a high-resolution ocean prediction system for the U.S. East Coast, specifically focusing on the Northwest Atlantic Shelf. This system uses the Modular Ocean Model 6 (MOM6) to dynamically downscale global predictions from GFDL's Seamless System for Prediction and Earth System Research (SPEAR). The downscaled simulations feature a refined resolution of 1/12°, allowing for more accurate predictions of oceanic processes in the region. The study produced a 10-member ensemble of decade-long predictions from 1965 to 2022, resulting in a total of 5,800 years of simulation. When compared to observations, these downscaled simulations demonstrated a significantly higher skill in capturing regional ocean variability than previous coarse-resolution models. It also identified a temporary reprieve in warming for the Northwest Atlantic Shelf from 2022 to 2031, driven by internal variability linked to a transient strengthening of the Atlantic Meridional Overturning Circulation (AMOC) and a southward shift in the Gulf Stream. Despite this pause, century-scale projections from both SPEAR and the high-resolution model indicate a continued long-term warming trend.

These findings are especially relevant for NOAA's Climate, Ecosystems, and Fisheries Initiative, which aims to provide critical ocean and climate information to support marine resource management. The predicted pause in warming could offer a brief respite for marine ecosystems stressed by rising temperatures, offering time to adapt. The 10-member ensemble not only enhances confidence in decadal predictions but also provides crucial insights into prediction uncertainty, which is vital for improving decision-making about the region's future ocean and climate conditions. While uncertainties exist e.g., results of continued rapid warming from some other global positioning systems, how global forcings influence the regional forecasts for the Northwest Atlantic Shelf is a needed focus in future studies.

OAR Goals: Make Forecasts Better, Explore the Marine Environment

Decadal predictions of the Gulf of Maine sea surface temperature anomalies and the Gulf Stream Index



(a) Observed (from in situ observations (OBS) and the Optimum Interpolation SST dataset (OISST)) and predicted decade-long sea surface temperature (SST) anomalies (relative to the 1982–2022 mean) in the Gulf of Maine (GOM) ecological production unit. Light-colored lines represent individual ensemble members, while the dark line indicates the ensemble mean. Both the Seamless System for Prediction and Earth System Research (SPEAR) and the Modular Ocean Model 6 Northwest Atlantic 12-degree (MOM6_NWA12)-based forecasts suggest a temporary pause in warming over the next decade.

(b) Gulf Stream Index (GSI) based on altimeter data (black) and SPEAR and MOM6_NWA12 model historical simulations (dashed lines), along with predicted GSI from both models (solid lines). Positive values indicate a northward shift of the Gulf Stream and negative values indicate a southward shift. Decadal forecasts from both systems indicate a southward shift of the Gulf Stream over the next decade.

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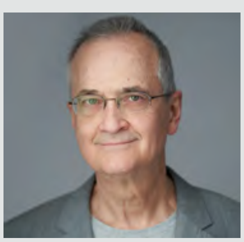
Nadir Jeevanjee Honored with the 2025 AMS Henry G. Houghton Award

Dr. Nadir Jeevanjee, Physical Research Scientist at GFDL, has been awarded the 2025 Henry G. Houghton Award from the American Meteorological Society (AMS) for "providing robust and comprehensive theoretical frameworks to illuminate complex phenomena in climate physics." Since joining GFDL in 2016, he has become a leading figure in physical climatology, recognized for his ability to develop robust theoretical frameworks that simplify complex climate phenomena. Dr. Jeevanjee's work on radiative forcing and climate feedbacks have provided critical insights into the spatial patterns of CO_2 forcing, influencing how climate sensitivity is understood and predicted. His publications, including several collaborative works, span a diverse array of topics—from convection dynamics to the conceptual foundations of climate model hierarchies to the innovative scientific understanding of Earth's climate and climate change. Beyond his research contributions, Dr. Jeevanjee is a dedicated mentor and an associate editor for Climate Science at Reviews of Modern Physics.

Lucas Harris Receives the 2024 AGU Atmospheric Sciences Ascent Award

Dr. Lucas Harris, Deputy Division Lead of the Weather and Climate Dynamics Division at GFDL, has been awarded the 2024 American Geophysical Union (AGU) Atmospheric Sciences Ascent Award. This award recognizes his outstanding research and leadership in high-resolution atmospheric model development and its applications for weather and climate predictions. Dr. Harris has played a pivotal role in advancing GFDL's efforts in developing the Finite-Volume Cubed-Sphere Dynamical Core (FV3) and System for High-resolution prediction on Earth-to-Local Domains (SHiELD) models. His work has greatly improved predictions of tropical cyclones, severe storms, and extreme weather, enhancing the accuracy of climate simulations at unprecedented scales. He leads NOAA's Global-Nest Initiative, aimed at building the next-generation global-to-regional and global storm-resolving models for improved extreme weather predictions. His collaborative efforts include contributions to the development of the NOAA Hurricane Analysis and Forecasting System (HAFS) and working closely with NOAA's Environmental Modeling Center (EMC) and other partners, setting novel standards for weather and climate models.

2024 AGU Robert E. Horton Medal Awarded to P.C.D. (Chris) Milly



Dr. P.C.D. (Chris) Milly, formerly a U.S. Geological Survey (USGS) research hydrologist, based at GFDL since 1988 under a NOAA-USGS Memorandum of Understanding, and currently a USGS Scientist Emeritus, has been awarded the 2024 Robert E. Horton Medal by the American Geophysical Union (AGU). His work has been transformative in the community's understanding of global and continental hydrology and their interactions with a changing climate. As a key figure in the development of NOAA/GFDL models, Dr. Milly significantly advanced the integration of hydrological processes into global climate models. His efforts improved the prediction of hydrological extremes, such as droughts and floods, providing critical insights for climate modeling and global water resource management. Dr. Milly's contributions have also been pivotal to the Intergovernmental Panel on Climate Change (IPCC) Assessment Reports, helping inform policymakers worldwide about the effects of climate change on water resources. His interdisciplinary scientific approaches and inspirational leadership in sustainable water management has made a lasting impact on the field.