GFDL BULLETIN

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Research Highlights from the Geophysical Fluid Dynamics Laboratory Community

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

Bridging the gap between global weather prediction and global storm-resolving simulation: introducing the GFDL 6.5-km SHiELD

Journal of Advances in Modeling Earth Systems *Linjiong Zhou[1], Lucas Harris[2], Jan-Huey Chen[2], Kun Gao[1], Kai-Yuan Cheng[1], Mingjing Tong[2], Alex Kaltenbaugh[2], Matthew Morin[3], Joseph Mouallem[1], Lauren Chilutti[2], Lily Johnston[4]*

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Global weather prediction models must balance computational efficiency with the ability to accurately simulate high-impact weather systems, such as tropical cyclones and intense convective storms. Zhou et al. present the development and evaluation of a 6.5-km global version of the System for High-Resolution Prediction on Earth-to-Local Domains (SHiELD) at GFDL, designed to bridge the gap between global medium-range weather prediction and global storm-resolving simulation. This study assesses the model's performance in improving prediction accuracy at global, regional, and mesoscale levels.

The 6.5-km global SHiELD model builds on the 13-km version by doubling the resolution and incorporating refined physical parameterizations, improving the representation of atmospheric processes in the convective "gray zone" (resolutions below 10-km). The model was evaluated through three years of hindcast experiments covering over 200 cases and demonstrated significant improvements in global and regional prediction skill. Compared to the 13-km version, the 6.5-km SHiELD reduces biases in precipitation and tropical cyclone intensity, and improves the representation of post-frontal cumulus clouds. At the mesoscale level, it enhances the prediction of continental convective precipitation.

By refining its ability to capture both large-scale circulations and storm-scale features, the 6.5-km SHiELD serves as a scalable solution bridging operational weather forecasting and high-resolution atmospheric research. This research supports NOAA's goal of improving numerical modeling techniques and medium-range forecast capabilities, with potential applications in global extreme weather prediction and disaster preparedness.

Ten-day near-real-time forecasts using the 6.5-km global SHiELD are generated four times daily and are publicly available at shield.gfdl.noaa.gov. Based on available information, this appears to be the only publicly accessible global model at this resolution. This work is part of the NOAA Research Global-Nest Initiative and represents the first major deliverable.

OAR Goals: Make Forecasts Better, Drive Innovative Science

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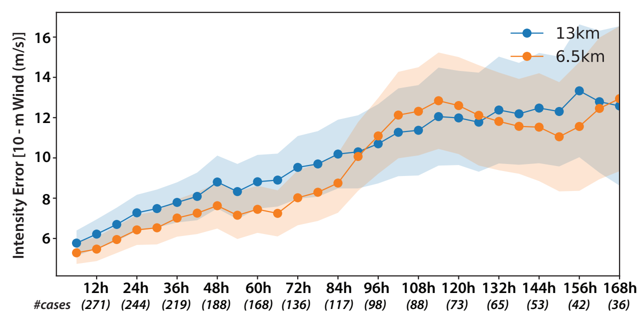
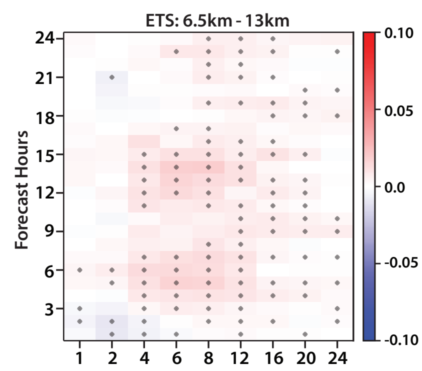
Global Tropical Cyclone Intensity Prediction



Global mean tropical cyclone intensity error for the maximum 10-meter wind speed as a function of lead time, relative to the Automated Tropical Cyclone Forecast best track. Lower errors indicate better performance. The shaded area represents the 95% confidence interval. The number of cases at each lead time is shown in the x-axis labels.

Quantitative Precipitation Forecast over the Contiguous United States



Equitable Threat Score (ETS) differences between the 6.5-km global SHiELD and the 13-km global SHiELD over the Contiguous United States as a function of precipitation thresholds. Positive differences (red) represent improved forecast accuracy. Color-coded boxes with center dots indicate differences that are statistically significant at the 95% confidence level.

A global–land snow scheme (GLASS) v1.0 for the GFDL Earth System Model: formulation and evaluation at instrumented sites

Geoscientific Model Development *Enrico Zorzetto[1,2,3], Sergey Malyshev[4], Paul Ginoux[4], and Elena Shevliakova[4]*

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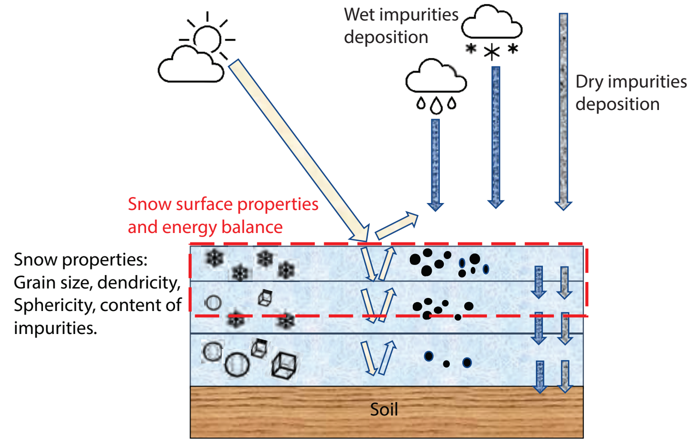
Snowpacks play a significant role in water storage over land and in determining the strength of the surface albedo feedback, which influences energy exchanges between land surface and the atmosphere. To enhance the representation of snow processes, the Global LAnd–Snow Scheme (GLASS) v1.0 was developed for the GFDL land model (LM4.1). This new snowpack model incorporates a dynamic vertical-layering structure that tracks snow grain properties and their evolution over time.

GLASS integrates key processes such as snow compaction, wind drift, and snow metamorphism, encompassing both wet and dry aging effects. As the snow ages, the evolution of its microstructure impacts how light transfers through it and, in turn, the melt rates. These updates allow for improved simulations of snow depth, thermal conductivity, and optical properties while maintaining computational efficiency for large-scale weather-to-climate research. The model dynamically adjusts its vertical discretization to balance physical detail with computational demands, ensuring its suitability for global simulations.

The performance of GLASS was evaluated at ten benchmark sites spanning diverse climatic and geographic conditions, including forested and non-vegetated regions. Results demonstrate improved predictions of seasonal snow water equivalent, attributed to better snow albedo representation. Soil temperature simulations also showed reduced bias, with an average improvement of 1.5K across the test sites. A minor negative bias of approximately 1K in snow surface temperature was observed, providing a target for further refinement.

Schematic representation of GLASS energy and mass fluxes



A schematic representation of the fluxes of solar radiation and energy balance (beige arrows) and light-absorbing particles deposited on snow (blue and grey arrows) represented in the Global LAnd-Snow Scheme (GLASS) snow model. The snowpack is represented by a multi-layer medium with snow properties (including snow grain size and shape) which evolve dynamically in each layer based on the thermal conditions of the snowpack. Both snow grain properties and the content of light-absorbing particles are used to compute the optical properties of snow.

In addition to its physical advancements, GLASS incorporates detailed representations of snow grain properties such as dendricity, sphericity, and optical diameter. These parameters enhance the model's ability to capture the effects of snow microstructure on albedo and energy dynamics, offering greater insight into snow-atmosphere interactions.

The development of GLASS supports the broader goal of improving the accuracy of land-atmosphere interaction modeling and hydrological processes within Earth System Models. Ongoing efforts will focus on addressing identified biases and refining the model's capabilities to further enhance its applicability for weather-to-climate research. These advancements ensure GLASS contributes meaningfully to global-scale modeling while maintaining computational feasibility.

OAR Goals: Make Forecasts Better, Drive Innovative Science

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Weakening of the AMOC and strengthening of Labrador Sea deep convection in response to external freshwater forcing

Nature Communications *Xinyue Wei[1] and Rong Zhang[1,2]*

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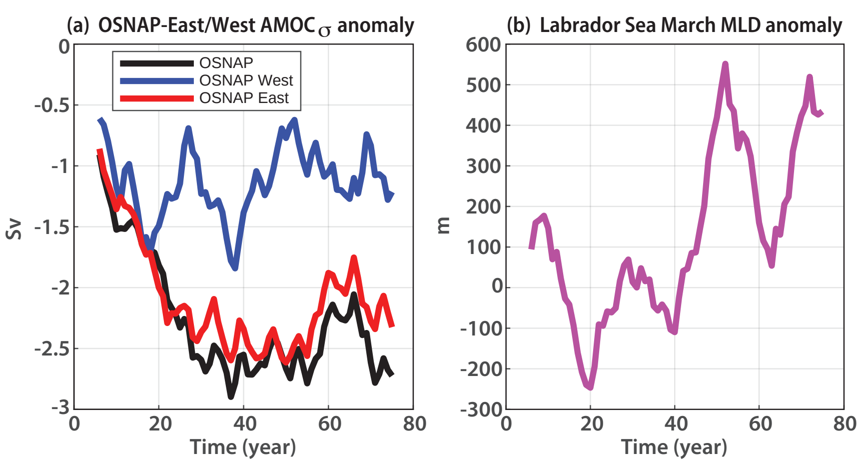
A recent study by Wei and Zhang examined the response of the Atlantic Meridional Overturning Circulation (AMOC) and Labrador Sea deep convection to external freshwater forcing using GFDL's Coupled Model version 4 (CM4). This study investigates whether an alternative relationship exists between changes in the AMOC and Labrador Sea deep convection under external freshwater forcing, as well as how changes in the Iceland-Scotland Overflow (ISO) influence deep convection in the Labrador Sea.

Using water-hosing experiments in which external freshwater forcing is applied over the southern Nordic Sea in the GFDL CM4 modern-period simulation, the authors found that the decline in the subpolar AMOC is primarily driven by changes in the eastern component, rather than in the western component across the Labrador Sea (Fig. a). Unlike previous studies linking AMOC weakening to subsurface warming and reduced Labrador Sea deep convection, this study associates AMOC decline with subsurface cooling and strengthened Labrador Sea deep convection (Fig. b) in response to external freshwater forcing. This strengthening of Labrador Sea deep convection is linked to enhanced freshening in the deep Labrador Sea, resulting from the weakening and freshening of the ISO entering the region. As the deep ISO layer in the Labrador Sea becomes fresher and lighter, the vertical stratification decreases, allowing for a stronger deep convection. However, this strengthening of Labrador Sea deep convection (Fig. b) is not a driver of the AMOC decline (Fig. a).

Many climate models struggle to accurately represent the deep ISO layer in the Labrador Sea. However, GFDL's CM4 includes an enhanced representation of this feature, enabling the simulation of how ISO variability affects deep convection in the Labrador Sea. These findings advance the understanding of mechanisms driving AMOC changes and highlight the role of ISO in Labrador Sea deep convection dynamics under external freshwater forcing.

OAR Goals: Make Forecasts Better, Drive Innovative Science, Detect Changes in the Oceans and Atmosphere

Anomalies of the Atlantic Meridional Overturning Circulation (AMOC) across the subpolar section monitored by the Overturning in the Subpolar North Atlantic Program (OSNAP) and Labrador Sea March mixed layer depth (MLD) in response to external freshwater forcing



(a) Time series of anomalies in the maximum AMOC across the entire OSNAP section (black line; approximately 53°–60°N), OSNAP West extending from southern Labrador to the southwestern tip of Greenland (blue line; approximately 53°–60°N, 45°–60°W), and OSNAP East extending from the southeastern tip of Greenland to Scotland (red line; approximately 53°–60°N, 15°–45°W) in density space. (b) Time series of March MLD anomalies in the Labrador Sea. Both series (a, b) use an 11-year running mean. The decline in the subpolar AMOC (black line) is primarily driven by changes in the eastern component (red line), rather than the western component (blue line). As the deep Iceland-Scotland Overflow (ISO) layer entering the Labrador Sea becomes fresher and lighter, vertical stratification decreases, allowing for stronger deep convection in the Labrador Sea (b).

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Seasonal predictions of summer compound humid heat extremes in the southeastern United States driven by sea surface temperatures

npj Climate and Atmospheric Science *Liwei Jia[1], Thomas L. Delworth[1], Xiaosong Yang[1], William Cooke[1], Nathaniel C. Johnson[1], Liping Zhang[2], Youngji Joh[3], Feiyu Lu[2], Colleen McHugh[4]*

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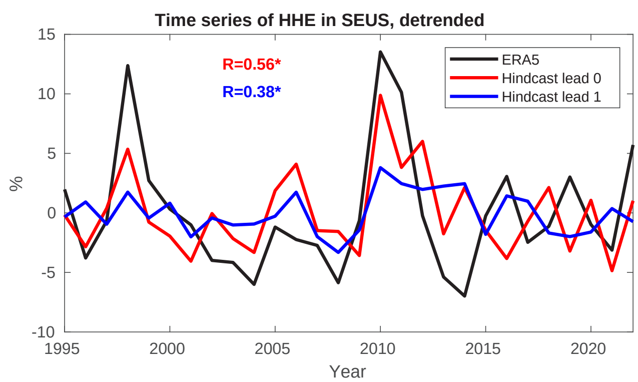
Humid heat extremes (HHE) occur when high temperatures coincide with high humidity, posing a risk as it affects the body's ability to dissipate heat. These compound extreme events have been increasing in frequency, as observed in both climate records and model simulations, and are projected to continue rising. Understanding the predictability of HHE is essential for developing early warning systems, yet most studies have focused on future projections rather than near-term prediction. Jia et al. evaluated the seasonal predictability of summertime HHE in the southeastern United States (SEUS) using GFDL's Seamless System for Prediction and EArth System Research (SPEAR). Rather than analyzing individual extreme events, the researchers examine the frequency of HHE occurrences during the summer season (June–August) and assess the skill of retrospective forecasts made on May 1 and June 1.

The findings indicate that SPEAR can skillfully predict the frequency of HHE occurences during June-August in the SEUS when forecasts are made on May 1 and June 1. It also identifies sea surface temperatures (SSTs) in the tropical North Atlantic (TNA) as a key driver of this predictability. Warmer-than-average SSTs in the TNA influence large-scale atmospheric circulation patterns that facilitate the transport of heat and moisture from the Gulf of Mexico into the SEUS, increasing the likelihood of HHE. Slowly varying ocean conditions play a key role in modulating atmospheric patterns, providing a basis for short-term seasonal forecasting of HHE. This research addresses a gap in understanding the near-term predictability of HHE, with potential applications for early warning systems to mitigate the impacts of extreme heat.

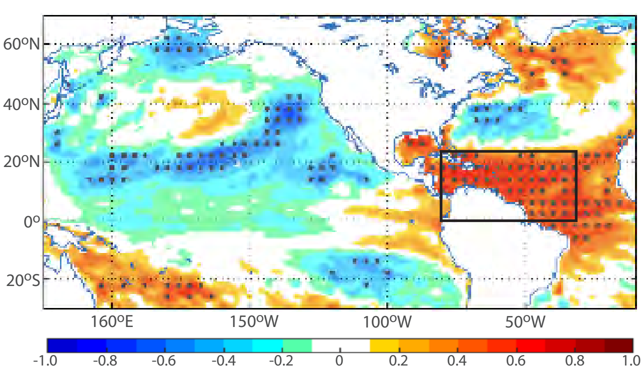
OAR Goals: Make Forecasts Better

The Frequency of Humid Heat Extremes during June-August in the Southeastern United States is Skillfully Predicted when Retrospective Forecasts are Made on May 1 and June 1



Linearly detrended time series of humid heat extreme (HHE) frequency during June–August (JJA), averaged over the southeastern United States (SEUS; 23°–38°N, 77°–100°W), based on ERA5 reanalysis (black), SPEAR hindcasts initialized on June 1 (0-month lead retrospective forecasts for JJA; red), and hindcasts initialized on May 1 (1-month lead retrospective forecasts for JJA; blue). Correlation coefficients between ERA5 and hindcast HHE frequencies are indicated, with asterisks denoting statistical significance at the 5% level.

Sea Surface Temperatures in the Tropical North Atlantic Basin are the Primary Driver of Seasonal Predictions of Humid Heat Extremes in the Southeastern United States



Correlations between linearly detrended June–August (JJA) mean sea surface temperatures (SSTs) and the linearly detrended frequency of JJA humid heat extremes (HHE) averaged over the southeastern United States (SEUS) in SPEAR hindcasts made on June 1. Dotted regions indicate correlation coefficients that are locally significant at the 5% level based on the t-test. The black box highlights the tropical North Atlantic (0°–23°N, 80°–35°W), where SSTs exhibit strong correlations with HHE frequency in the SEUS.

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GFDL SCIENTISTS IN THE SPOTLIGHT

Dr. John Dunne Named to Clarivate's 2024 Highly Cited Researchers List

Dr. John Dunne, Supervisory Research Oceanographer and head of GFDL's Earth System Processes and Interactions Division, was named to Clarivate's 2024 list of Highly Cited Researchers. This recognition identifies scientists whose published work over the past decade ranks among the top 1% of citations in the Web of Science, highlighting their significant influence on their fields. As one of only five NOAA scientists included on the 2024 list and the sole representative from GFDL, Dr. Dunne's research focuses on advancing the understanding of ocean and climate systems, with applications in marine biogeochemistry, ecosystem dynamics, and coupled carbon-chemistry-climate modeling. His work aims to improve predictions and projections of climate variability and change, as well as their feedbacks and impacts on Earth systems.

Dr. Nadir Jeevanjee Awarded the Presidential Early Career Award for Scientists and Engineers

Dr. Nadir Jeevanjee, a Physical Research Scientist in GFDL's Atmospheric Physics Division, has been awarded the 2021–2022 Presidential Early Career Award for Scientists and Engineers (PECASE). Established in 1996, this prestigious honor is the highest award by the U.S. government to early-career scientists and engineers, recognizing their contributions to advancing science and technology while addressing societal and global challenges. Dr. Jeevanjee's research focuses on cloud physics, convection, and radiative transfer, with applications in weather and climate modeling. He has applied high-resolution cloud-resolving models to investigate how convection and cloud dynamics interact with radiative cooling, offering new insights into their influence on large-scale atmospheric circulation. Dr. Jeevanjee is also actively engaged in mentoring students and scientific outreach.