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

SEASONAL PREDICTION OF NORTH AMERICAN WINTERTIME COLD EXTREMES IN THE NOAA/GFDL SPEAR FORECAST SYSTEM

Climate Dynamics *L. Jia[1,2], T.L. Delworth[2], X. Yang[2], W. Cooke[2], N.C. Johnson[2], C. McHugh[2,3], F. Lu[4]*

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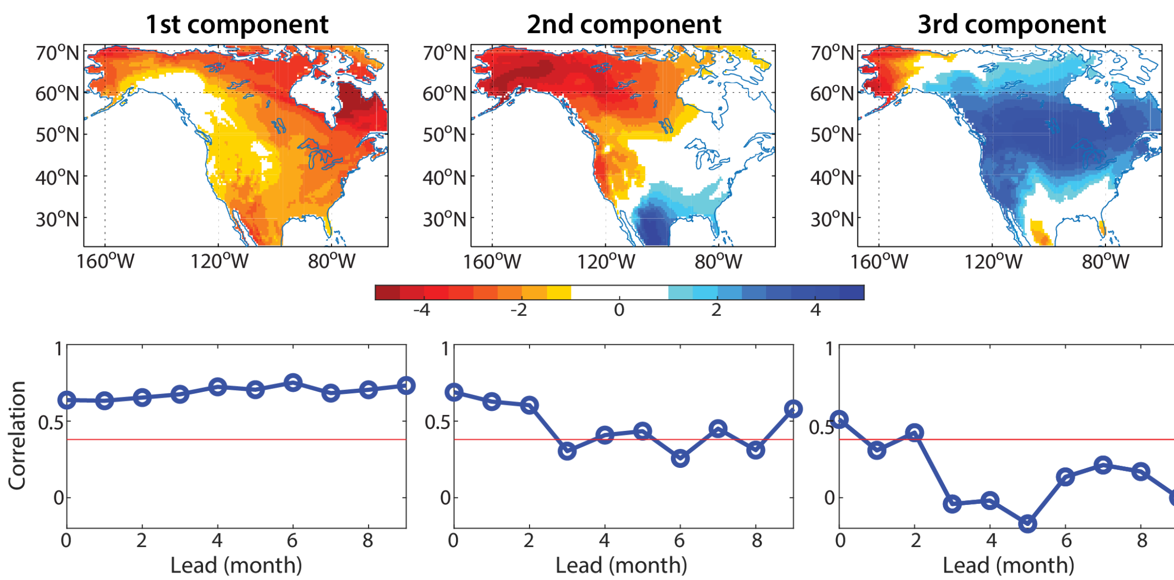
In the realm of seasonal forecasting, the accurate prediction of wintertime cold extremes holds significant value across numerous societal and economic sectors. A recently published study by GFDL researchers highlights the impressive prediction of North American winter cold extremes several months in advance. The study identifies three key components contributing to this forecast skill, utilizing the GFDL's Seamless system for Prediction and EArth system Research (SPEAR) climate model.

The first component reveals a continent-wide decrease in the frequency of cold extremes during winter, primarily attributed to radiative forcing. Predicting this component up to nine months ahead, offers essential insights for proactive measures. Another component features a dipole structure over North America, exhibiting notable correlation skill for up to two months and closely linked to the central Pacific El Niño-Southern Oscillation (ENSO). ENSO plays a pivotal role in influencing the spatial distribution of cold extremes, making this component a valuable tool for seasonal forecasting. The third component shows significant correlations with snow anomalies over mid-to-high latitudes of the North American continent. Understanding this connection between snow cover and cold extremes aids in improving the accuracy of winter extremes predictions.

By refining forecasts accounting for these three predictable components, the SPEAR system exhibits higher/comparable skill compared to raw forecasts, offering potential benefits for stakeholders relying on precise and timely information to take precautions, and manage and allocate resources effectively. Leveraging advanced forecasting models like SPEAR enhances the resilience against extreme winter events. The research underscores the importance of cutting-edge science-based forecasting systems, utilizing reliable seasonal forecasts for implementing effective resource allocation, disaster preparedness plans, and policy measures. Protecting communities and vital infrastructure during extreme cold events ensures greater resilience against changing climate.

OAR Goals: Make Forecasts Better, Drive Innovative Science

Three predictable components of the frequency of winter cold days in North America



The spatial patterns (Units: %) and rank correlation skill of three predictable components of the frequency of winter cold days in North America. The horizontal lines in bottom panels indicate the 95% confidence level.

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A GLOBAL SURVEY OF ROTATING CONVECTIVE UPDRAFTS IN THE GFDL X-SHiELD 2021 GLOBAL STORM RESOLVING MODEL

Journal of Geophysical Research: Atmospheres

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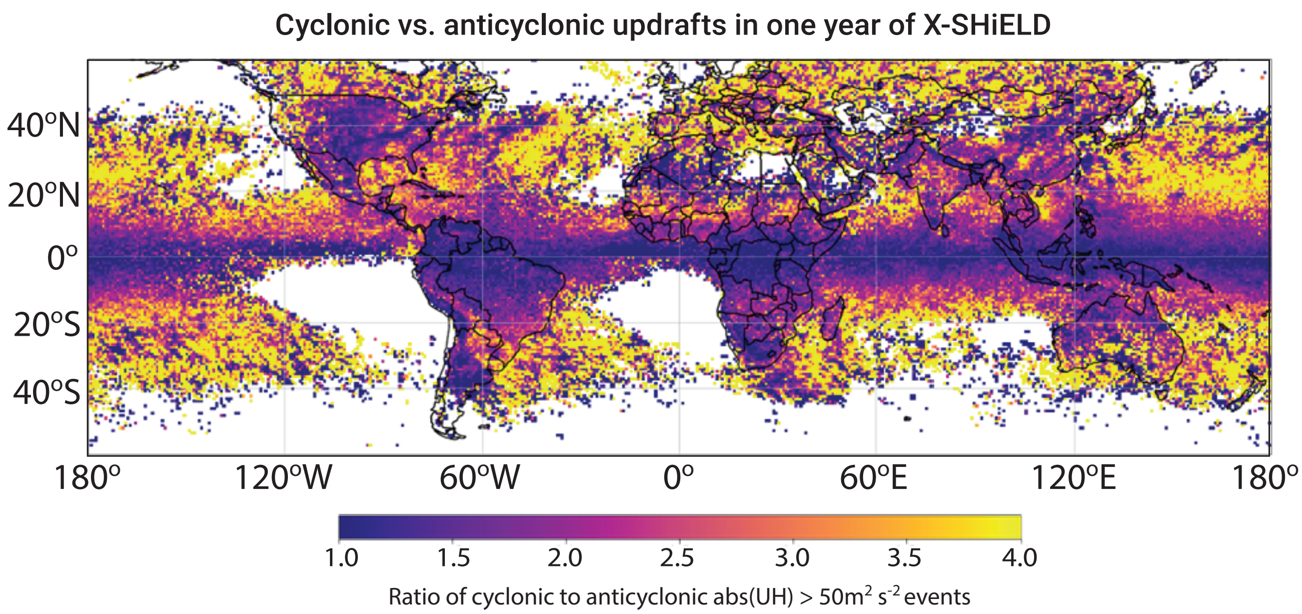
Rotating thunderstorms are some of nature's most powerful storms and can cause destructive tornadoes, hail, and winds. However, these spinning updrafts have remained relatively unexplored beyond the central United States, where tornado research is concentrated, and almost exclusively in the context of severe weather. A recent study by GFDL scientists has uncovered a previously hidden aspect of thunderstorm dynamics – the global prevalence of rotating updrafts. Using the innovative X-SHiELD atmospheric model*, GFDL scientists simulated individual thunderstorm updrafts and their rotation on a global scale for the first time, for an entire year. This is not possible with traditional global climate models that are unable to represent these individual storms. Contrary to previous assumptions, the modeling study revealed that rotating updrafts are widespread, occurring frequently over tropical oceans, mid-latitude continents, and other warm regions. This finding challenges the notion that rotating storms are confined solely to severe weather.

The research also highlighted the intricate relationship between thunderstorm rotation and Earth's rotation. Thunderstorm rotation is influenced by a complex interplay between large-scale weather systems and the behaviors of individual thunderstorms. Notably, counterclockwise rotations predominate in the northern hemisphere, but weaker clockwise rotations are frequent especially over continents and in the equatorial oceans. Conversely, the southern hemisphere exhibits the opposite trend. While the study of rotating updrafts has predominantly concentrated on severe weather contexts, their prevalence beyond these scenarios remains largely unknown due to limited observations outside of the contiguous United States. However, the authors suggest that the use of advanced radar systems and innovative modeling techniques like X-SHiELD, could yield insights into the frequency and properties of rotating updrafts, even under non-severe conditions.

The impact of this discovery extends beyond immediate weather impacts. Rotating updrafts provide invaluable insights into the life cycle of thunderstorms and their interactions with the large-scale environment. This newfound knowledge proves consequential not solely for regions vulnerable to severe weather, but also for tropical waves, tropical cyclones, and air-mass convection. While uncertainties exist concerning model representation and interannual variability, this study shows what global storm-resolving models such as X-SHiELD are capable of as they advance a global perspective on rotating convection illuminating intricate aspects of Earth's weather patterns. As researchers continue to leverage these innovative capabilities, further hidden intricacies and finer structures of the planet's storm features may be unraveled.

*Cheng et al., August 2022: Impact of warmer sea surface temperature on the global pattern of intense convection: Insights from a global storm resolving model. *Geophysical Research Letters*, 49(16), DOI:10.1029/2022GL099796.

OAR Goals: Drive Innovative Science



A global view: The ratio of cyclonic (counter-clockwise in the northern hemisphere, clockwise in the southern hemisphere) to anticyclonic thunderstorms. It is clear that the ratio gets larger the farther away from the equator, and is relatively lower over the continents.

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THE LONG-TERM TRENDS OF GLOBAL LAND PRECIPITATION IN GFDL's CM4 AND ESM4 CLIMATE MODELS

Journal of Climate *Y. Zhang[1], T.R. Knutson[2], E. Shevliakova[2], D. Paynter[2]*

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Global land precipitation is an integral part of the hydrological cycle and climate system, influencing various aspects from freshwater resources to agricultural productivity, ecosystems, and human well-being. Understanding how global land precipitation has changed historically and predicting its future variations is vital. Climate models representing the Earth's atmospheric, oceanic, land, and ice behaviors, provide a method to explore land precipitation changes. For example, NOAA/GFDL's CM4, which emphasizes the physical features of the climate system, and ESM4, which includes in addition biogeochemical cycles and interactive carbon-climate feedback, can simulate past, present, and future climate changes. Historical precipitation trends produced by such models can be compared to the observed trends to evaluate the accuracy of the simulations. The authors compare the simulations of historical precipitation trend (1915-2014) over global land areas – when forced by the best estimates of climate forcing agents – to observational data over the same time period.

An important feature of observed precipitation trends from 1915-2014 is the strong increase in annual mean precipitation over northern hemisphere mid- to high-latitude land regions. However, the models struggle to capture the magnitude of these upwards trends. Figure (a) illustrates the comparison between observed trends (top panel) vs. the ESM4 climate model (middle panel). Figure (b) shows precipitation averaged over the latitude band 45°N-80°N. The observations show a significant increase, while the model outputs indicate a strong decline in precipitation from about 1945-1975 that is not seen in the observations. Alternative simulations driven solely by anthropogenic aerosol change display a steep decline during the same period when the model with all historical forcings diverges from the observed trend. In contrast, simulations using only greenhouse gas changes mirror the observed long-term positive trend. Overall, the analysis suggests that excessive aerosol forcing and/or exaggerated aerosol responses within the models are likely explanations for the underestimate of the observed precipitation trends over this region, though other processes may also have contributed to the model-observation differences. The authors identified other types of model discrepancies in other regions. For global-mean precipitation over land, there was little trend in observations, but a decreasing trend in the models' All-Forcing historical runs, as typified by the aerosol-related decreases in the East Asia/China region.

These findings indicate that the ESM4 and CM4 models need enhancements to better simulate historical precipitation trends over the northern mid-to-high latitudes. Precipitation trends and multi-decadal variability in various regions serve as important indicators of the models' performance regarding long-term trends/variability for climate change metrics with high societal implications (e.g., precipitation trends and variability, links to shifts in drought and flood risk over time). The study underscores the essential role of climate models like CM4 and ESM4 in understanding global land precipitation trends and simulating their past and future evolution.

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

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Observed vs. Modeled Precipitation Trends (1915-2014)

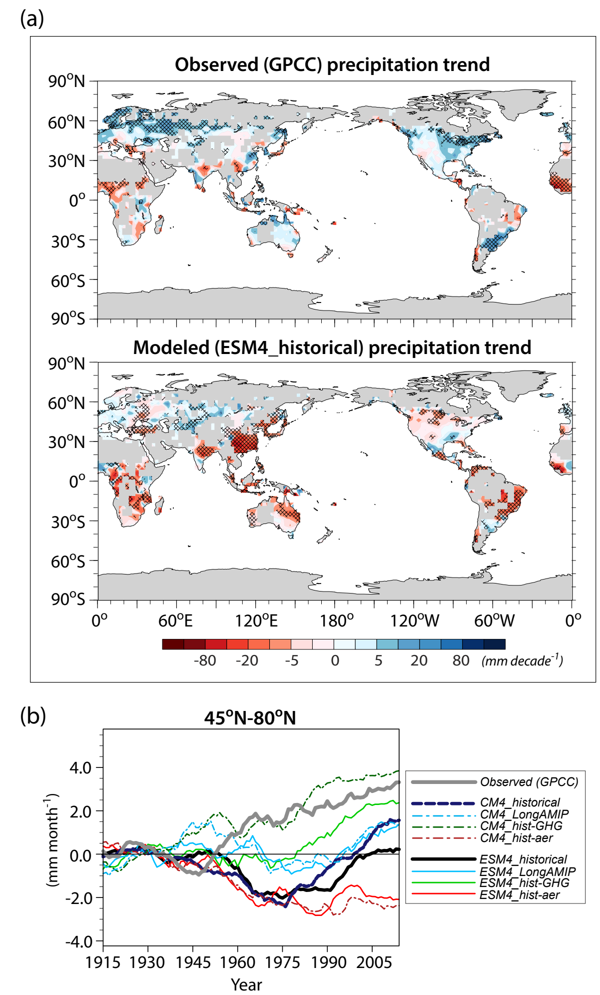

Fig. (a) *Precipitation trends (1915-2014) over land regions with adequate temporal coverage for trend calculation, based on GPCC observations (top) and the GFDL ESM4 climate model (middle). Blue and red colors denote increasing and decreasing trends, respectively. The cross-hatching indicates where the observed or simulated trends are statistically significant (p=0.05).* ***Fig. (b)*** *Precipitation anomalies averaged over the latitude band 45°N-80°N, relative to early 20th century mean values. Gray line: GPCC observations; Black, Red, Blue, and Green lines: Historical simulations using all climate forcings (Black); anthropogenic aerosols only (Red): greenhouse gas concentration changes only (Green); and natural forcing from volcanic eruptions and solar variability only (Blue). Solid and dashed lines are from the GFDL ESM4 and CM4 models.*

PROCESS-ORIENTED DIAGNOSTICS: PRINCIPLES, PRACTICE, COMMUNITY DEVELOPMENT AND COMMON STANDARDS

Bulletin of the American Meteorological Society

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As climate models grow in resolution and complexity, accurately representing key climate phenomena and their underlying processes becomes increasingly important. As the demand for products from climate simulations grows, it is essential that these models produce the “right results” for the “right reasons.” At the core of this effort lies a need to transcend traditional performance-based metrics and gain deeper insights into the physical processes driving model behavior through process-oriented diagnostics (PODs). In response to these challenges, NOAA’s Model Diagnostics Task Force (MDTF) is strategically developing Process Oriented Diagnostics (PODs) to unravel the physical underpinnings behind model biases. The cornerstone of the MDTF framework is collaboration between academic and modeling centers, enabling model developers to access a rich diagnostics repository. Led jointly by UCLA, NOAA/GFDL, and NCAR, and with funding from NOAA/CPO, the task force has included representation from leading academic institutions since 2015.

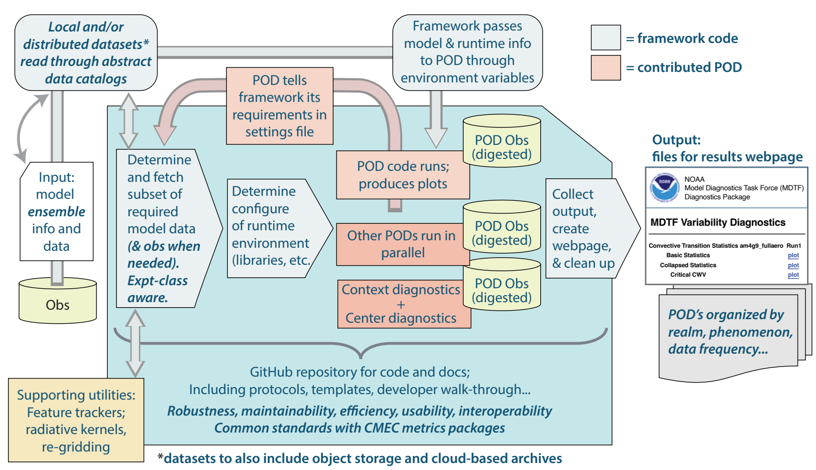
The MDTF effort, currently in its third phase, has an established suite of PODs focusing on weather and climate processes including variability. Results from the MDTF PODs of NCAR’s Community Atmospheric Model CAM5 and CAM6 simulations demonstrate improvements in the phasing of the diurnal precipitation cycle from one generation of the model to the next. Similarly, the MDTF PODs show improved strength and eastward propagation in the Madden Julian Osciallian (MJO) in GFDL’s latest generation fully coupled models (Climate Model 4 and Earth System Model 4) compared with the atmosphere-only model. The process-oriented approach is not unique to analyzing precipitation or atmospheric processes and that the rest of the climate system would benefit from the process-oriented approach. Rather than functioning as isolated efforts, these PODs are designed to integrate with the needs of the modeling centers, enabling their incorporation into the model development workflows. A grass-roots collaboration between the MDTF effort and the Department of Energy’s Coordinated Metrics and Evaluation Capabilities (CMEC) has generated a set of common model diagnostic standards and protocols aimed at standardizing many elements of diagnostic development. These common standards, adopted by both the MDTF and CMEC, are geared toward making the transfer and application of diagnostics and PODs to new frameworks and workflows more straightforward. Utilizing the process-oriented diagnostic approach offers unique avenues for delving deeper into the insights of climate models. Through these collaborative efforts between model developers and process-level experts, the resulting diagnostics shed light on the intricate mechanisms shaping model behavior. Identifying discrepancies between observations and model simulations – and more importantly, answering the question as to “why” models behave the way they do – are necessary to improve future climate projections. This is essential to make model projections more robust and reliable for end users.

OAR Goals: Explore the Marine Environment, Detect Changes in the Ocean and Atmosphere, Make Forecasts Better, Drive Innovative Science

Schematic of the MDTF Framework: Connecting Models and Observations through Process-Oriented Diagnostics

The diagram illustrates how the NOAA Model Diagnostics Task Force (MDTF) is integrating specialized diagnostic tools (PODs) into climate modeling.

By creating standardized protocols for information sharing, MDTF enables diagnostic developers to collaborate seamlessly. This approach enhances comprehensive understanding of physical processes in climate models.



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