FINAL REPORT

Useful Prediction of Climate Extreme Risk for Texas-Oklahoma at 4-6 Years

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The southern United States, particularly Texas and Oklahoma, has experienced intensified spring rainstorms and summer hurricanes in recent years, leading to increased frequency of extreme rainfall and flood risks. This project aimed to improve the understanding and predictive capability of hydroclimatic extremes affecting Department of Defense assets in the region.

The project had two main objectives:
1. Explore physical processes enabling decadal prediction for precipitation extremes
2. Analyze past/future conditions at high resolution for specific sites

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Executive Summary

This project aimed to improve the understanding and predictive capability of hydroclimatic extremes affecting Department of Defense (DoD) assets in the southern United States, particularly Texas and Oklahoma. The project explored physical processes enabling decadal prediction for climate extremes and analyzed past/future conditions at high resolution for specific sites. The technology approach involved using global climate models, regional downscaling, and partial assimilation experiments to assess the predictability of ENSO cycles and associated impacts on southern states. The project yielded two key publications, with Chang et al. (2023) demonstrating that dynamical downscaling using convective-permitting Weather Research and Forecast (WRF) model significantly improves the representation of heavy precipitation events, and the relative strength of the subtropical jet stream versus the polar jet stream influences whether Texas experiences wet or dry conditions. Chikamoto et al. (in revision) provided a critical review of a study investigating the role of tropical inter-basin interactions in driving late-spring precipitation variability over the Southern Great Plains. The project's findings can help improve the predictability of climate extremes in the southern U.S., benefiting DoD installation management and decision-making for resource allocation and risk assessment. A SERDP and ESTCP webinar titled "Predicting Climate Risks to Improve Resilience" was held on February 8, 2024, to disseminate the project's findings and engage with the broader community working on climate resilience and adaptation.

Introduction

The southern United States, particularly Texas and Oklahoma, has experienced intensified spring rainstorms and summer hurricanes in recent years, leading to increased frequency of extreme rainfall and flood risks. This project aimed to improve the understanding and predictive capability of hydroclimatic extremes affecting Department of Defense (DoD) assets in the region.

Objectives

The project had two main objectives:

1. Explore physical processes enabling decadal prediction for precipitation extremes

2. Analyze past/future conditions at high resolution for specific sites

Technical Approach

The project utilized the following approaches:

- Used NCAR's Community Earth System Model (CESM) to assess predictability of the 4-6-year ENSO cycle and associated impacts on extreme precipitation risks in southern states

- Utilized partial assimilation experiments to identify and quantify impacts of model biases, systematic errors of inter-basin interactions, and climate sensitivity on tropical Pacific climate predictability

- Examined the role of ocean memory outside the ENSO region in prediction performance

- Utilized Weather Research and Forecast (WRF) model for dynamic downscaling of CESM data to assess distribution and intensity of spring storms at convective-permitting resolutions

Results and Discussion

The project yielded two key publications that significantly advance our understanding of the predictability of hydroclimatic extremes in the southern United States and the role of ocean-atmosphere interactions in driving precipitation variability.

1. Chang et al. (2023) in Journal of Geophysical Research: Atmospheres:

This study demonstrated the value of dynamical downscaling using convective-permitting Weather Research and Forecast (WRF) model in improving the representation of heavy precipitation events compared to coarser resolution global climate models like the Community Earth System Model (CESM). By using a high-resolution regional model with a grid spacing of 4 km, the study was able to capture the spatial patterns and intensity of extreme precipitation during the Texas flooding event of May 2015 and the drought onset in May 2011 much more accurately than the driving CESM simulations.

The study also identified the relative strength of the subtropical jet stream and the polar jet stream as a key factor influencing whether Texas experiences wet or dry conditions. When the subtropical jet is stronger than the polar jet, it facilitates the transport of moist air from the Gulf of Mexico into Texas, increasing the likelihood of heavy precipitation events. Conversely, when the polar jet is stronger, it tends to bring dry air from the north, leading to drier conditions in Texas.

Furthermore, the study showcased the efficiency of using a combination of low-resolution CESM with ocean data assimilation and high-resolution WRF simulations in potentially extending the predictability of extreme precipitation at subseasonal-to-seasonal timescales. By leveraging the strengths of both global and regional models, this approach can provide more accurate and reliable predictions of hydroclimatic extremes, which can benefit decision-making for resource allocation and risk assessment.

2. Chikamoto et al. (in revision):

This study provided a critical review of a separate study investigating the role of tropical inter-basin interactions in driving late-spring precipitation variability over the Southern Great Plains. The original study found that the contrast in sea surface temperature anomalies between the tropical Pacific and Atlantic has a higher correlation with April-June rainfall over Texas compared to the December-January Nino3.4 index, suggesting that tropical inter-basin interactions may be important predictors of precipitation variability in this region.

Chikamoto et al. offered several suggestions to strengthen the original study's findings and implications. They recommended discussing the implications of not removing linear trends from the North American Multi-Model Ensemble (NMME) dataset, as the validation period (1982-2020) includes decades with significant increasing trends in surface and ocean temperatures. They also suggested including an assessment of the precipitation hindcast skill of the NMME models for the April-June season over Texas and composite maps of rainfall anomalies for years overlapping with the observed composites. Chikamoto et al. also proposed exploring how the value added by using a downscaling approach to better resolve convective events might be tied to the work presented in the original study. This suggestion aligns with the findings of Chang et al. (2023), which demonstrated the benefits of dynamical downscaling using convective-permitting models in improving the representation of heavy precipitation events.

In addition to these two key publications, our project further investigated the hard-core dynamics of ENSO and its predictability. Borhara and Wang (2024; in review) documented a series of warm and cold sea surface temperature anomalies (SSTAs) propagating from the western North Pacific to the central-eastern equatorial Pacific over the course of 2-3 years, culminating in the development of El Niño and La Niña events, respectively. The study proposed that the propagation is related to the asymmetry of the North Pacific Subtropical Gyre and its shifting in and out of geostrophic equilibrium. The slow, broad, and shallow eastern boundary current of the gyre facilitates the prolonged propagation across the basin, while the equatorward flow is influenced by the wind stress curl, Coriolis deflection, and the sea surface height gradient from the subtropics to the tropics. As the SSTAs originating from the western North Pacific are always either at or near geostrophic equilibrium, their persistence can extend ENSO prediction up to 3 years in advance.

Furthermore, Borhara et al. (2023) investigated the role of the western North Pacific (WNP) as an ENSO precursor in a warmer future climate. The study applied a conditional probability approach and sea surface temperature budget analysis on historical and Shared Socioeconomic Pathway 3-7.0 (SSP370) model runs. The results showed that with enhanced warming, cold WNP SST anomalies in the boreal winter further strengthen summer westerly anomalies in the western equatorial Pacific, which promote the intensification of surface convergence, anomalous Ekman and geostrophic advection, and positive SST anomalies in the central equatorial Pacific in the seasons prior to the El Niño. Downwelling equatorial Kelvin waves induced by the westerly wind stress facilitate entrainment of subsurface water into the mixed layer during the transition period, triggering stronger thermocline feedback in the central-eastern equatorial Pacific. Consequently, the amplitude and frequency of El Niño and its tropical precursors are projected to increase with warming under the WNP influence. The study also found that the intensification of positive Pacific Meridional Mode (PMM) southwesterlies during the WNP-ENSO transition suggests a strengthened three-way link between WNP, PMM, and ENSO under enhanced warming, which may promote stronger and/or more frequent El Niños.

These studies highlight the importance of understanding the role of extratropical precursors and ocean gyre dynamics in improving long-lead ENSO predictions, as well as the potential changes in ENSO dynamics and predictability under future warming scenarios. Moreover, two supplemental papers, “Ocean Temperatures Do Not Account for a Record-Setting Winter in the U.S. West” by LaPlante et al. (2024) and “Enhanced jet stream waviness induced by suppressed tropical Pacific convection during boreal summer” by Sun et al. (2022), provide valuable insights into teleconnection dynamics and predictability, supporting the objectives of this project. LaPlante et al. (2024) demonstrate that the record-setting winter of 2022-2023 in the Upper Colorado River Basin did not align with the typical patterns of tropical ocean temperatures associated with high-snowpack winters in the region, suggesting that stochastic variability plays a significant role in influencing water availability, even in extreme years. Sun et al. (2022) suggest that the suppression of tropical convection along the Inter Tropical Convergence Zone, induced by sea surface temperature cooling trends over the tropical Eastern Pacific, contributed to the increased summertime midlatitude waviness in the Northern Hemisphere over the past 40 years through the generation of a Rossby-wave-train propagating within the jet waveguide and the reduced north-south temperature gradient, with less influence from Arctic amplification than previously estimated.

Implications for Future Research and Benefits

The project's findings can help improve the predictability of climate extremes in the southern U.S. by leveraging global climate models, regional downscaling, and partial assimilation experiments. The enhanced understanding of ocean-atmosphere interactions and high-resolution insights can benefit DoD installation management and decision-making for resource allocation and risk assessment. However, to fully realize the potential of these hard-earned theoretical and modeling breakthroughs, continued research is necessary to put them into practical use. It is crucial to maintain the momentum and develop interactive social media and chatbot platforms to effectively deliver crucial prediction information to stakeholders, decision-makers, and the general public.

The integration of advanced language models, such as Claude or ChatGPT, can revolutionize the way weather and climate outlooks are disseminated and utilized for installation management and decision-making. These AI-powered chatbots can provide personalized, context-aware information by combining data from various sources, including weather forecasts, climate predictions, and installation-specific details. By engaging in natural language conversations, these platforms can make complex scientific information more accessible and understandable to a wider audience. For instance, a decision-maker at a DoD installation could interact with a chatbot to inquire about the potential impacts of an upcoming El Niño event on their specific location. The chatbot would draw upon the latest research findings, such as those from Borhara and Wang (2023) and Borhara et al. (2023), to provide a tailored assessment of the risks and recommend appropriate preparedness measures. This interactive approach can facilitate more informed and proactive decision-making, ultimately enhancing the resilience of DoD installations to climate extremes. Moreover, social media platforms can be leveraged to disseminate timely and actionable information to a broad audience. By integrating cutting-edge research findings into engaging and easily digestible content, such as infographics, videos, and interactive visualizations, the project's outcomes can reach a larger audience and foster greater public awareness and engagement with climate-related issues.

Moving forward, while the project has made significant strides in advancing our understanding of climate extremes and their predictability, it is essential to continue pushing the boundaries of research and innovation. The benefits of utilizing AI-driven chatbots and social media platforms extend beyond the DoD context. These tools can also support the development of more effective early warning systems, improve risk communication, and facilitate the co-production of knowledge between scientists, policymakers, and local communities. By bridging the gap between research and practice, these innovative approaches can contribute to building a more climate-resilient society. Investing in the development and deployment of these cutting-edge tools will be crucial in strengthening our ability to anticipate, prepare for, and respond to the challenges posed by a changing climate.

Outreach Activity

A SERDP and ESTCP webinar titled “Predicting Climate Risks to Improve Resilience” was held on February 8, 2024. The webinar disseminated the project’s findings and engaged with the broader community of scientists, infrastructure managers, and decision-makers working on climate resilience and adaptation. The co-PI, Mr. Matthew LaPlante, presented the results of the project (RC20-3056), highlighting the stable signals identified at four-to-six years ahead of periods of drought and deluge in Texas and Oklahoma, and the potential for increased predictability due to strengthening connections between these cycles and ocean temperature oscillations.

Recording available at ttps://serdp-estcp.mil/toolsandtraining/details/dcc871c3-1194-45f2-855b-f376399e0cdf/predicting-climate-risks-to-improve-resilience

Conclusions and Implications for Future Research/Implementation

This project advanced the predictability of climate extremes in the southern U.S. by integrating global climate models, regional downscaling, and partial assimilation experiments. The findings provide valuable insights into ocean-atmosphere interactions and high-resolution projections that can inform DoD installation management and decision-making. To build upon these accomplishments and ensure the effective dissemination and utilization of the project's outcomes, we propose a follow-on project for future research focusing on the development of AI-driven platforms for risk communication and decision support.

The proposed research aims to leverage the advancements made in this project by integrating the refined models, expanded regional analyses, and predictive tools into an AI-powered, user-friendly platform that facilitates the dissemination of crucial risk information to stakeholders, decision-makers, and the general public. The platform will incorporate advanced language models, such as Claude or ChatGPT, to provide personalized, context-aware information by combining data from various sources, including weather forecasts, climate predictions, and installation-specific details. By engaging in natural language conversations, the platform will make complex scientific information more accessible and understandable to a wider audience, ultimately enhancing the resilience of DoD installations to climate extremes.

The follow-on project could focus on the following key objectives:

1. Develop an AI-driven platform that integrates the project's findings, models, and predictive tools to provide tailored risk assessments and recommendations for DoD installations and decision-makers.

2. Conduct user-centered research to identify the specific needs, preferences, and challenges of stakeholders in accessing and utilizing climate risk information, ensuring the platform's design and functionality align with their requirements.

3. Collaborate with DoD partners to pilot the platform at selected installations, gathering feedback and evaluating its effectiveness in supporting climate-resilient decision-making and resource allocation processes.

4. Develop a comprehensive dissemination strategy that leverages social media, interactive visualizations, and engaging content to raise public awareness and foster greater engagement with climate-related issues.

Pursuing this follow-on project can bridge the gap between research and practice, ensuring that the valuable insights gained from this project are translated into tangible benefits for the DoD and society at large. The feasibility and potential of such a follow-on project have been demonstrated through our pilot study, "Feasibility of Adding Twitter Data to Aid Drought Depiction: Case Study in Colorado" by Mukherjee et al. (2022). This study investigated the use of social media data, specifically Twitter, in conjunction with meteorological records to improve the detection and monitoring of drought progression. By applying machine learning techniques, the study found that integrating Twitter data with meteorological records enhanced the prediction of drought severity compared to models that did not include social media input, highlighting the potential of leveraging social media data to augment traditional data sources and improve the accuracy and timeliness of drought detection and monitoring.

By integrating the lessons learned from this pilot study and building upon the successes of the current project, the follow-on project will further advance the development of innovative tools and approaches for climate risk management. The AI-driven platform will incorporate traditional data sources and harness the power of social media data to provide more comprehensive and timely insights into the progression and impacts of drought and other climate extremes. Ultimately, this continued research will contribute to the creation of a more sustainable and secure future in the face of a changing climate, enabling the DoD and other stakeholders to make more informed and proactive decisions in the face of climate-related risks, enhancing the resilience of DoD installations, and serving as a model for other organizations and communities seeking to build climate resilience in an increasingly complex and interconnected world.

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