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Scientists gain powerful tool to scrutinize changing US weather patterns

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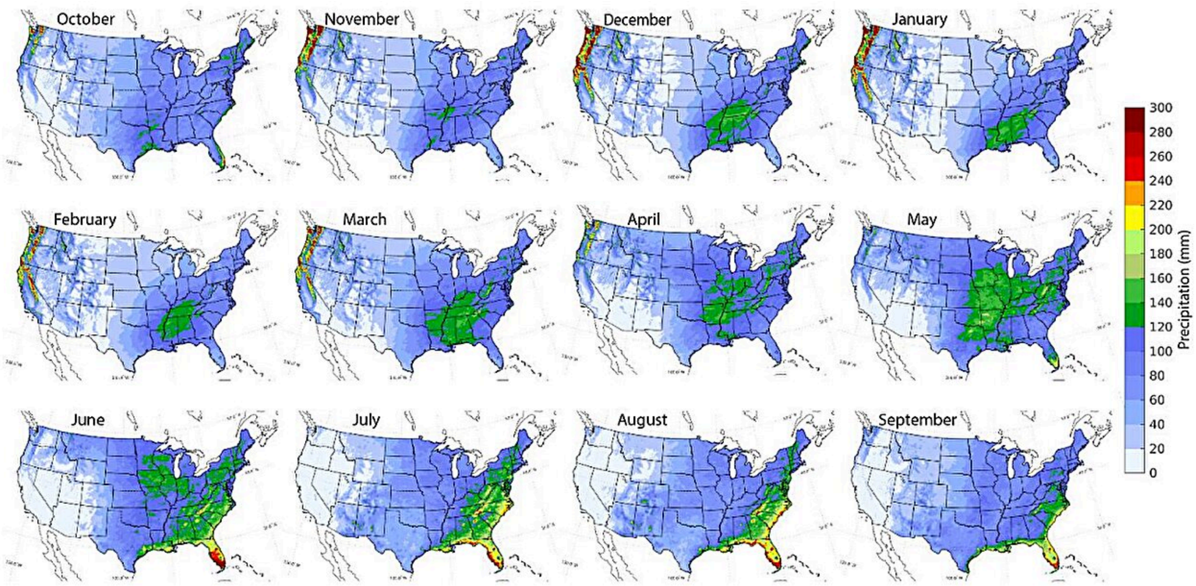

CONUS404 monthly precipitation climatology from 1986-2020. Credit: NCAR & UCAR

An extraordinary new dataset of high-resolution weather simulations that span more than four decades over the continental United States is now available to the Earth system science community.

The unprecedented resource—which required almost a year's worth of supercomputing time to create and is nearly one petabyte in size—provides rich opportunities for scientists and stakeholders interested in how weather patterns may have already shifted as the climate warms, among many other applications. For example, scientists are already using the data to dig into new techniques for improving long-range forecasting, planning for water resource allocation, and to better understand the causes and impacts of extreme and rare weather events.

The dataset, known as CONUS404, is the result of a collaboration between the National Center for Atmospheric Research (NCAR) and the U.S. Geological Survey (USGS).

"To study rare and extreme weather events that we are really interested in, you need decades worth of data and that data need to be at high resolution," said Roy Rasmussen, the NCAR senior scientist who led the project. "With CONUS404 it is possible to study both long-term events that can stretch for many years, like droughts, and rare events that don't last long but rarely occur, like extreme floods."

Filling a gap for water managers

The weather in the United States is relatively well observed by local weather stations, stream gauges, snowpack sensors, radars, weather balloons, satellites, and more. But on their own, these observations cannot always give a clear picture of how weather patterns may be changing over time. That's because the data are often regionally clumped—with sparse information on conditions in remote and rugged terrain—and unreliable. The accuracy of temperature, humidity, winds and other important weather data, for example, can be affected by instrument performance and local conditions. And measurements across different observational platforms do not always line up.

Because of these factors, scientists rely on meteorological "reanalyses" that combine observations and modeling to create datasets that provide internally consistent weather information at fixed points on a grid across an entire region or the globe. These reanalysis products are important tools for scientists. For example, they can be used to verify how well climate models are able to simulate past conditions—a crucial test for determining how well they might be doing at simulating the future. Scientists also use these products to initialize, or "kick off," model simulations with real-world conditions.

Despite the importance of reanalysis products, they are generally low resolution with about 30 kilometers (19 miles) or more between grid points—a spacing too coarse to capture relatively fine-scale weather events, like summer thunderstorms, and the local topography that impacts those events, like mountain ranges. They're also too coarse to give meaningful data about precipitation in individual watersheds, which is critical information for water managers. It's this last point that has been a particular frustration for the USGS, which is responsible for collecting and distributing information to the nation about water resources, including streamflow and groundwater data.

To address this gap, the USGS partnered with NCAR to "downscale" one of the most widely used global reanalysis datasets, called ERA5, to create a high-resolution dataset for the contiguous United States (CONUS) using NCAR's Weather Research and Forecasting model (WRF).

The resulting dataset covers more than 40 years (1980–2021) at 4-kilometer grid spacing—hence the name, CONUS404.

A weather simulation that covers such a large area over such a long time at such a high resolution has never before been possible. But several factors have come together over the last decade to make the undertaking practical, including an advancement in capabilities of both supercomputing and of weather models. Even with advances in computing, it still took more than 11 months to complete the simulation on the USGS Denali supercomputing system.

Improvements in WRF over the last few years have corrected several issues that showed up in earlier attempts to run the model at high resolution over CONUS, though for shorter time periods. One problem was that WRF tended to make the central U.S. too hot and too dry, which in turn affected the ability of the model to accurately simulate thunderstorms in the region. But the updated version of WRF includes a groundwater module that both cools and dampens the area, leading to a much more realistic simulation. The updated version also does a better job of simulating Western snowpack, which affects stream runoff and surface temperatures, and corrects a tendency in the model to make wintertime temperatures too cold in snow-covered regions.

"We're now able to capture the primary factors that are causing the weather in the real world," Rasmssen said. "We're not perfect, and we're still learning all the time, but the model does a striking job of getting the historical weather right."

Digging into the data

The paper introducing the dataset was published earlier this summer in the *Bulletin of the American Meteorological Society*, but many scientists are already digging into the data to answer their research questions. For example, the CONUS404 dataset has helped researchers uncover patterns during historical droughts that are now being used to improve seasonal drought predictions in the West.

Scientists are also looking for subtle evidence of changing weather patterns over the last few decades, including one study that has identified a shift in the way precipitation falls, from less drizzle and light rain to more downpours. Climate models have long predicted that this change should be occurring, but the low-resolution reanalysis datasets that existed up to this point were not detailed enough to pinpoint the change.

Researchers are also analyzing changes to the damaging local winds that sometimes accompany storms. Other scientists are looking at extremes in streamflow and whether CONUS404 data can be used as an input into crop models to simulate water use and food production.

While the new dataset has just begun to be tapped, the NCAR-USGS collaboration is already working on part two of the project: another 40-plus year simulation of weather across the United States, this time in the future. The scientists will be using the same methodology, but instead of downscaling a reanalysis of what has happened in the past, they'll be using data from NCAR's Community Earth System Model, version 2, (CESM2) to project what they believe conditions will be like in the future. Together, the two datasets will provide more than 80 years of simulated data that will give an unprecedented look of how our weather may continue to change as the climate warms.

"Connecting these two pieces—NCAR's climate and weather modeling—is extremely important," said NCAR scientist Andreas Prein, a co-author of the study. "We have to be smart about how we use the climate data to bring it to a scale that's useful."

CONUS404 data is freely accessible from NCAR's Research Data Archive.

More information: R. M. Rasmussen et al, CONUS404: The NCAR–USGS 4-km Long-Term Regional Hydroclimate Reanalysis over the CONUS, *Bulletin of the American Meteorological Society* (2023).
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