International research collaboration computes climate past, present, and future

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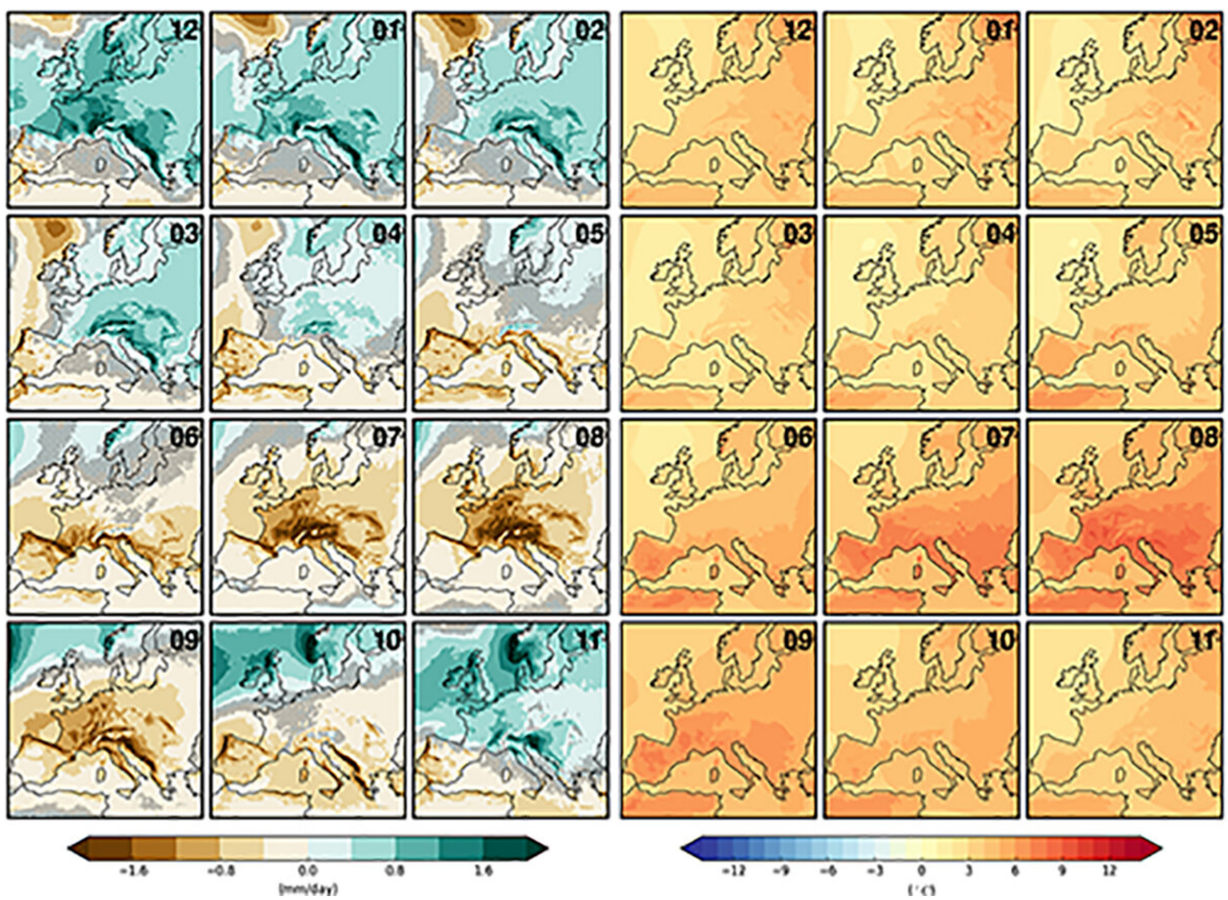

Using the CRCM5 climate model, researchers calculated climate changes in Europe and northeastern North America from 1950-2100. Comparing data from 2000-2019 and 2080-2099, the image on the left shows changes in monthly precipitation over Europe, while the image on the right shows the mean change in monthly surface-air temperature. Credit: Leduc, et al.

Many of the world's largest cities are built near coasts, whether along rivers or oceans. Humanity relies on waterways for transportation, trade and sustenance. However, waterways can also unleash devastating floodwaters that lead to billions in damage, loss of life, and years-long cleanup efforts.

Two geographically distinct areas that are prone to dealing with the fury of flood waters, the Canadian province of Quebec and the German state of Bavaria have been collaborating for a decade to investigate the impacts of climate change on water resources. The latest endeavor of this partnership, the ClimEx Project, aims to improve researchers' understanding of severe flooding dynamics under changing climate conditions. "This knowledge is of fundamental importance," says Prof. Dr. Ralf Ludwig, Geography Professor at Munich's Ludwig-Maximilians-Universität (LMU) and project leader of ClimEx. "Understanding these phenomena helps us better prepare and improve adaptation to the increasing extreme events we expect to face in our future."

"The goal of ClimEx is to investigate extreme floods associated with long return periods," said Martin Leduc, climate researcher at the non-profit research organization Ouranos and partner in the ClimEx project. "If you look at observations, you only have a relatively short time period to reference—often less than 30 years of accurate, detailed data. For the most extreme floods, these are once-a-century phenomena."

For efficiently modeling long-term climate trends, the ClimEx collaborators are using the SuperMUC supercomputer at the Leibniz Supercomputing Centre (LRZ). The team published its most recent results in the *Journal of Applied Meteorology and Climatology*, simulating the climate in Quebec and Bavaria from 1950 to 2100.

Zooming in, spreading out

To study climate trends and changes computationally, researchers use a climate model to divide the area of study into a grid for simulating the countless meteorological processes and properties that form an area's climate.

With a finite amount of computing power available for any given simulation, researchers have to simulate a representative area of the globe across a long enough period of time to establish climate trends while also capturing enough detail to verify a model's ability to predict past climate behavior and, in turn, predict future climate events. Therefore, such an experiment involves a balance between the length of the simulations, the level of detail (resolution) of the grid, and the size of the covered area.

To balance these demands, climate scientists use a combination of a global climate model (GCM) and a regional climate model (RCM). While GCMs simulate the climate over the entire globe, they have to sacrifice the level of detail, meaning that the distance between two neighbouring grid cells must be more than 100 kilometres. Using the Canadian Regional Climate Model version 5 (CRCM5) that was developed by the ESCER Centre of l'Université du Québec à Montréal in collaboration with Environment and Climate Change Canada, the researchers are able to study areas of the globe at much higher detail using grids with a 12-kilometre resolution. This allowed the LMU-Ouranos-LRZ team to run its simulations including relevant climate phenomena in high resolution.

In order to better understand and predict flooding, the team further downscales the ClimEx simulations statistically to provide input data for hyper-accurate, high-resolution hydrological modeling. Not only does this level of detail help better anticipate and plan for large-scale flooding events in Bavaria and Quebec, but it also helps provide higher-quality information for other impact models and decision makers.

Leduc also brought up the "butterfly effect" as it related to climate simulations—even the highest resolution simulations cannot account for all the miniscule changes that can influence climate changes. Further, researchers have no way of knowing how much humanity will curb its emissions in the coming decades, which could significantly influence climate patterns. In ClimEx, the team ran 50 simulations for Bavaria and 50 for Quebec, with each iteration introducing slight changes in input data, giving them a total of 7,500 years of climate data for each location.

Not only are these simulations computationally expensive, but they also generate an extremely large amount of data—more than 500 terabytes, in fact. To get meaningful results from these simulations and the data analysis that follows, researchers need access to world-leading computing resources.

"Doing these simulations required an incredible amount of computational resources and the calculations last for more than 6 months," Leduc said. LRZ staff helped ensure that the team could run its simulations as efficiently as possible, and helped the team get access to a full computational island on SuperMUC to expedite its simulations, and was able to help the team optimize its code and manage its massive amount of data.

Forecasting the future

The team's simulations showed good agreement with historical climate data, leaving them confident in its predictive power and its ability to help improve impact models and regional adaptation strategies. Ludwig confirms that the team is sharing its data with the research community, and explains that the ClimEx experiment can help researchers study the future probabilities of extreme events such as heat waves, floods, and fires, and linking meteorological patterns with the development of these extreme events. This dataset helps scientists and government officials better evaluate flood risk projections and develop more robust methods to mitigate floods' impacts.

Under the worst-case scenario, in which carbon emissions continue to grow by roughly one percent per year, the model predicts that European summers be hotter by an average of up to eight degrees Celsius per year starting in 2080, and that Quebecois winters would be up to 12 degrees warmer during the same time period.

"These projections are referencing the summer in Europe, and this is important, because this warming will occur at the same time as a decrease in precipitation, meaning that Europe could have much warmer and drier summers, which raises the possibility for more extreme heat waves and drought," Leduc said. "We should keep things in perspective, though. The model assumes a pathway for future greenhouse gas emissions, and that part is still uncertain. We don't know how much we will limit CO2 emissions in the future."

More information: Martin Leduc et al, ClimEx project: a 50-member ensemble of climate change projections at 12-km resolution over Europe and northeastern North America with the Canadian Regional Climate Model (CRCM5), *Journal of Applied Meteorology and Climatology* (2019). DOI: 10.1175/JAMC-D-18-0021.1

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