Climate change has a dramatic impact on the global water cycle, say researchers

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For more accurate forecasting, climate models also need to accurately map small, local thunderstorm cells. Credit: Juergen Freund / Nature Picture Library / Science Photo Library

For Christoph Schär, ETH Zurich's Professor of Climate and Water Cycle, "global warming" is not quite accurate when it comes to describing the driver of climate change. "A better term would be 'climate humidification,'" he explains. "Most of the solar energy that reaches the Earth serves to evaporate water and thereby drives the hydrological cycle." Properly accounting for the implications of this is the most challenging task of all for climate modelers.

In order to build a global climate model, grid points spaced around 50 to 100 kilometers apart are used. This scale is too coarse to map small-scale, local thunderstorm cells. Yet it is precisely these thunderstorm cells—and where they occur—that drive atmospheric circulation, especially in the tropics, where solar radiation is highest.

The workaround, at present, is to add extra parameters to the model in order to map clouds. "But predicting future climate change is still pretty imprecise," Schär says. "If we don't know how many clouds are forming in the tropics, then we don't know how much sunlight is hitting the earth's surface—and hence we don't know the actual size of the global energy balance."

Amazing precision

Over the next few years, scientists hope to address this imprecision. Schär, for example, is now working with models at a much higher resolution—1 to 2 kilometers—which provide a much more accurate picture of meteorological activity. To illustrate this, he and his group run a sequence on a supercomputer that simulates weather events in the Tropical Atlantic over a period of years to decades.

The visualization is strikingly similar to a satellite image: rain fronts shift from east to west across Africa; finely structured cloud fields form off the coast of Brazil; hurricanes develop in the middle of the Atlantic and then head north. "The model doesn't know anything at all about the tropical climate," Schär enthuses. "But based on the laws of physics alone, it can still provide us with a realistic picture of what's going on." It is still not feasible to create longer-term scenarios with such high-resolution models, but they do serve to make current global models more accurate.

Using the example of southwestern Europe, Schär shows how high-resolution models are also able to predict extreme weather events much more accurately. Current models massively underestimate the amount of rain that can fall in an hour. By contrast, high-resolution models generate highly realistic distributions and correctly identify that in autumn, for example, there is a strong likelihood of especially heavy rainfall and flooding on the southern edge of the Alps, along the Ligurian coast and in Provence.

Today's projections of extreme precipitation events are consistent with a physical law formulated in the 19th century by Rudolf Clausius and Émile Clapeyron. "They were just doing basic research," Schär explains. "Practical applications in climate change weren't even on their radar back then." The Clausius-Clapeyron relation says that the atmosphere can hold around 6% more water vapor per degree Celsius of warming. In other words, we can expect to see substantially heavier precipitation events in future. "That will have consequences for flood prevention," says Schär. "We'll no longer be able to design flood protection on the basis of past events."

The laws of physics tell us that a warmer atmosphere will absorb more water vapor. Despite this, many regions are expected to suffer from water shortages. Schär explains the apparent paradox: "The absolute moisture content of the atmosphere is rising overall, but relative humidity can also fall regionally. In other words, more water will evaporate from the ground; but at the same time, cloud formation will also decline in certain regions, where there will then be less precipitation." This will have serious consequences not only for southern Europe, says Schär, but also for North African countries, which are already struggling with water shortages.

Floods and forest fires

Too much water, or too little, is likewise a key concern for hydrologist Manuela Brunner. An assistant professor at ETH, she focuses on the impact of extreme climate events on mountain regions. "Mountain water plays a central role in the development of both flooding and drought," she explains. "And mountains are especially impacted by climate change because temperatures there rise more than they do in lowland regions."

To investigate whether flooding is likely to become more frequent and more intense in the future, Brunner uses a combination of observational data and model-based simulations. "In the Alps, it's very much a mixed picture for the kind of moderate flooding that typically occurs once every 10 to 20 years," she explains. "In some areas, this risk has increased; in others, it's actually declining." One key factor here is the state of the soil. "If the soil is dry, it can absorb a lot of water and thereby mitigate flooding. But if the ground is already saturated, this effect is lost."

However, Brunner expects an increasing risk of extreme, 100-year flood events across the entire Alpine region. "In that case, there's so much rainfall that the condition of the ground doesn't make much difference," she says. And while we know the individual factors that can cause flooding, she explains, we still lack the understanding of how they interact. "What happens, for example, when there's heavy rainfall during snowmelt?" she asks. "When does this develop into an extreme event? And how often will we see this combination?"

Flooding is not the only threat facing the Alpine region. "In future, we're going to see more frequent periods of drought on the northern flank of the Alps and possibly even forest fires," Brunner says. A number of factors come into play here: firstly, rainfall in summer is decreasing; secondly, soil evaporation is increasing because of higher temperatures;

and thirdly, snow levels in spring are declining, which in turn means that vegetation is more prone to drying out.

"Although precipitation in the winter months is generally increasing, higher temperatures mean that less and less of this is stored in the form of snow," Brunner explains. "And if there's less snow cover in spring, as we enter the warmer months, this can aggravate water shortages during dry summers."

Brunner is particularly alarmed by the prospect of drought periods lasting several years. "In the past, we didn't have to worry after a dry summer in the Alps, because there was always enough precipitation by the end of the following winter to compensate," she says. "But in future, water shortages may in fact worsen over the winter."

How fast are Glaciers melting?

To make matters worse, it is now clear that glaciers will soon cease to deliver the same amount of meltwater in summer as they have done in the past. "In a best-case scenario, Switzerland will still have 40% of its current glacier volume by the year 2100," says Daniel Farinotti, Professor of Glaciology at ETH Zurich. "In the worst case, only a few percent will be left." Whatever the case, he is confident in Switzerland's ability to track these changes. "We know exactly how much ice is still there because we've already done radar surveys on most of the glaciers."

Things are more complicated in the Himalayas, where Farinotti and his team are also running a project. There, the glaciers lie at a much greater altitude, which makes a survey more difficult. At the same time, surrounding countries are reluctant to provide data for research because of strategic and geopolitical reasons. Forecasts of when glacier melt will peak in the Himalayas can therefore vary by as much as a decade. "For the lowlands, which are much more densely populated, that makes a huge difference," he says.

In Switzerland, too, there is an urgent need to know how much water will be contributed by glacier melt in future—not least because the concessions for a number of hydropower plants are up for renewal in the next few years. Such operators not only need to know how much water will be available to them in the future; they also require detailed forecasts regarding extreme weather events. "They're anxious about whether water intakes have sufficient capacity," Farinotti explains.

Another issue is of even graver concern: the melting of the polar ice sheets. "In our group, we're currently building a detailed flow model of the Greenland Ice Sheet based entirely on physical processes," Farinotti explains. "We're mapping the ice masses to a resolution of 25 meters in order to assess what will happen to the ice sheet over the next few decades." To run this complex simulation, the team is set to make use of LUMI, Europe's fastest supercomputer.

Alongside other researchers, Farinotti's group is also investigating the Antarctic Ice Sheet, which faces a number of threats. In particular, there are issues with the Western Antarctic Ice Sheet, which rests on bedrock beneath the surface of the ocean. "The topography of this bedrock plays a key role in how quickly the ice will retreat," he explains.

This is, without doubt, a vital question for a number of coastal regions around the world. "If the West Antarctic Ice Sheet starts melting, sea levels could rise by as much as 1 meter by the end of the 21st century," Farinotti says. With 250 million people living in areas that would then be underwater, there's no need to ask why the future of the polar ice sheets is also of such importance at lower latitudes.

Provided by ETH Zurich

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