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Hydroclimate: Understanding rainfall extremes

Warming induced by greenhouse gases will increase the amount of moisture in the atmosphere, causing heavier rainfall events. Changing atmospheric circulation dynamics are shown to either amplify or weaken regional increases, contributing to uncertainty in future precipitation extremes.

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It is widely expected that anthropogenic warming will lead to an increase in the intensity of extreme rainfall[1]. However, the latest climate models do not project spatially uniform increases, but rather show large uncertainties in the regional patterns of change, hampering the development of efficient adaptation strategies. Now, writing in Nature Climate Change, Stephan Pfahl and colleagues[2] demonstrate that shifting atmospheric dynamics contribute to the variability in projections of precipitation extremes. Through quantifying the processes responsible for regional contrasts, their analysis acts to reduce the uncertainty surrounding global warming impacts on strong rain events.

The intensity of extreme precipitation is anticipated to increase by approximately 7% per 1 °C of warming[1]. This expectation is based on the Clausius–Clapeyron (C–C) relationship, which describes the change in atmospheric moisture holding capacity with temperature. On average, the actual rate of moisture increase is rather close to this value[3], and as changes in precipitation extremes are, to first order, related to atmospheric moisture, the C–C relation provides an approximate guide to understanding future changes in heavy rainfall.

On this basis, various studies use a statistical (or scaling) approach to relate precipitation extremes to surface temperature[4]. This method assumes that temperature is a reliable proxy for humidity, and that the intensity of rain responds directly to the humidity perturbation. The approach has been pioneered for short-duration precipitation extremes, and in a few areas has been shown to relate to long-term observed trends and future projections[5].

For many areas of the globe, however, the scaling methodology suggests precipitation extremes may deviate from the C–C relationship[4]. In the mid-latitudes, or regions of low-intermediate temperatures, changes in precipitation intensity can be up to twice the C–C relationship for hourly extremes[4,5]. By contrast, in high temperature regimes such as the tropics and sub-tropics, negative scaling rates are often observed, indicating a reduction in precipitation intensity with warming. Several recent papers further show that no reliable projections can be made based solely on temperature scaling[6–8].

These inadequacies have often been attributed to the fact that temperature does not necessarily correspond to humidity, a limitation that can be circumvented with the use of dew point temperature, a direct measure of humidity[4,5]. Nevertheless, the scaling method is also constrained by the impacts of atmospheric circulation, which influences both temperature and precipitation, making it difficult to disentangle cause from effect. Strong cyclonic activity, for example, can cause lower temperatures as well as high precipitation[8]. Likewise, high-pressure systems cause relatively dry weather with high temperatures[9]. Thus, temperature–precipitation scaling cannot be used straightforwardly to explain changes in future rainfall extremes[6–9].

To overcome these limitations, Pfahl *et al.*[2] use a simple measure of condensation in rising air to diagnose extreme precipitation in a large ensemble of global climate model simulations, building on the tight coupling between rising air and rain formation. With this simple physical-based formulation, the modelled pattern of daily precipitation extremes across the globe is accurately reproduced for the present-day climate. Since the diagnostic depends on both the atmospheric humidity and the vertical velocity of the air column, it can be used to separate the thermodynamic contribution due to the increase in moisture from the dynamic contribution due to changing vertical motions.

Pfahl *et al.*[2] find that the thermodynamic contribution follows a rate slightly lower than C–C, and has a rather uniform global pattern. In most areas, it determines the positive sign of the response of the daily precipitation extremes. However, over the tropics and subtropics in particular, the dynamically generated contribution is large. Over the tropical Pacific Ocean and the Asian monsoon region it enhances the thermodynamic response, whereas over the subtropical oceans, the Mediterranean, South Africa and Australia it dampens the response, even leading to future reductions in precipitation extremes over the subtropical oceans and the Mediterranean. Differences in the response within the model ensemble are also primarily explained by the dynamic contribution.

Thus, changing atmospheric circulation patterns play a key role in explaining future precipitation extremes and uncertainty therein. Pfahl *et al.* further show that the circulation response is partly explained by a poleward shift of circulation patterns. However, circulation changes are themselves closely related to atmospheric moisture; latent heat — that released during condensation — is important in explaining vertical motions in the atmosphere at various scales.

Given that the diagnostic used by Pfahl *et al.*[2] cannot be applied directly to observations, their results are based on global climate model simulations which employ relatively coarse computational grids of ~100–200 km. It must be remembered, however, that the main processes leading to extreme precipitation, including vertical motion associated with convective clouds, take place at much smaller scales. Climate models therefore use simplified schemes that try to capture the essential physics, but are nevertheless crude approximations of reality.

To further develop our understanding of precipitation extremes, the availability of observations is essential, not only of rainfall at different spatial and temporal and resolutions, but also of the atmospheric state. Under the auspices of the GEWEX Hydroclimatology Panel, an initiative is presently underway to collect and quality control sub-daily rainfall at a global scale. Models that explicitly resolve convection also need to be further developed and applied, and intercomparison projects are necessary to understand model differences and the value added over coarser resolution models. A targeted effort to understand changes in large-scale dynamics of the atmosphere and their linkages to moist processes in the atmosphere is also urgently needed[10].

Both precipitation–temperature scaling and the physical diagnostic of Pfahl *et al.* provide a framework to better quantify the roles of physical processes leading to precipitation extremes in a warming climate: atmospheric moisture, dynamical feedback to increased latent heat release, and changes in atmospheric circulation on larger scales. This understanding is the key for better predictions of future precipitation extremes.

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