Precipitation extremes probabilities: GCM evaluation, theory, and its implications under global warming

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Society and ecosystems are not only adapted to mean precipitation conditions but to the whole probability distribution (PDF). To leading order, observed daily precipitation PDFs are characterized by two regimes. In most regions, the PDF decays slowly with size, approximately as a power law τ_P, for low and moderate precipitation values, and then more sharply, for values larger than a characteristic cutoff-scale P_L. This cutoff is important because it limits the probability of extreme daily precipitation occurrences in current climate. A stochastic model is formulated to understand why daily precipitation PDFs follow this shape, and what environmental factors control the power law exponent $\tau_P$and exponential cutoff-scale P_L in a given region. It is found that both τ_P and P_L depend on the moisture budget, with P_L (and hence extremes) depending on moisture convergence variance during precipitating times. We evaluate how well GCMs represent daily precipitation probabilities under different metrics. We find that most models simulate a more complex PDF shape than reanalyses and station data, with models often simulating additional spurious probability peaks in the power law range not present in observations. In contrast, the shape of the large event range (beyond P_L) is generally well simulated, although not its magnitude. We argue that model projections of changes in low and moderate precipitation are less reliable than projections of changes in precipitation extremes. We use the insight gained from theory to interpret future increases in intensity and frequency of daily precipitation extremes simulated by the CMIP6 ensemble under global warming.