www.nature.com/scientificreports

SCIENTIFIC REPORTS

OPEN

Precipitation variability increases in a warmer climate

Angeline G. Pendergrass[1], Reto Knutti[1,2], Flavio Lehner[1], Clara Deser[1] & Benjamin M. Sanderson[1]

Received: 10 August 2017
Accepted: 4 December 2017
Published online: 21 December 2017

Understanding changes in precipitation variability is essential for a complete explanation of the hydrologic cycle's response to warming and its impacts. While changes in mean and extreme precipitation have been studied intensively, precipitation variability has received less attention, despite its theoretical and practical importance. Here, we show that precipitation variability in most climate models increases over a majority of global land area in response to warming (66% of land has a robust increase in variability of seasonal-mean precipitation). Comparing recent decades to RCP8.5 projections for the end of the 21st century, we find that in the global, multi-model mean, precipitation variability increases 3–4% K^{-1} globally, 4–5% K^{-1} over land and 2–4% K^{-1} over ocean, and is remarkably robust on a range of timescales from daily to decadal. Precipitation variability increases by at least as much as mean precipitation and less than moisture and extreme precipitation for most models, regions, and timescales. We interpret this as being related to an increase in moisture which is partially mitigated by weakening circulation. We show that changes in observed daily variability in station data are consistent with increased variability.

Precipitation variability is a crucial climatic factor for society, agriculture, and the environment; increased precipitation variability can reduce agricultural yield[1], and in developing countries can affect growth of children[2]. Precipitation variability also connects extreme wet and dry events, floods and droughts, which pose threats to the environment and society[3]. Yet it is sometimes assumed that precipitation variability does not change in a warming climate [e.g., refs[4,5]], or that mean precipitation and its variability change at the same rate[6]. While temperature variability does not change systematically in response to projections of global warming in most regions[7,8], it is not clear that this should hold for precipitation.

The reigning conventional wisdom of how precipitation changes with warming is that mean precipitation change is energetically constrained to about 2% K^{-1} [9], while extreme precipitation change is driven primarily by the change in near-surface moisture with little change in coincident circulation, with a magnitude of about 6% K^{-1} for the 99.9th all-day percentile of daily precipitation[10]. To formulate a complete theory of how precipitation changes with warming, we must connect explanations for the mean and extremes by addressing how variability responds to warming. Remarkably few studies have undertaken this charge.

Two decades ago, early climate model simulations indicated that daily to interannual precipitation variability increases in response to a doubling of carbon dioxide[11–13]. This notion was supported by station observations showing increased variability on decadal timescales[14] and confirmed for interannual timescales by studies with small ensembles of model simulations[15,16]. But in the mid-2000s, the changes in interannual to decadal variability were deemed slight in the face of large present-day variability[17], and subsequent work downplayed its importance[18,19]. Very recent work has focused on changes in precipitation variability at regional scales, including the monsoons[20], and one study has examined decadal prediction and identified increases in interannual precipitation variability[21]. However, most work in the last decade focused on the robust response of ENSO-related precipitation change across models, which occurs despite disagreement on changes in ENSO-related sea-surface temperature variability[22–27]; these studies are all limited to interannual timescales and focused on the tropics.

Here we quantify the change in precipitation variability on timescales from daily to decadal with warming in three ensembles of global climate model simulations: the Coupled Model Intercomparison Project version 5 (CMIP5) ensemble, and two large initial-condition ensembles using the CESM1 and GFDL models (see Methods for details). We use standard deviation of precipitation as a metric of its variability (following refs[4,5]; alternative metrics are discussed in the Supplementary Information). We primarily focus on land because this is where most

[1]National Center for Atmospheric Research, Boulder, CO, USA. [2]Institute for Atmospheric and Climate Science, ETH Zurich, CH-8092, Zurich, Switzerland. Correspondence and requests for materials should be addressed to A.G.P. (email: apgrass@ucar.edu)