Explaining Extreme Events of 2019 from a Climate Perspective

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EXPLAINING EXTREME EVENTS OF 2019 FROM A CLIMATE PERSPECTIVE

Editors

Stephanie C. Herring, Nikolaos Christidis, Andrew Hoell,
Martin P. Hoerling, and Peter A. Stott

BAMS Special Editors for Climate

Andrew King, Thomas Knutson,
John Nielsen-Gammon, and Friederike Otto

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Corresponding Editor:

Stephanie C. Herring, Ph.D.
NOAA National Centers for Environmental Information
325 Broadway, E/CC23, Rm 1B-131
Boulder, CO 80305-3328
E-mail: stephanie.herring@noaa.gov

Cover: Ruins and rubble are all that are left of homes destroyed by Hurricane Dorian viewed from a U.S. Customs and Border Protection rescue helicopter 5 September 2019 in Marsh Harbour, Abaco, Bahamas. Dorian struck the small island nation as a Category 5 storm with winds of 185 mph. (credit: Planetpix/Alamy Stock Photo)

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Anthropogenic Contribution to the Rainfall Associated with the 2019 Ottawa River Flood

Megan C. Kirchmeier-Young, Hui Wan, and Xuebin Zhang

Anthropogenic forcing increased the likelihood of the 30-day high rainfall over Ontario and Quebec that contributed to the 2019 Ottawa River floods by a factor of 2 to 3.

AFFILIATIONS: Kirchmeier-Young, Wan, and Zhang—Climate Research Division, Environment and Climate Change Canada

CORRESPONDING AUTHOR: Megan C. Kirchmeier-Young, megan.kirchmeier-young@canada.ca

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Spring 2019 saw a record-setting flood on the Ottawa River, impacting parts of the provinces of Ontario and Quebec in Canada. The river crested on 1 May, but the state of emergency in Ottawa lasted into the second week of June. The floods resulted in thousands of people evacuated, extended states of emergency, and about \$200 million in insured losses (IBC 2019). This flood came just two years after the previous record flood for the region.

The 2019 flood was fed by a month of well above average rainfall over the basin, demonstrated in Fig. 1a using the maximum 30-day accumulation from spring (March–May) expressed as an anomaly relative to the 1981–2010 mean of spring 30-day accumulations. This included contributions from several days with heavy rainfall, shown in Fig. 1b as counts of days exceeding the local 1981–2010 90th percentile. In addition, the ground was still frozen throughout this period, limiting infiltration of the rainwater and increasing flow over the land surface. The melting of above-average snowpack upstream also contributed to the flood.

Fig. 1. (a) Spring Rx30day anomaly in mm and (b) the count of heavy rainfall days during spring (March–May) from ERA5. The light gray outline is the Ottawa River Basin (ORB) and the white circle the city of Ottawa. The dark gray boxes indicate the two regions used in this analysis, the smaller encompassing the ORB (~271,000 km²) and the larger including much of Ontario and southern Quebec (ON/QC) (~2,576,000 km²). (c),(e) Time series for the Rx30day anomaly and (d),(f) count of heavy rainfall events averaged over (c),(d) the larger ON/QC region and (e),(f) the smaller ORB region. Individual realizations from ALL simulations are in red and NAT simulations in blue. Multimodel ensemble means are in bold, with equal weight for each model. ERA5 is in black, with the 2019 value emphasized with the horizontal dashed line.

In this region, most spring floods are related to snowmelt, often in combination with heavy rainfall (Buttle et al. 2016; Teufel et al. 2019; Lin et al. 2019). Here, we investigate the anthropogenic influence on the 2019 Ottawa River flood, with a focus on the rainfall component.

Data and methods.

We use a multimodel ensemble of CMIP6 simulations (Eyring et al. 2016; see Table ES1) with all available realizations that provide daily rainfall data. This includes 90 realizations with both anthropogenic and natural forcing (ALL) that combine historical forcing with SSP3–7.0 beginning in 2015 (O’Neill et al. 2016). The different scenarios do not noticeably diverge through the dates we use (2023); thus scenario choice should have little impact. A set of 48 natural-only (NAT) forcing simulations from the Detection and

Attribution Model Intercomparison Project (DAMIP; Gillett et al. 2016) will represent the reference, or counterfactual world, for the attribution. The ERA5 reanalysis (C3S 2017) serves as a representation of the observations. ERA5 improves the biases of its predecessor, ERA-Interim, and in terms of driving a hydrologic model is as skillful as using observations in most regions of North America (Tarek et al. 2020). The ranges of the trend and variability of monthly precipitation over 1981–2019 from the CMIP6 models both include the values from ERA5. There is not sufficient station density in this region to estimate a regional average that is comparable to the models, but the timing of the 2019 spring maximum 30-day rainfall from ERA5 is similar to that from two stations in Ottawa, Ontario (see Fig. ES1 in the online supplemental material).

The Ottawa River system contains several reservoirs, particularly in the northern tributaries. The reservoirs are typically emptied prior to the spring freshet for flood prevention and receive contributions from snowmelt from almost half of the basin. Because of this regulation capacity, major flood events are usually caused by a long period of heavy rainfall over a few weeks, in combination with the snowmelt. As such, the spring maximum 30-day rainfall accumulation (Rx30day) was calculated for each year to represent rainfall contributing to a spring flood. Similarly, monthly precipitation was used in an event attribution study for a previous flood in this basin (Teufel et al. 2019). Rainfall accumulations were determined by summing precipitation from days with a mean temperature greater than 0°C, which should capture the distinction between rain and snow in most cases. Model anomalies were remapped to a common 1.5° grid. After calculating regional averages, the maximum 30-day period was chosen. Additional data processing details are described in the supplemental material. Regional averages were determined for a rectangle enclosing the Ottawa River Basin (ORB), which is where the flood occurred. Changes in extreme precipitation are often small compared to natural variability, especially at small scales. Since variability is smaller over a larger region, we also use an area covering the majority of Ontario and southern Quebec (Fig. 1). For attribution, the event threshold was the standardized (by subtracting the mean and dividing by the standard deviation; see supplemental material) 2019 spring Rx30day from ERA5. NAT anomalies and standardization were computed relative to ALL simulations of the same model.

To account for the role of heavy rainfall, we also calculated the number of heavy rainfall days during spring each year. Heavy rainfall days were defined for each grid box as those exceeding the 90th percentile from spring days over 1981–2010 and using the method of Zhang et al. (2005). Exceedance counts were determined on each model's native grid and then remapped to the common grid before the calculation of regional averages. NAT exceedances used the 90th percentile from an ALL simulation by the same model. For attribution, we used event thresholds from 7 to 12 days.

For event attribution, we use the standard risk (probability) ratio (PR) framework (e.g., NASEM 2016) to compare the ratio of the probability of occurrence between ALL and NAT forcing simulations. To calculate probabilities by counting exceedances, ALL data were pooled from ensemble members for 2014–23, a 10-yr period centered on the 2019 event, and NAT from 1996–2020. The NAT simulations end in 2020 and, given the general stationarity, a longer period can provide more robust estimates of smaller probabilities. The 5th to 95th percentile range was determined by randomly resampling both ALL and NAT independently.

Results.

Maps of the 2019 spring Rx30day anomaly and the number of heavy rainfall days from the ERA5 reanalysis are shown in Figs. 1a and 1b, respectively. There is a large area of positive rainfall anomalies over the ORB, southeastern Ontario, and the Great Lakes region. This area coincides with some high counts of heavy rainfall days.

For the spring Rx30day anomalies using ERA5, the 2019 anomaly is one of the largest in the record (Figs. 1c,e). The 2017 value is only slightly larger and was associated

with another high-impact spring flood. A slight positive trend is apparent in the re-analysis data between 1981 and 2019. In the CMIP6 ensemble, ALL anomalies are generally more positive than NAT anomalies, indicating higher rainfall with ALL forcing. The ensemble mean is calculated giving equal weight to each model, but only minor differences were noted if equal weight is instead given to each realization. The ensemble spread covers a wide range of anomalies.

Histograms for the standardized Rx30day anomalies show the ALL data shifted slightly toward larger values, compared to the NAT realizations. The difference between the ALL and NAT distributions is more distinct for the larger Ontario/Quebec region than for the smaller ORB region. The PR for the standardized 2019 spring Rx30day is greater than 1.0 for both the regions (Fig. 2c), implying an increase in likelihood due to anthropogenic forcing. We estimate that the 2019 Rx30day is about 3 times as likely with the inclusion of anthropogenic forcing for the larger region and about 2 times as likely for the smaller region. The error bars are wide, implying large uncertainty on the estimated PR. However, there is confidence of an increase in likelihood, particularly for the larger region.

Similarly, for the number of heavy rainfall days, 2019 and also 2017 show the largest values in the record for ERA5 (Figs. 1d,f). Slightly larger values, including the most extreme counts, are found in the ALL simulations compared to those from NAT. A shift

Fig. 2. Histograms for (a),(b) the standardized spring Rx30day anomaly and (d),(e) the number of heavy rainfall days expressed in percent of values. ALL is shown in red and NAT in blue. Probability ratios for the (c) standardized Rx30day anomaly and (f) number of events are shown for the larger region in purple and the smaller region in teal. The higher counts in the larger region do not occur in either the ALL or NAT simulations. A horizontal line at 1.0 indicates equal likelihood between ALL and NAT, with values larger than 1.0 indicating an increase in likelihood in the ALL simulations.

toward higher counts of heavy rainfall days under ALL is also demonstrated through the histograms in Figs. 2d and 2e. PRs for the number of days are only slightly larger than 1.0 for the smaller count thresholds (Fig. 2f). Larger PRs but also larger uncertainties are found with most of the higher count thresholds. Overall, we find that anthropogenic forcing resulted in an increase in the likelihood of a higher number of heavy rainfall days.

Conclusions.

An increased likelihood of flood-producing rainfall has been identified for other events in Canada and the neighboring regions of the United States (Teufel et al. 2019, 2017; Szeto et al. 2015; Winter et al. 2020). Our results are in agreement with those of Teufel et al. (2019), who performed an assessment of the 2017 Ottawa River floods. Using a different set of model simulations at a much higher resolution, they found a small increase in likelihood for the flood-producing monthly rainfall. However, they did not identify an attributable change in surface runoff and it was suggested that a warming-induced decrease in spring snowpack could offset the increased precipitation.

Event attribution PRs depend on the event definition, including the specific location and spatial and temporal scales used. For our analysis of flood-inducing precipitation, different regions, in size and/or location, different event thresholds, a different spring time period, or a different set of models in the ensemble may change the attribution results. Exact PR values will likely depend on the specific choices, but we expect the finding of a small increase in likelihood to be consistent across slight changes in framing. This is confirmed in Fig. ES2, where the PRs change only slightly if an Rx-20day metric or a 15-year ALL period is used instead. Even with making different methodological choices, we reach the same general conclusion as Teufel et al. (2019) for the 2017 flood. Additionally, Kirchmeier-Young et al. (2019) demonstrated consistent changes in likelihood between Rx1day and Rx30day in this region. Finally, increases in extreme precipitation are consistent with a warming atmosphere.

Flood events are complex and often the result of the interaction of many variables, including rainfall, snowpack, and characteristics of the land surface. While increases in the likelihood of large positive precipitation anomalies are increasingly identified and attributed to anthropogenic climate change, the interaction of rainfall with other variables to produce a high-impact flood in a warming climate remains uncertain.

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