Extreme Rainfall Trends in the United States of America

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Abstract

The European Centre for Medium Range Weather Forecast (ECMWF) fifth-generation reanalysis of the global climate (ERA5) and the Climate Hazards Group InfraRed Precipitation with Station (CHIPPS) daily measurements are used to examine extreme rainfall (1981-2022) in the contiguous U.S.A. Linear spatiotemporal trends in indicators of extreme rainfall frequency, magnitude, and duration recommended by WMO, as identified by the Theil-Sen slope estimate and its Mann Kendall significance ($p < 0.05$), are calculated. Temporal trends in the annual number of days with rainfall 20 mm (R20) are most significant in the Ohio Valley and in parts of Florida (increasing), and isolated parts of Texas, Oklahoma, elsewhere in the Southwest and West (decreasing). Annual frequency of days having 10 mm (R10) shows similar spatiotemporal patterns, but with broader areas of decreasing trends in the southern Great Plains and Southwest. Annual trends in total rainfall on the 5\% of the most precipitating days (R95P) increased significantly in parts of Florida and from Louisiana to Maine and decreased significantly across much of the Southwest. Annual trends in maximum five-day rainfall (Rx5day) increased significantly in parts of the Appalachians and other isolated pockets and decreased significantly in parts of the Southwest. Annual maximum number of consecutive dry days (CDD) increased significantly in parts of California and adjacent western U.S. and decreased significantly in much of the south-central U.S. Trends in annual maximum number of consecutive wet days (CWD) changed significantly only in isolated areas, with Colorado having the most significantly decreasing trends. The area having >2.5 mm day\textsuperscript{-1} of rainfall over a given meteorological season expanded for DJF and MAM but shrunk for SON, from the 1981-1990 to 2011-2022 periods. If such trends continue, floods, landslides, and droughts may intensify.
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Introduction
To characterize the spatiotemporal trends of extreme rainfall in the continental United States, 6 out of the 27 extreme climate indices defined by the Joint C3S/WCRP/CMIP Expert Team on Climate Change Detection and Indices (ETCCDI) were derived, analyzed, and visualized. Derived daily rainfall values from the 6th generation ECWMF atmospheric reanalysis of the global climate (ERA5, Hersbach et al., 2020) and the Climate Hazards Group InfraRed Precipitation with Station Data (CHIRPS, Funk et al., 2015) were used to calculate the indices. CHIRPS and ERA5 underwent post-satellite and radiosonde rainfall data in capturing extreme rainfall upon validation with gauge-based measurements (Bhattacharya et al., 2022). Moreover, the areal extents of mean daily rainfall above a specific threshold have been compared for the current and the past decade, classified meteorologically seasons, following a similar approach to Safarli et al. (2023).

Data and Methods

**Annual count of days when daily rainfall ≥ 10 mm**
- Mississippi, Louisiana, Alabama, and Tennessee show the maximum R10 (2-22 days), while Utah, Nevada, and Wyoming show the minimum R10 (<1 day).
- Significant positive temporal trends in Ohio Valley and in isolated parts of the Southeast, Northeast, and upper Midwest.

**Severity and trends of consecutive dry days**
- Significant negative temporal trends in discrete regions of the Southeast and the West

**Analysis of daily rainfall data downloaded from ERA5, CHIRPS, and GHCN (1/2/1981 – 12/31/2022)**

**Study area: continental United States; spatial resolution of both gridded rainfall data sets: 0.25° × 0.25°**

**GHCN data were used for validation of the two gridded rainfall datasets.**

**Extreme rainfall indices considered in this study:**

<table>
<thead>
<tr>
<th>Index</th>
<th>Description</th>
<th>Unit</th>
<th>Type of index</th>
</tr>
</thead>
<tbody>
<tr>
<td>R10m</td>
<td>Number of rainy days with daily rainfall ≥ 10 mm</td>
<td>days</td>
<td>Frequency</td>
</tr>
<tr>
<td>R20m</td>
<td>Number of rainy days with daily rainfall ≥ 20 mm</td>
<td>days</td>
<td>Frequency</td>
</tr>
<tr>
<td>R95p</td>
<td>Wettest year(s)</td>
<td>mm/day</td>
<td>Intensity</td>
</tr>
<tr>
<td>Rx5</td>
<td>Maximum 5-day maximum rainfall</td>
<td>mm</td>
<td>Intensity</td>
</tr>
<tr>
<td>RX5</td>
<td>Maximum 5-day maximum rainfall</td>
<td>days</td>
<td>Duration</td>
</tr>
<tr>
<td>CDD</td>
<td>Maximum number of consecutive dry days</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CWD</td>
<td>Maximum number of consecutive wet days</td>
<td>days</td>
<td>Duration</td>
</tr>
</tbody>
</table>

**Performing the performance of the ERA5 and CHIRPS data sets in terms of the mean annual values of the calculated extreme rainfall indices with respect to GHCN data is compared in the table below:**

<table>
<thead>
<tr>
<th>Year</th>
<th>ERA5</th>
<th>CHIRPS</th>
<th>GHCN</th>
<th>Correlation</th>
<th>Bias</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>0.85</td>
<td>0.83</td>
<td>0.84</td>
<td>0.88</td>
<td>0.89</td>
</tr>
<tr>
<td>2009</td>
<td>0.86</td>
<td>0.85</td>
<td>0.86</td>
<td>0.87</td>
<td>0.88</td>
</tr>
<tr>
<td>2011</td>
<td>0.86</td>
<td>0.85</td>
<td>0.86</td>
<td>0.87</td>
<td>0.88</td>
</tr>
</tbody>
</table>

**Results**

**Heavy Rainfall Days (R20)**
- Mississippi, Louisiana, Alabama, and Tennessee show the maximum R20 (2-22 days), while Utah, Nevada, and Wyoming show the minimum R20 (<1 day).
- Significant positive temporal trends in Ohio Valley and in isolated parts of the Southeast, Northeast, and upper Midwest.

**Wet Days Precipitation (R95p)**
- Mississippi and Louisiana show the maximum R95p (>70 mm), while Utah and Nevada have the minimum R95p (<30 mm).
- R95p increased significantly in parts of the South, Ohio Valley, upper Midwest, and the East Coast.

**Annual Maximum 5-Day Rainfall (Rx5day)**
- Mississippi, Louisiana, Alabama, and Florida show the maximum Rx5day (>120 mm), while Utah, Nevada, and Wyoming have the minimum Rx5day (<40 mm).
- Annual trends in Rx5day increased significantly in parts of the Appalachian and other isolated pockets.
- Decreased significantly in small segments of the Southwest and the upper Midwest.

- A general increase in the area affected by rainfall > 2.5 mm/day from 1981-1990 to 2012-2022 for DIF and MAM.

**Conclusions**
- CHIRPS performed better than ERA5 for R20, R95p, Rx5, and CWD. Of all the indices, the agreement of the CWD is the best when compared to gauge-based observation.
- Temporal trends in the frequency indices (R10 & R20) generally increased significantly in the Ohio Valley and the northeastern, southeastern, and southern States and decreased significantly in the Southwest. R10 showed a broader spatial pattern of significant annual decrease.
- The intensity indices (R95p and Rx5) show similar spatial patterns to the frequency indices in terms of annual increase/decrease.
- The duration indices (CDD & CWD) show considerably less spatial clusters of significant annual change except for increasing CWD along much of the Southeast and the West.
- The general trend that can be inferred from our analysis is that the dry spells are becoming much drier at a relatively faster rate than the wet spells are becoming wetter. Some areas of the wet spells are becoming drier to some extent, but the reverse has not been observed.
- Comparison of seasonal shifts of areal rainfall patterns between 2011-2022 and 1981-1990 averaging periods suggests that general increase in hydroclimatological extremes have occurred. If such trends continue, floods, landslides, and droughts may intensify.

**Acknowledgments**

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