

Abstract

Compound Extremes (CEs) refer to the occurrences of multiple extremes (e.g., meteorological, hydrological, or agricultural extremes) concurrently or with slight temporal lags due to their mutual dependence pattern (i.e., drought and heatwaves, and sequential extreme drought and flood)—which can potentially exert higher disastrous impacts than individual extremes. Though the primary idea of the joint probability of multiple extremes emerged long ago, the explicit research arena on CEs has surged in the last few years (2018-2024). On the verge of climate change, extremes (e.g., drought or heat), as well as CEs (e.g., drought and heat), have not only expanded in spatiotemporal extents across various parts of the world but also severely affected aspects, including crop yields, fire risk, vegetation productivity, air quality, and human health—thus impacting the overall environmental, socioeconomic conditions, and Food-Water-Energy Nexus (FWEN). For instance, global land and cropland areas affected by dry-hot CEs have reportedly increased 1.7–1.8 times between the late 20th and 21st centuries across different seasons, mostly in summer. Also, a noticeable impact on global maize yield has been reported in compound drought and hot event scenarios (31% decrease), whereas hot events (4% decrease) or droughts (7% decrease) alone have a significantly lower impact. Under these circumstances, using new multivariate statistical approaches in this field (i.e., copula theory and meta-gaussian model), this research focuses on the probabilistic association assessment of temperature- and precipitation-associated individual extremes and CEs, followed by a probabilistic impact assessment given dry-hot CEs and their counterparts (drought and heat) on the yield of four regionally important crops (i.e., corn, soybean, cotton, and peanut) of a CE-hotspot of the USA, the southern USA, under different severity levels and irrigation scenarios—which are still underexplored at regional scales with higher-resolution data and regionally significant variables. The southern USA is one of the hotspots of CEs, with a prediction of 1.5°C to 6°C change in temperature and -40% to +40% change in precipitation by the end of the 21st century. This region is also an agriculturally significant region containing pluvial agricultural lands around the Mississippi River System and a significant representative of humid-subtropical climate-dominated areas of the globe, which makes it a critical region to be studied for CE-associated risk assessments. The results indicated that ~80% of the below-normal yield loss incidents in the southern USA are associated with meteorological (temperature and precipitation) compounds and individual extremes, where dry-hot compounds

Compound Extremes in Agrometeorological and Hydrometeorological Domains

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had the highest, while other extremes (e.g., wet-cold and wet) had significant association probabilities. Additionally, our findings showed that the analyzed major field crops in the southern USA had a 61%-86% probability of below-normal yield for compound dry-hot summer, which increased to 67%-96% in the most severe scenarios in case studies of their top growing states. Results also indicated significant impact variations in crop-specific cases and irrigation scenarios. Moreover, spatial variations were most significant, as the analysis results interestingly indicated low-lying areas near the coast, rivers, aquic soil, and high precipitation normals seemed to have lower association and impacts from dry-associated extremes, and vice-versa. Furthermore, a systematic review study was completed preceding the analysis by presenting major analysis frameworks, impact hotspots, and components of drought- and heatwave-associated, while also covering temperature- and precipitation-associated CE analysis, which provided a basis for identifying the research gaps and study area for this dissertation. This dissertation's major novelties were to 1) summarize the analysis framework into three novel categories (i.e., event-event, event-driver, and event-impact), 2) uniquely divide temperature and precipitation indices' probability space with a non-zero threshold to define nine events and find their association probabilities with crop-specific yields, and 3) overlay local climate subtypes and soil moisture regimes with finer climate division scale compound dry-hot extreme impacts. Parallely, it also addressed several other knowledge gaps, such as assessing so far unexplored regional crops (i.e., cotton and peanut), scale effects, and irrigation effects with CE frameworks. This dissertation's findings can be helpful not only for prospective scientists to identify future research needs and overall understanding of the analyzed CEs but also for planners and decision-makers to ensure sustainable planning and resource allocations in the identified higher-impact zones. Thus, this dissertation can significantly improve the understanding and representation of complexity in individual meteorological extremes and CEs in the agrometeorological and hydrometeorological domains by assessing these extremes' association and impacts in an unexplored impact variable (e.g., crop yield) in the southern USA, which will help multiple stakeholders design sustainable mitigation measures in the warming and changing climate.

Keywords: climate extremes, drought, heat, climate change, statistical modeling