A general framework for impact assessments of compound dry-hot events on different sectors based on vine copula

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I. Introduction

The compound weather and climate extremes have attracted more attention due to their amplified impacts on various sectors under global warming. However, quantifying the impacts of compound extreme is complicated due to the multiple variables involved in the atmospheric processes and impact variables. In addition, uncertainties generally exist in the assessment of impacts from different compound events due to the limited sample size. Thus, a flexible framework is needed in the impact assessments of compound weather and climate events or extremes on different sectors.

The aim of this study is to proposes a framework for assessing impacts of compound dry and hot events on crop yield and soil moisture with a flexible dependence structure. The joint distribution of multiple variables is first constructed based on the vine copula. The conditional probabilities of different variables are then evaluated.

II. Data and Methods

- **Climate data**

The monthly precipitation and temperature data at 0.5°×0.5° for the period 1961-2016 were collected from Climate Research Unit (CRU) (http://www.cru.uea.ac.uk/data). The precipitation and temperature are converted into the Standardized Precipitation Index (SPI) and Standardized Temperature Index (STI) based on the Normal Quantile Transformation (NQT).

- **Crop yield data**

The annual French maize yield data from 1961 to 2016 were obtained from Food and Agriculture Organization (FAO) (http://faostat.fao.org). The growing season of June-July-August for maize was selected based on the crop calendar from the United States Department of Agriculture (USDA). The annual maize yield is converted into the Standardized Crop yield Index (SCI) based on NQT.

- **Hydrology data**

Monthly soil moisture data from 1932 to 2017 were obtained from climate divisions in Texas, which were obtained from the Climate Prediction Center (CPC) website (ftp://ftp.cpc.ncep.noaa.gov/wd51yf/us). Similarly, the soil moisture was also transformed into the Standardized Soil moisture Index (SSI) based on NQT, which represents the deficiency of water resources.

- **Vine copula**

We first take the three-dimensional C-vine copula as an example to construct the joint distribution of the random vector (x_1,x_2,x_3):

$$f(x_1,x_2,x_3) = f_1(x_1)\cdot f_2(x_2)\cdot f_3(x_3)\cdot c_{12}[F_1(x_1),F_2(x_2)\cdot c_{23}[F_2(x_2),F_3(x_3)\cdot c_{13|2}[F(x_1|x_2),F(x_3|x_2)] \quad (1)$$

where $c_{12}[F_1(x_1),F_2(x_2)$ and $c_{23}[F_2(x_2),F_3(x_3)$ both indicate the copula density function and $c_{13|2}[F(x_1|x_2),F(x_3|x_2)]$ denotes the copula density function of x_1 and x_3 given x_2.

- **Impact of compound dry and hot events**

To show the impact of compound dry and hot events, we compute the conditional cumulative distribution function (CDF) of the impact variable given three conditions (e.g., individual dry condition, individual hot condition, and compound dry and condition) based on equation (1), which can be expressed as followed:

Dry	$P(impact\ variable \mid SPI \le 0)$	(2)
Hot	$P(impact\ variable \mid STI > 0)$	(3)
Compound dry and hot	$P(impact\ variable \mid SPI \le 0, STI > 0)$	(4)

III. Results

- **Validation of the Vine copula model**

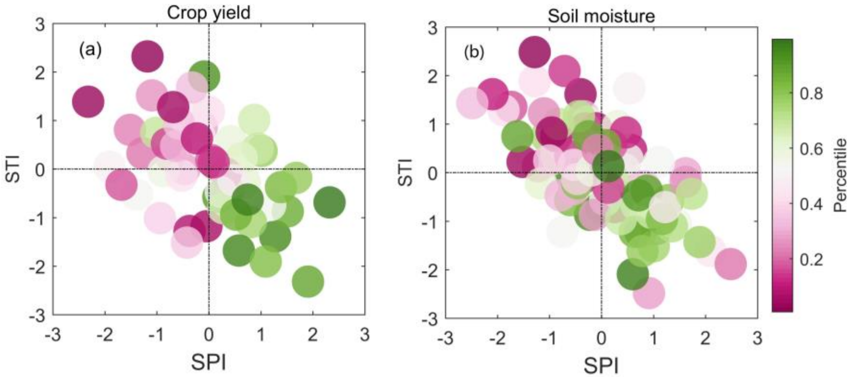

Figure 1 Scatterplots of compound dry and hot events and their impacts on (a) crop yield and (b) agricultural drought (represented by Standardized Soil moisture Index, or SSI). Standardized Precipitation Index (SPI) and Standardized Temperature Index (STI) are employed to represent dry and hot conditions.

- **Probabilistic impact of compound events on crop yield**

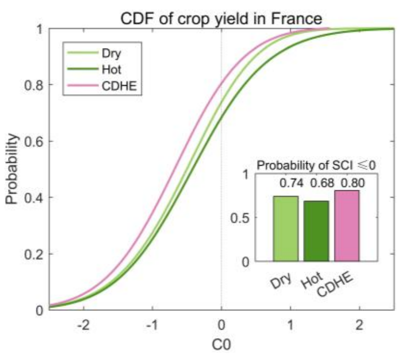

Figure 2 The conditional cumulative distribution function (CDF) of crop yields conditional on individual dry conditions, individual hot conditions, and compound dry-hot conditions (CDHEs).

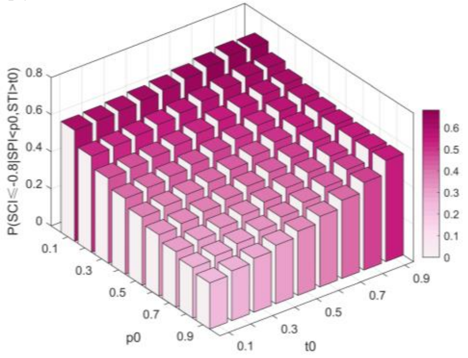

Figure 3 Conditional probability of crop yield reduction given different severity levels of compound dry-hot conditions.

- **Changes in the response of droughts to compound extremes**

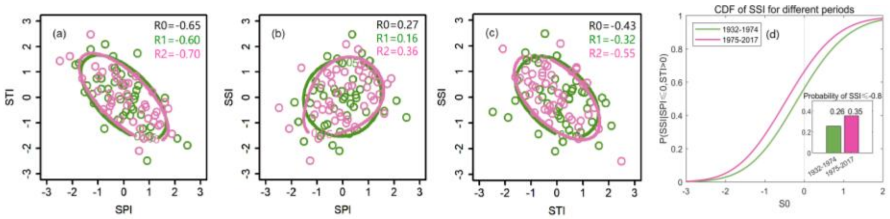

Figure 4 (a-c) SPI-STI, SPI-SSI, STI-SSI correlations for three different periods (full periods: 1932-2017, first periods:1932-1974, and second period: 1975-2017). R0, R1, and R2 indicate the dependence for the three periods, respectively. The contour of the joint probability density corresponding to the same density 0.05 of the two separate periods (1932-1974 and 1975-2017) is also shown. (d) Changes in the conditional probability of P(SSI|SPI≤0,STI>0) for two separate periods.

IV. Conclusion

- The impact from compound dry and hot conditions was higher than that from the individual dry or hot extremes based on the maize yield data in France.
- The dependence among climate extremes and agricultural drought in climate divisions of Texas was shown to increase, which induced higher impacts of compound dry and hot extremes in the recent period.
- The proposed framework is expected to aid the impact assessments of compound evens on different sectors under global warming.

References:

- Zscheischler, J. and Seneviratne, S.I., 2017. Dependence of drivers affects risks associated with compound events. Sci. Adv., 3(6): e1700263.
- Zscheischler, J., Westra, S., van den Hurk, B.J.J.M., Seneviratne, S.I., Ward, P.J., Pitman, A., AghaKouchak, A., Bresch, D.N., Leonard, M., Wahl, T. and Zhang, X., 2018. Future climate risk from compound events. Nat. Clim. Chang., 8(6): 469-477.

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