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Bivariate analysis of water stress duration and severity as a tool for long term planning of irrigation

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As many other natural hazards, the crop water stress has a typical multivariate nature, i.e. it is characterized by the contemporary presence of multiple characteristics correlated with each other (e.g. duration, severity, peak, areal extension, etc.). In this situation, a risk analysis based on a traditional univariate approach is inadequate for a complete interpretation of the phenomenon. The probabilistic joint analysis of two or more random correlated variables can be effectively solved by copula models. Copulas are functions that join univariate probability distributions to form multivariate probability distributions, modelling the dependence structure among random variables independently of their marginal distributions. This work illustrates how the joint probability and return periods of the Duration (D, days) and Severity (S, mm) of the crop water stress, can be used to analyse the effect of a certain irrigation strategy/planning on the return period of specific user-defined critical events, thus providing a tool for an optimal long term irrigation planning. The case study refers to two localities of central Italy and to olive, a crop widely grown in that area under rainfed or deficit irrigation regimes.
In the case study, 65 years of daily precipitation and maximum and minimum temperature were used to simulate (following the FAO 56 guidelines) the daily soil water dynamics (SWt) for olive. This simulation was performed according to 10 different irrigation strategies: strategy 1 (group 1) is rainfed, the strategies from 2 to 5 (group 2) consider a single irrigation at the end of one of the months between May and August, the strategies from 6 to 10 (group 3) consider two irrigations at the end of two of the months between May and August (consecutive or not). The irrigation volume of each irrigation was assumed equal to 50 mm applied in 15 days, thus simulating a drip irrigation distributing 3.3 mm/d. Then, by applying the Theory of Runs to SWt, with a threshold equal to the crop critical point, the water stress events were identified and characterized by their D (days) and S (i.e. the cumulative evapotranspiration deficit, mm) for each locality and strategy.
A 2-parameter Gamma distribution was fitted to both D and S, whilst their dependence structure was modelled by a Frank copula. A critical water stress event having D=74 days and S=105 mm was arbitrary selected. Those values correspond to the 90th percentiles of the D and S samples deriving from all the localities and strategies considered.
Finally, the localities and strategies were compared in terms of joint return period for $D \geq 74$ days and $S \geq 105$ mm. Results show that the return period of the critical event is significantly affected by both the climate (i.e. locality) and the irrigation strategy. Within group 1 the optimal strategy (i.e. that characterized by the highest return period) is represented by an irrigation applied at the end of June or July (depending on the climate). Within group 2 the optimal strategy involves two interventions at the end of June and July for both localities.