C304

Compound Drought-Fire Weather Conditions and Their Role in the 2025 Ofunato Wildfire in Japan

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1. Introduction

Wildfire occurrence and spread are typically influenced by multiple meteorological and environmental factors. Under drought conditions, the concurrence of adverse fire weather factors, including high temperature, low humidity, and strong winds, can substantially increase fire risk and intensify fire behavior. Extreme wildfire events tend to occur when such unfavorable factors co-occur and reach extreme states.

Copula functions provide an effective probabilistic framework for characterizing statistical dependence among multivariate variables, allowing the representation of nonlinear relationships and extreme tail dependence[1]. Fire weather conditions exhibit pronounced variability at short time scales, and rapid day-to-day fluctuations play an important role in wildfire occurrence and spread. At monthly or longer temporal scales, such short-lived extremes are often smoothed by temporal averaging. In this context, a daily-scale copula framework is more suitable for characterizing the dependence structure and joint extremes between drought and fire weather variables.

In February 2025, an extreme wildfire occurred in Ofunato City, Iwate Prefecture, representing the largest wildfire event in Japan over the past three decades. The burned area reached approximately 3,370 ha, which is nearly four times the total annual burned area of Japan in 2023. This study takes the Ofunato wildfire as a case study and develops a daily-scale analytical framework based on copula functions to quantify the compound drought–fire weather conditions associated with this event. Meteorological drought and soil drought are characterized using the 3-month Standardized Precipitation Index (SPI3) and soil moisture (SM), respectively, while effective humidity (EH) and wind speed (WIND) are employed to represent key fire weather variables. Copula functions are used to characterize the statistical dependence structure among these variables, and joint probability–based thresholds are applied to assess the intensity of compound drought and fire weather conditions during this extreme wildfire.

2. Method

A copula-based approach was applied at the daily scale to characterize the relationships between drought conditions and fire weather factors. For each calendar day, joint distributions were constructed using historical samples of drought (SPI3 and SM) and fire weather variables (EH and WIND) from the same calendar day during 1964 to 2025. All variables were transformed into uniform marginal probabilities using empirical cumulative distribution functions prior to modeling. The joint distributions were modeled using seven candidate copula functions including Gaussian, Student t, Clayton, Gumbel, Frank, Joe and the independence copula. Distance correlation and the Akaike Information Criterion was first used to select the optimal copula functions. Joint probabilities were calculated and combined with marginal probability thresholds to define compound events and to classify their intensity levels.

3. Result

Figure 1 shows the frequencies of daily optimal copula types for drought and fire-weather variables during February-March (1964-2025) in Ofunato. The copula-based analysis indicates that the statistical dependence between meteorological drought (SPI3) and fire weather variables is generally independent, with the optimal copula type is mainly the independence copula. For the SM-WIND, the daily optimal copula is predominantly the Independence copula, indicating a generally weak statistical dependence between SM and wind speed at the daily scale. In contrast, the SM-EH exhibits a more complex dependence structure, with the daily optimal mainly distributed among the Gaussian, Frank, Gumbel, and Joe families. The frequent selection of Gaussian and Frank copulas suggests a stable overall dependence between SM and EH within the central range of their distributions, whereas the occurrence of Gumbel and Joe copulas indicates stronger co-variability at higher quantiles, corresponding to wetter conditions.

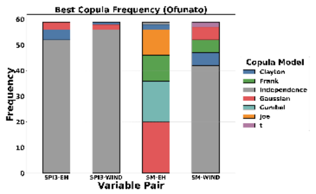

Figure 1 Frequency of Daily Optimal Copula Types for six variable pairs

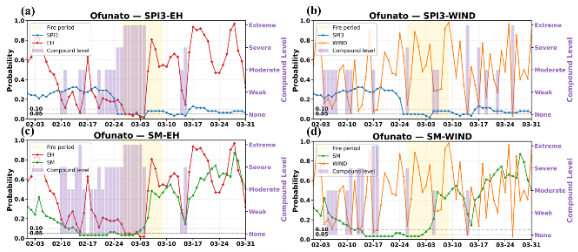

Figure 2 Temporal Evolution of Marginal Probabilities and Compound Levels of Drought-EH Conditions from February to March 2025: (a) SPI3-EH, (b) SPI3-WIND, (c) SM-EH and (d) SM-WIND

The temporal evolution of the compound drought-fire weather conditions is presented in **Figure 2**. The left axis shows the temporal evolution of single-variable probabilities, while the right axis represents compound level. The results indicate that SM had already declined to an extreme low state by mid-February, whereas the extreme low values of SPI3 occurred later, in late February. Although EH exhibits relatively large day-to-day variability, it shows an overall decreasing trend throughout February and reaches an extreme low level by the end of the month. In contrast, wind speed does not reach extreme levels during the wildfire period but remains at a relatively elevated level. In addition, both SPI3–EH and SM–EH enter and persist at extreme compound levels from the early stage of the wildfire period, whereas compound conditions involving wind remain comparatively weak.

4. Conclusion

This study applies a daily-scale copula approach to evaluate compound meteorological conditions during the extreme wildfire event in Ofunato in 2025. The results show that the dependence between drought and fire weather variables is generally weak and can be approximated as statistically independent under drought conditions. During the spread of the Ofunato wildfire on 26 February, compound drought and fire weather conditions reached extreme levels, highlighting the presence of pronounced compound meteorological anomalies during the extreme wildfire event.

5. Acknowledge

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6. Reference

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