

The authors would like to thank the reviewer for their comprehensive review and constructive comments that have improved this manuscript.

The reviewer's comments have been numbered using the format QX.Y where Q is the reviewer query, X is the reviewer comment number and Y represents a subdivision of the comment if there are multiple items requiring attention. Responses follow the format of reviewer's "nhess-2021-241-RC2_supplement.pdf". The authors' response to each comment is given below each question/comment using the format RX.Y.

Q1.1 Their definition of compound events are not correct. The sampled AM extremes do not represent the compound event. Since unlike drought, which is a slowly developing phenomena, the occurrence of floods is faster; varies from few hours (e.g., flash flood) up to a week of time scale (considering inundation effects). The authors define AM event to be when the maximum sampling pairs of single largest precipitation and Observed Water Level (OWL) happens within a year or month. However, the paired events can only be qualify as 'compound coastal-pluvial or riverine floods' when the two drivers occurs coincidentally if not successively within a limited time window.

R1.1. The authors agree that the annual maximum method does not represent an observed compound event. However, FEMA, a primary flood regulatory agency in the United States specifically suggests characterizing compound events using the annual maximum pairing (FEMA, 2016). The text has been substantially updated to reflect this key distinction that the reviewer points out. The new text in L103-114 of the revised manuscript is:

Compound flood probabilities are determined with combinations of sampling methods: Annual Maximum (AM), Annual Coinciding (AC), Wet Season Monthly Maximum (WMM), and Wet Season Monthly Coinciding (WMC). AM sampling pairs the single largest precipitation and OWL observations within a given year (without regard to co-occurrence), where AC sampling pairs the single largest precipitation observation within a given year to the largest OWL observation within its 24-hour accumulation period. A summary of each sites' associated gauges, observation windows, and number of pairs is provided in Table 2. Southern California's wet season is defined between October to March and provides a majority of the total annual rainfall (Cayan and Roads, 1984; Conil and Hall, 2006). It is likely for extreme compound events to occur during this period.

Wet season monthly maximum pairs the single largest precipitation and OWL observations within each wet season month. Although strictly speaking maximum parings (annual or wet season) do not technically represent an observed compound event since the co-occurrence of precipitation and water levels follows the FEMA guidance for considering a "worse case scenario" approach (FEMA, 2016c). Wet season monthly coinciding sampling pairs the single largest precipitation observation within each wet season month to the largest OWL observation within its 24-hour accumulation period, providing more realistic pairs compared to maximum sampling.

Q1.2 Based on large-scale climatic pattern this time window is often taken as a within a week of occurrence of the first event. This is because it may take a few days to inundate from rivers as well as coast to know the combined impact, which may not be possible to detect within ± 1 -day of occurrence of the event. Secondly, a large watershed may respond within few days of occurrence of the storm event – it may take a few days' time to reach water to flow to the outlet, when it meet with coastal

storms. Therefore, a lag-days to be considered to sample such events, however, it would be based on the time of concentration of the watershed and not the user defined input.

Considering a single largest precipitation observation within a year or month to the largest OWL observation within its 24-hour accumulation period, is the one, which could be categorized as a compound event, per se. However, here also the question lies whether the watershed is large/medium sized and the land use pattern of the watershed. For example, in case of a large rural (or agricultural intensive) watershed the time of concentration would depend upon the catchment area and flow path length to travel water from the remote point to the catchment outlet. Therefore, the choice of 24-hr/a day may not be adequate to model dependency between two drivers.

Based on the above two comments I find the definition of compound event sampling adopted in the manuscript is erroneous. Rather, their definition could be categorized to solely a multivariate interpretation of extremes.

R1.2 This study considers the co-occurrence of precipitation and high marine water in a semi-arid, highly urbanized coastal watersheds. The key distinction is that the precipitation component causes pluvial (i.e., surface water flooding from intense rainfall) rather than fluvial (i.e., riverine) flooding and occurs on much shorter time scales. The United State Geological Survey (USGS) and the United States Department of Agriculture (USDA) classify individual watersheds with hydrologic unit codes (HUC). HUC10 officially represent watersheds. The time of concentration (T_c) for each HUC watershed were estimated using digital terrain data and the Kirpich (Kirpich, 1940), FAA (1970), and SCS Lag (1975) methods that have been previously applied in southern California coastal watersheds (e.g., Kang et al., 2008, Parker et al., 2019). HUC10 watershed T_c range is ~ 1 -10 hours depending on individual watershed characteristics. All locations are less than 24-hour T_c . From literature perspective, storm surge and precipitation 24 hour windows are commonly used (e.g., Wahl et al. 2015, Xu et al., 2014, Xu et al., 2019, Yang et al., 2020). Given both the rapid T_c of these particular watersheds and the literature, the authors believe the 24-hour time window is appropriate.

Q1.3 Further, for wet season monthly maximum and wet season monthly coinciding method of samples, the sampling methods are not properly described.

R1.3 The authors have provided additional detail and substantially updated the text to more expansively describe the sampling methods. The new text in L110-114 of the revised manuscript is:

Wet season monthly maximum pairs the single largest precipitation and OWL observations within each wet season month. Although strictly speaking maximum pairings (annual or wet season) do not technically represent an observed compound event since the co-occurrence of precipitation and water levels follows the FEMA guidance for considering a "worst case scenario" approach (FEMA, 2016c). Wet season monthly coinciding sampling pairs the single largest precipitation observation within each wet season month to the largest OWL observation within its 24-hour accumulation period, providing more realistic pairs compared to maximum sampling.

Q1.4 It is not clear whether these two samples follow the iid behavior. This is because as the sampling was performed only based on wet seasons, if they are sampling large number of events then the method fails to preserve iid assumption for frequency analysis. This would calls for nonstationary method, instead of stationary method adopted here.

For example, in Page 24, Line 309: By sampling entire wet season, you would not be able to sample iid events; also it is not the true representative of rare events.

R1.4 Our assumption for iid behavior is consistent with current literature (Mendoza and Jiménez, 2006, Li et al., 2014, Kapelonis et al., 2015, Shao et al., 2020) considering fast time scale events. These studies ensure iid using a minimum separation window between events on the scale from hours to 5-days. Similarly, in our study the separation window between events is sufficiently large to ensure iid given we sample a single event per year, when using annual sampling, and once per month during the wet season (October to March), when using wet season sampling. Additionally, the events occurring in the watersheds within this study are fast responding and will occur within a 24-hour window (please see response R1.2).

Q2.1. The authors have used the vast array of copulas, based on their simulation they infer that the three families are describing the paired event characteristics sufficiently well. However, they have not shown any formal goodness-of-fit that suggests credibility of selected copulas to fit the multivariate extremes. Neither, they discuss out of the three which copula family performs the best for modelling multivariate extremes.

R2.1 The Bayesian Information Criterion (BIC) and Maximum Likelihood (ML) goodness of fit metrics are provided in section 3.5, equations 16-19. Figure 4 presents the ML values for each tested copula and sampling strategy. ML values describe how well the parameters of an assumed distribution represent a given sample (Chapter 7.5 and 7.6 from DeGroot et. al., 2014), and have been previously used as a goodness of fit metric (e.g., Sadegh et al., 2017, 2018). The authors refrain from explicitly recommending a particular copula since a single ‘best’ copula did not emerge for given samplings across all three sites. However, the authors point out the most well fit (and poorly fit) copulas and their impacts on return periods (e.g., Tables 5, 6). Akaike Information Criterion (AIC, Figure A3) and BIC (Figure A4) goodness of fit metrics have been added to the Appendix and below.

Q3.1 Although they have coined a term “Structural” in the return period concept, but in the discussion or results section, I could not find any dedicated section that distinguishes structural or failure probability concepts.

R3.1 Section 3.2.5 specifically introduces the “Structural” hazard scenario and associated literature. The text has been substantially updated to provide additional context. The revised text (L171-175) now reads:

The “Structural” scenario considers the probability of an output from a structural function, $\Psi(x)$ exceeding a design load or capacity (z) (Salvadori et al., 2016). For example, De Michele et al. (2005) and Volpi and Fiori (2014) used a structural function to evaluate a dam spillway while Salvadori et al. (2015) considers the preliminary design of rubble mound breakwater. In this work, the structural failure function focuses on the question “what is the probability of a water level forcing tide valve closure and subsequent flooding during a precipitation event?”.

Q4.1 15. Line 327: ‘OR’ scenario may not provide an accurate estimate of compounding condition since in this case, only one of the variable is assumed to exceed over the other. The simultaneous or joint exceedance of variables are considered in ‘AND’ scenario case only.

R4.1 The authors agree with the reviewer’s comment that the ‘AND’ scenario provides only the joint exceedance of both variables. The ‘OR’ scenario probability space encompasses three regions: events dominated by the primary variable, events dominated by both variables, and events dominated by the secondary variable (Figure 1, Salvadori et al., 2016). Literature presents multiple studies that have considered the “OR” hazard scenarios (Table 1, Salvadori et al. 2016).

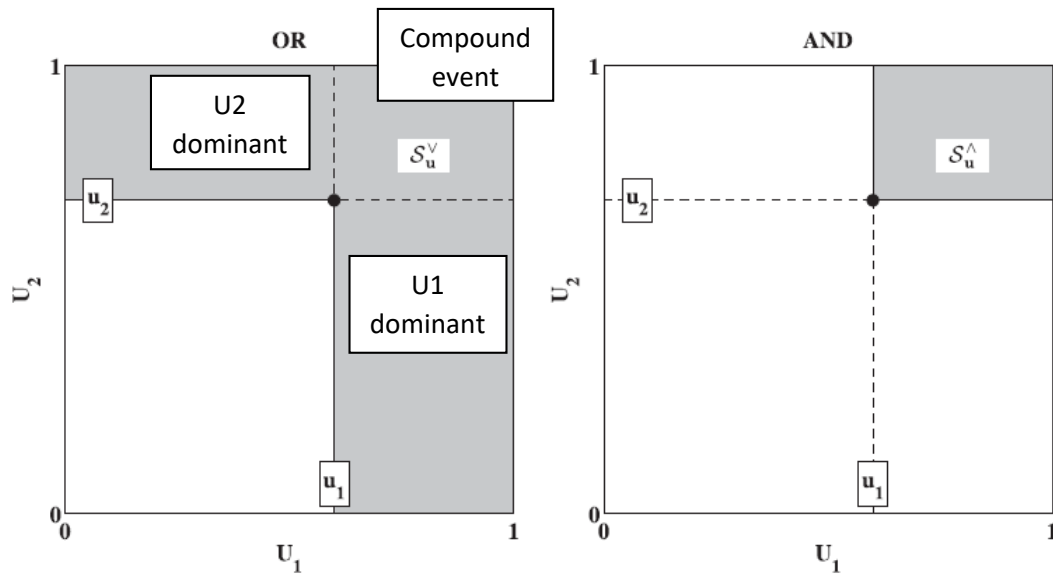


Figure 1 - ‘OR’ and ‘And’ Probability spaces. Adapted from Salvadori et al., (2016). All definitions are from Salvadori et al., (2016).

Q5.1 Page 3, line # 60: Although authors have pointed annual maxima sampling generates a worst case scenario; this has been followed earlier. Moftakhari et al. (2017) modeled failure probability for the extreme scenario aiding disaster response considering concurrence of the largest annual freshwater inflow to the lower estuary and the corresponding largest observed hourly water level within ± 1 day.

R5.1 Moftakhari et al. (2017) explores compound coastal-fluvial (marine-riverine) events. In contrast, our study explores a coastal-pluvial type event where high marine water levels and precipitation co-occur. In both cases indeed, the annual maximum presents a ‘worst-case’. However, the results are distinct since the events considered fundamentally differ.

Q6.1 Page 3, line # 65: cold & wet fall season (Ganguli et al., 2019a.b), where authors compare coastal compound floods relative to winter seasonal peak discharge and found larger amplifications upon considering compounding effects than solely accounting for high winter (November-March) discharge over northwestern Europe.

R6.1 The authors would like to thank the reviewer for pointing out this work and have added the suggested citations to the text. The definition of “winter” used in Ganguli et. al., 2019a, 2019b does not strictly align with the definition of ‘wet season’ given the differences in climatology, hydrology, and coastal dynamics between Southern California and Northwestern Europe.

Q7.1 Page 3, line # 89: The authors have claimed that in current compound flood literature, the terms tides and storm surges are interchanged; this is not true. Check Devlin et al., (2017); Ganguli and Merz,

(2019); Ganguli et al. (2020) as a reference. While in Ganguli and Merz (2019) observed high coastal water level was used that includes tides, storm surges and wave setup, for Ganguli et al. (2020) only meteorologically driven skew surge was considered.

R7.1 The authors thank the reviewer for pointing this error out. The term 'storm surge' should have been 'water level'. The text has been updated to reflect this change and now reads. "It is worth noting, that within the body of compound flooding literature, the terms tide and water level may be interchanged (e.g., Lian et al., 2013; Xu et al., 2014; Tu et al., 2018; Xu et al., 2019, Yang et al., 2020)."

Q8.1 Table 1: several references are missing:

- a. River discharge and water level: (Ganguli and Merz, 2019a, b).
- b. River discharge and storm surge: (Ganguli et al., 2020).
- c. River discharge and volume (Reddy and Ganguli, 2012).
- d. Rainfall and tide: (Bevacqua et al., 2020).
- e. Combination of river discharge, volume, and duration (Ganguli and Reddy, 2013).

R8.1 The authors thank the reviewer for providing these studies. Ganguli and Merz, (2019a, b) was added to "River discharge and water level". Ganguli et al., (2020) was added to "River discharge and storm surge". Reddy and Ganguli, (2012) and Ganguli and Reddy, (2013) were added to "Combination of river discharge, volume, and duration". Bevacqua et al., (2020) was added to "Rainfall and tide".

Q9.1 Fig. 2 Captions: Expand each of the terms, AM, AC, WMM, WMC, SM, S, and SD.

R9.1 The reviewer's suggestion has been adopted and the caption updated accordingly.

Q10.1 Page 8: Line #148: separates supercritical vs sub-critical region.

R10.1 The text has been updated to include the reviewer's suggestion and now reads: The "Kendall" (K) scenario highlights an infinite set of OR events that separate the subcritical (i.e., "safe") and supercritical (i.e., "dangerous") statistical regions.

Q11.1 In Eqn. 12: it was not shown how individual marginal CDFs were included in the expression to get the Kendall 'AND' return period.

R11.1 Equation 12 is related to the "Survival Kendall". The Survival Kendall scenario (Equation 11) utilizes a "survival copula" which utilizes "survival CDFs" detailed in Section 3.2.2. Additionally, the reader is referred to Salvadori et al. (2013), Salvadori and De Michele (2004), and Serinaldi (2015) for additional information.

Q12.1 In Eqn. 13: Are you considering Kendall's return period to define this case? If it is, it should be properly expressed.

R12.1 Equation 13 described the "Structural" scenario (e.g., De Michele et al., 2005, Salvadori et al., 2016). Section 3.2.5 specifically introduces the "Structural" hazard scenario and associated literature. Section 4.4 details the application of the "Structural" scenario which, in this case, follows a Conditional 1 type event. Please also see **R3.1** for additional details.

Q13.1 Page 10: Line 210, the choice of marginal distribution depends on the tail property: if the shape of density function show fast decaying pattern; exponential /Gumbel (GEV-I) distribution would be good; however, for long upper tail, heavier tail distribution is being preferred. Therefore, I would suggest to summarize the basic summary statistics of driver variables, including their skewness and excess kurtosis. Based on that they can make inferences, why certain univariate marginal fits the best.

R13.1 Marginal BIC values, which MvCAT uses to select optimal distributions, for OWL (Figure A1) and precipitation (Figure A2) are now provided in the Appendix and, for the reviewer's convenience, below. Additionally, marginal distributions were independently tested using a visual chi square test (e.g., Requena et al., 2013).

Q14.1 Page 12: line #245, It is not clear if the goodness-of-fit is performed for the choice of copulas? Different copulas behaves differently and one has to select a copula class, which can represent the sample on the basis of their ability to simulate complete vs upper tail dependences. This concern I have also raised as a major comment.

R14.1 Please see responses R2.1 for a comprehensive explanation of goodness-of-fit metrics.

Q15.1 Page 18: Line 269, We only consider compounding aspects if they occur within a limited or close time intervals, for example, within a week of occurrence; because of large sized of a catchment, it is physically may not be possible that both events co-occur simultaneously; a lag effect to be considered during event sampling. The response of medium to large sized watershed to a rain event is proportional to the time of concentration of the watershed. This can be utilized to estimate the lag effect.

R15.1 Precipitation drives a pluvial flooding event on the relatively small urbanized coastal watersheds which exhibit a rapid time of concentration on the order of 1-10 hours. The reviewer is referred to **R1.2** for additional information regarding the watershed time of concentration.

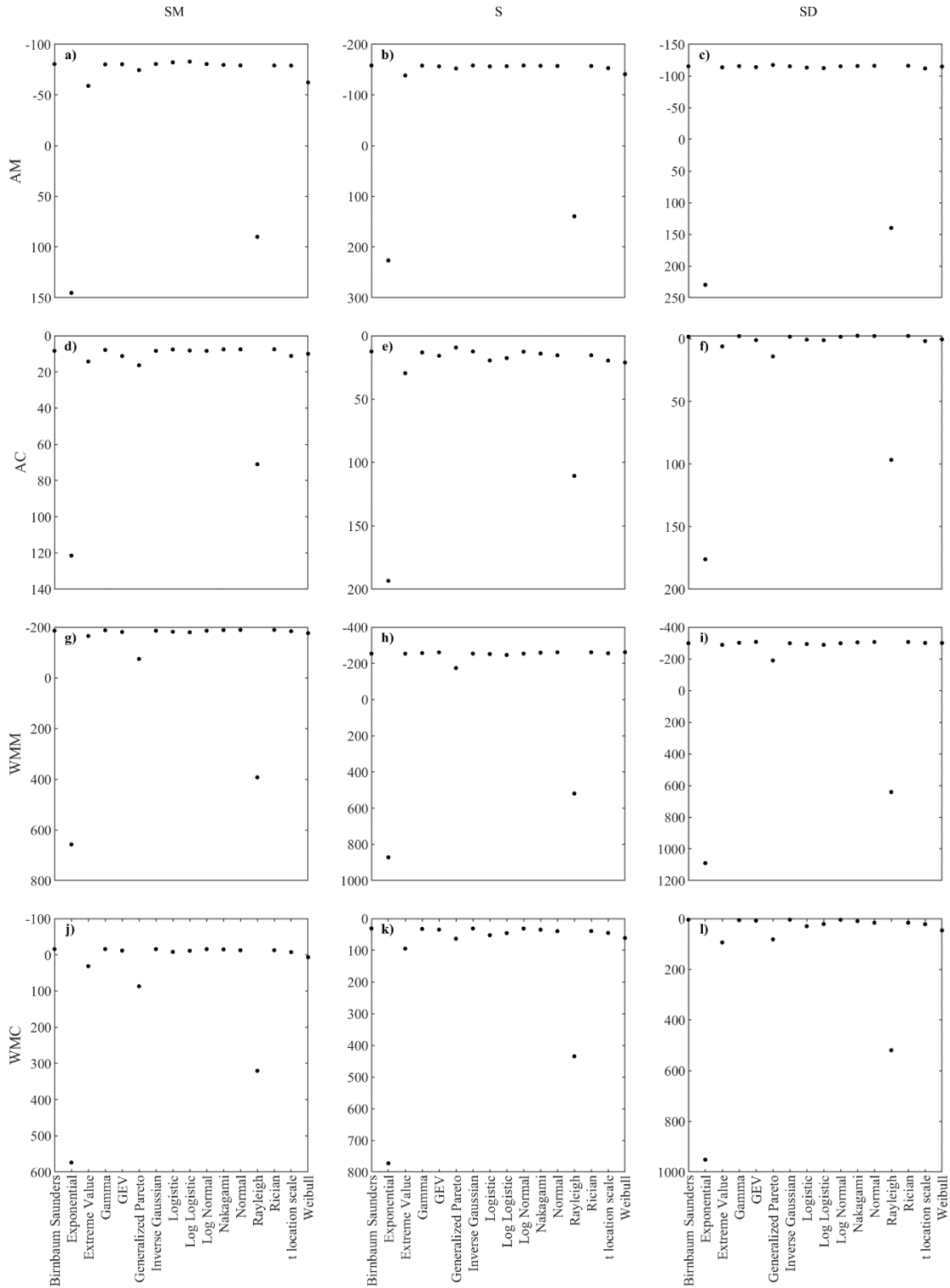


Figure A1 – Marginal OWL BIC values per fitted copula for SM (left column), S (middle column), and SD (right column). Annual Maximum (a), (b), (c); Annual Coinciding (d), (e), (f); Wet Season Monthly Maximum (g), (h), (i); and Wet Season Monthly Coinciding (j), (k), (l). The Y-axis is orientated to display best BIC (top) to worst BIC (bottom).

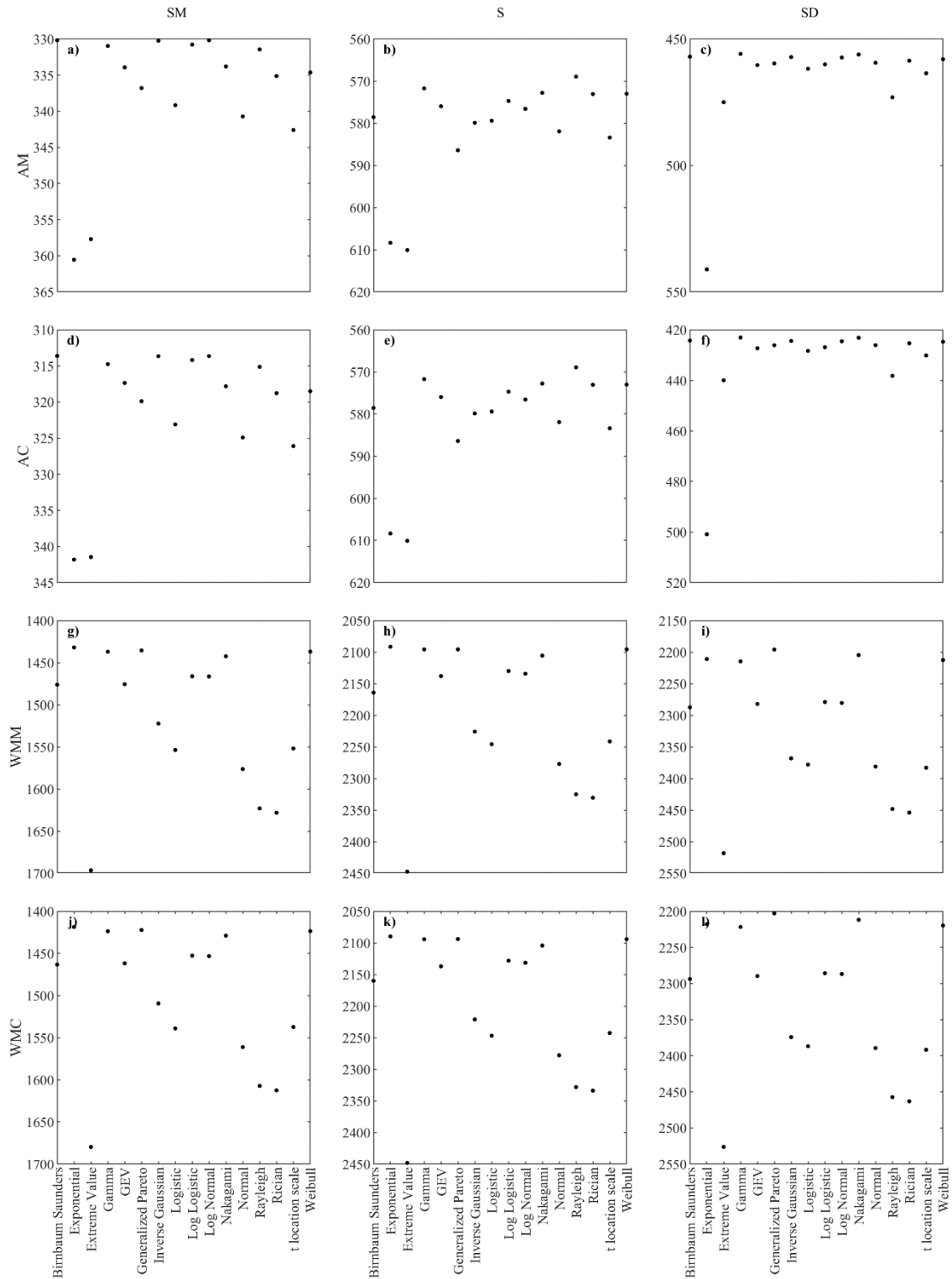


Figure A2 – Marginal precipitation BIC values per fitted copula for SM (left column), S (middle column), and SD (right column). Annual Maximum (a), (b), (c); Annual Coinciding (d), (e), (f); Wet Season Monthly Maximum (g), (h), (i); and Wet Season Monthly Coinciding (j), (k), (l). The Y-axis is orientated to display best BIC (top) to worst BIC (bottom).

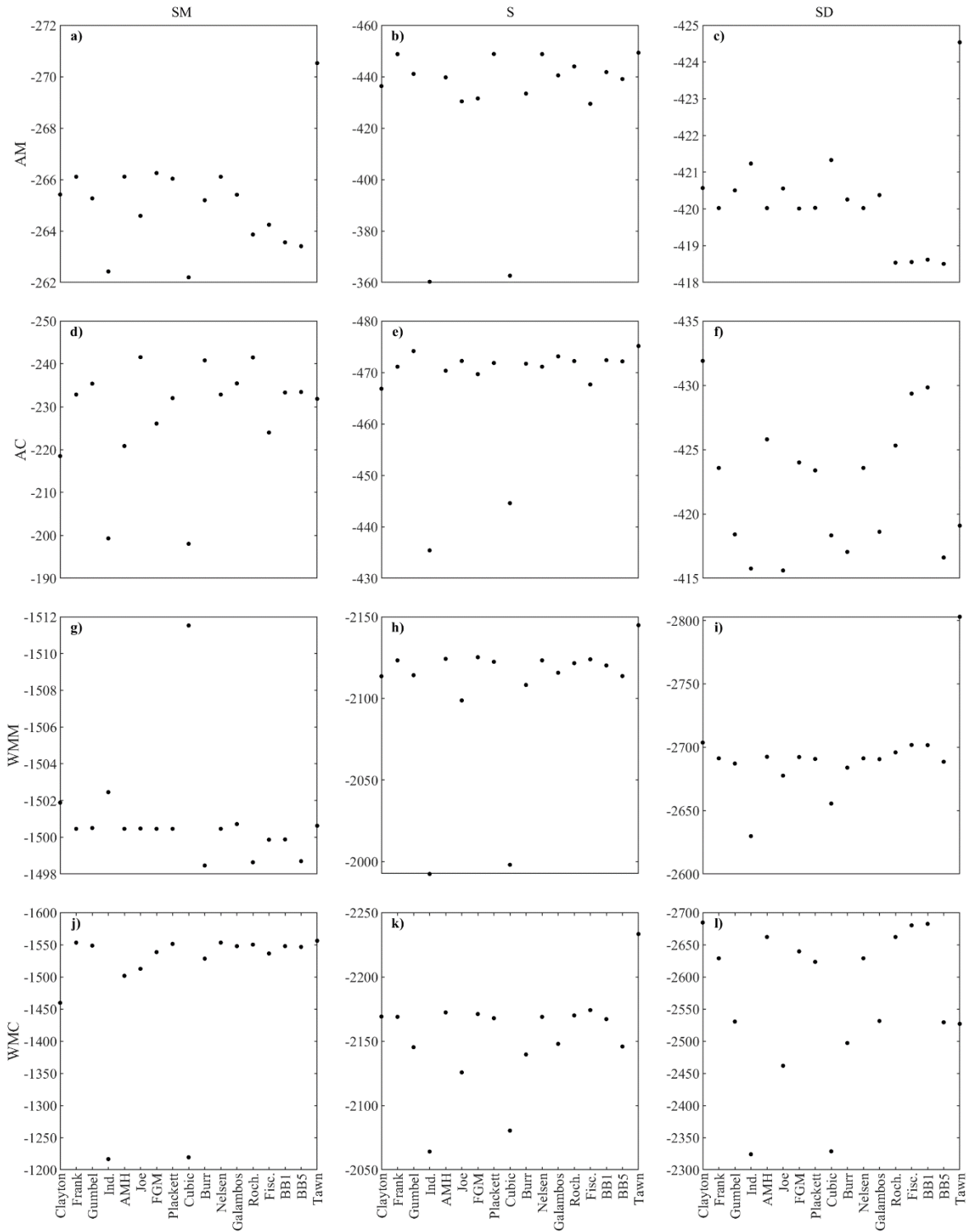


Figure A3 – Copula AIC values per fitted copula for SM (left column), S (middle column), and SD (right column). Annual Maximum (a), (b), (c); Annual Coinciding (d), (e), (f); Wet Season Monthly Maximum (g), (h), (i); and Wet Season Monthly Coinciding (j), (k), (l). The Y-axis is orientated to display best AIC (top) to worst BIC (bottom).

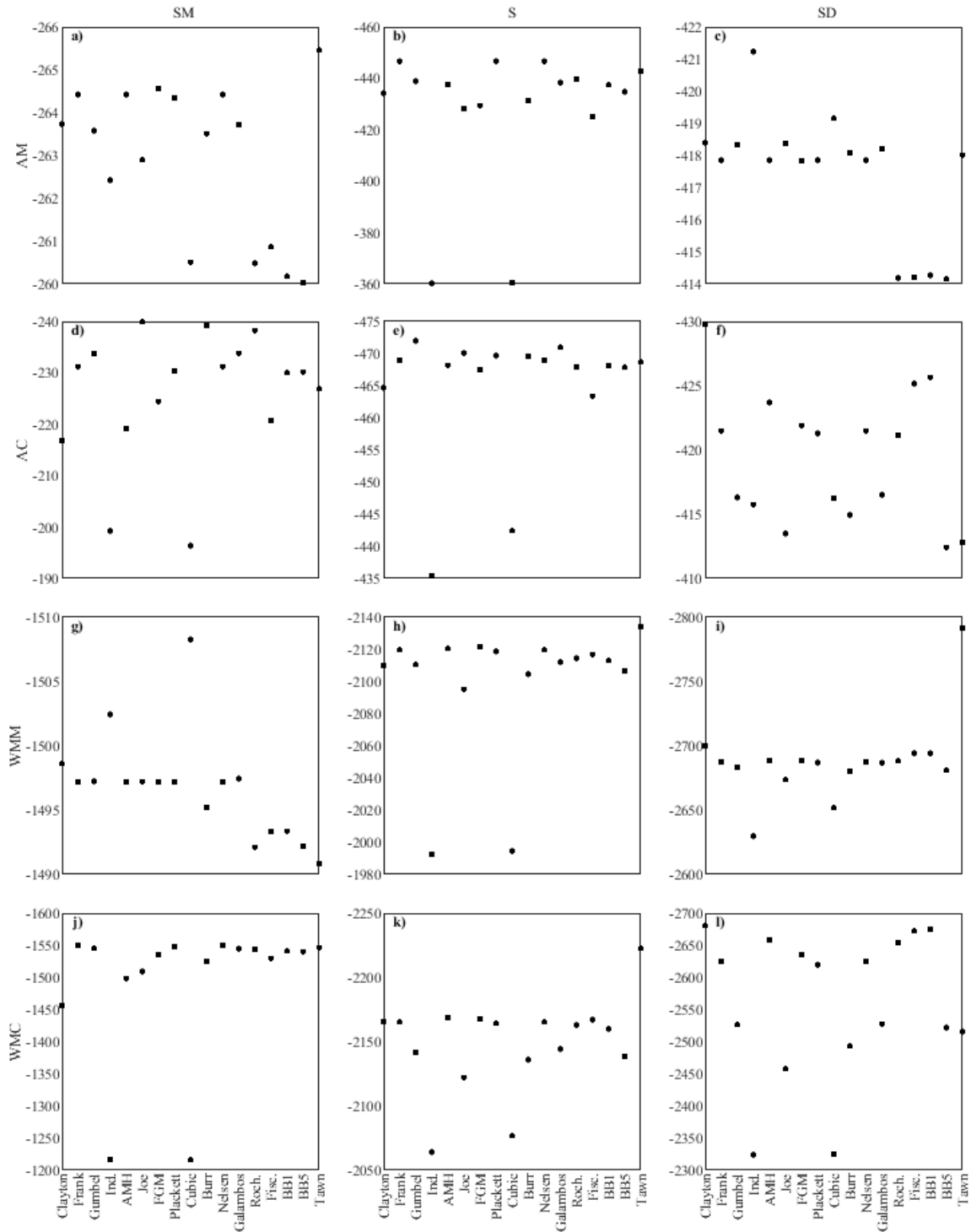


Figure A4 – Copula BIC values per fitted copula for SM (left column), S (middle column), and SD (right column). Annual Maximum (a), (b), (c); Annual Coinciding (d), (e), (f); Wet Season Monthly Maximum (g), (h), (i); and Wet Season Monthly Coinciding (j), (k), (l). The Y-axis is orientated to display best BIC (top) to worst BIC (bottom).

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