Lecture Notes in Civil Engineering

Yoshimitsu Tajima
Shin-ichi Aoki
Shinji Sato *Editors*

Proceedings of the 11th International Conference on Asian and Pacific Coasts

APAC 2023, 14–17 November, Kyoto, Japan

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Yoshimitsu Tajima · Shin-ichi Aoki · Shinji Sato
Editors

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Preface

This book presents peer-reviewed articles from the 11th International Conference on Asian and Pacific Coasts (APAC 2023) held in Kyoto, from 14 to 17 November 2023. The goal of the conference was to promote academic and technical exchange on coastal-related studies among researchers and engineers of Asian and Pacific countries/regions. Besides coastal engineering, the field of coastal-related studies includes, but not limited to, coastal environment, coastal management, natural hazards, marine ecology, coastal oceanography, and fishery science and engineering. APAC is jointly supported by the Chinese Ocean Engineering Society (COES), the Coastal Engineering Committee of the Japan Society of Civil Engineers (JSCE), and the Korean Society of Coastal and Ocean Engineers (KSCOE).

The first conference, named as Asian and Pacific Coastal Engineering (APACE), was held in Dalian, China, in 2001. To reflect a broader scope of the conference, it was renamed as Asian and Pacific Coasts (APAC) and had been subsequently held every two years in the following different cities, Makuhari in Japan (2003), Cheju in Korea (2005), Nanjing in China (2007), Singapore (2009), Hongkong in China (2011), Bali in Indonesia (2013), Chennai in India (2015), Manila in the Philippines (2017), and Hanoi in Vietnam (2019).

The 11th conference held in Kyoto, Japan, is the first conference held after a four-year period following the COVID-19 pandemic. Out of the 291 abstracts submitted to the conference, 103 peer-reviewed full papers were accepted for publication in the proceedings of APAC 2023. Topics of these papers cover variety of fields such as: observations, laboratory experiments, modeling, and numerical simulations of waves, currents, storm surges, tsunamis, other nearshore hydrodynamics including estuaries; wave forces and wave over-toppings on coastal structures; interactions among wave, seabed, and coastal structures; sediment transport; topography changes; coastal environment and ecosystem; impact of climate change; disaster prevention, mitigation, and management; and various sensing and monitoring techniques.

Under the influence of climate change and various human activities, Asian and Pacific coasts have experienced significant change and deterioration in various aspects. This book together with intensive discussions through the APAC 2023 conference significantly contributes to sharing and understanding our experience and knowledge that leads to better strategies and planning for coastal adaptation, protection, and conservation.

Last, but not least, sincere gratitude is expressed to APAC Council and International Steering Committee members for their continuous support for APAC over decades, to all the reviewers and APAC 2023 Paper Review Committee members for reviewing and giving comments for improvement of published articles, and Local Organizing Committee of APAC 2023, for their careful and diligent works to organize the conference.

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About the Editors

Dr. Yoshimitsu Tajima received his Ph.D. from Massachusetts Institute of Technology, the USA. He now serves as a professor at the School of Engineering, the University of Tokyo, Japan. He has experience of coastal engineering both in academic research and in practical projects since 1995. As an engineer of the Institute of Penta-Ocean Construction Co., Ltd., he was involved in various projects such as designs of coastal structures and environmental impact assessment of coastal development. As a faculty of the University of Tokyo since 2005, his research has mainly focused on monitoring and modeling of various nearshore dynamics such as waves, currents, tsunami, storm surge, sediment transport, and coastal topography changes.

Dr. Shin-ichi Aoki received his doctoral degree from Osaka University, Japan, in the field of Civil Engineering. He started his career at Osaka University as a research associate in 1983. He moved to Toyohashi University of Technology as an associate professor in 1993 and promoted to a full professor in 2003. He moved back to Osaka University in 2012 and retired in 2023. His academic activities are mainly with the Japan Society of Civil Engineers (JSCE), where he served as the director and the chair of the Coastal Engineering Committee from 2015 to 2016. His research field is coastal engineering, including coastal disaster prevention, coastal geomorphology, and coastal environment.

Dr. Shinji Sato graduated from the Graduate School of Engineering, the University of Tokyo, in 1983. He worked at the University of Tokyo and Yokohama National University until 1994. He moved to Public Works Research Institute, Ministry of Construction, and worked for the Coast Division until 1999. He then moved to the University of Tokyo and was appointed to a professor in 2000. His major is coastal engineering, especially sediment movement and beach evolution. His research topics include nearshore processes, large-scale, long-term coastal evolution, infragravity motion, coastal disaster mitigation against storm surge and tsunami, and sustainability of coastal environment. He has done pioneering works on oscillatory boundary layer flow over bedforms, numerical model development of nonlinear dispersive waves, nearshore currents due to waves and winds, and sediment movement in the watershed scale. He was awarded with Excellent Paper Award of Japan Society of Civil Engineers in 1998, Coastal Engineering Journal Award in 2005, and JSCE Excellent Book Publication Award in 2014. He currently serves as a professor at Kochi University of Technology.

Analysis of Wave and Current

Tools for Building Spatial Dependence Structure of Extreme Wave Heights at Regionally Neighboring Ports

Toshikazu Kitano

Abstract Multivariate normal distribution is widely used in the general statistical analyses. Extreme wave heights should be, if possible, examined according the extreme value theory, which is constructed by multivariate normal distribution, because it has great advantages like as the general normal statistics. In this study we clear the essential and useful properties of the model and propose a method of analysis as well as show the items in the toolbox: another simpler model, accordance index to grasp the dependencies, KS test of bivariate symmetry, Kendall distribution to check the bivariate dependency, etc. We remark the constraints also and demonstrate an example for the dependencies of annual maxima of wave height at the ports located along the pacific coast in Japan.

Keywords Joint occurrence · HR model · Accordance index · Return period

1 Introduction

Accumulating risk is an issue in the climate change as several different cities in wide range suffer from severe damages by the same storm event, because the recovery will become difficult in the point of view of the resources of funds and manpower. As the typhoon will become magnified due to the global warming, such joint occurrence of disasters in a vast region should be taken more in consideration for disaster reduction plan. Based on these backgrounds, multivariate extreme values models should be applied to examine the co-occurrence of regional hazards. Dependence structure of multivariate extremes is totally different from the normal statistical variations.

In the general statistical analysis, there is known many useful tools based on the normal distribution. The biggest advantage is the fact that it can be identified if only the variances for marginal univariates and the correlation coefficients between the pairs for all combination of variables are determined. This is important for the

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practical use in engineering. However multivariate extreme values do not follow a unique type of the distribution functions, which is contrast to the marginal (univariate) extreme value distribution which is only one form given by a generalized extreme value (GEV) distribution. Even though it will be complicated to deal with the multivariate extreme values seriously and rigorously, we believe there will be some relatively easy ways to apply the essential properties of multivariate extreme values to the practical uses of coastal engineering. Especially in case of the pairwise symmetry, it will be possible to apply the higher multivariate models with our proposed tools in this study.

2 Component-Wise Maxima of Wave Heights Data

2.1 Wave Heights Data at Neighboring Ports and the Joint Occurrences

Figure 1 shows the time history of the annual maxima (19 years between 1999 and 2017) of wave heights at neighboring 4 ports of the Pacific Ocean coast of Japan central coast (Tokai coast almost 200km long): from east to west, Shimoda (A), Shimizu (B), Omaezaki (C) and Isewanko (D) (data source: NOWPHAS [1]). Unfortunately at Isewanko (D) 3-year data (1999–2001) are not available. Bullet mark indicates joint occurrence. A and C in 2001, A, B and C in 2002, etc. were due to the same storm. All 4 ports in 2006 did occur jointly, not two different events for 2 pairs of ports, but it is due to same storm.

All sets of data are fitted to a generalized extreme value distribution, whose cumulative probability function is given by the Poisson probability with the occurrence rate

$$P(y) = \exp\{-\lambda(y)\}; \qquad \lambda(y) = \left(1 + \xi \frac{y - \mu}{\sigma}\right)^{-1/\xi} \tag{1}$$

We estimate the values of three parameters in the occurrence rate, and we checked visually the goodness of fit to the marginal distributions in the plot of Fig. 2 against the return period x for wave height y and the corresponding return periods $X(j, n)$ for the annual maxima of wave heights $Y(j; n)$ of increasing order.

$$x = \frac{1}{\lambda(y)}; \quad X_{(j,n)} = 1/\log\left(\frac{n+1}{j}\right) \quad \text{for } Y_{(j,n)} \tag{2}$$

where in case of $j = n$, the largest value X (n,n) is close to n when n is enough large.

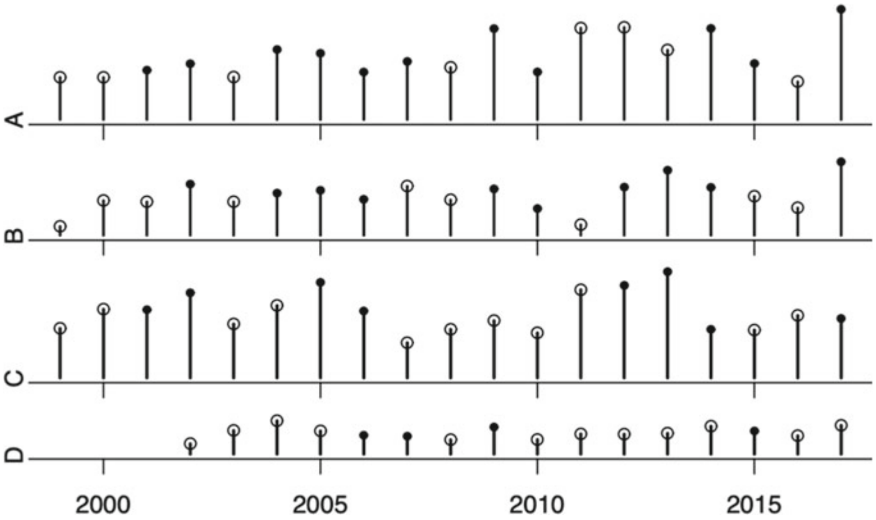

Fig. 1 Time history of annual maxima of wave heights (bullets are due to the same storm)

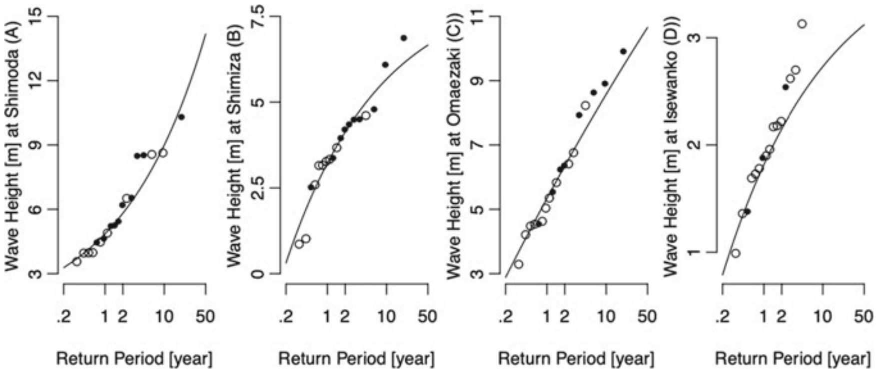

Fig. 2 Plots of wave heights shown in Fig. 1 in increasing order against the return period

2.2 Accordance Index

Figure 3 shows the bivariate scatter plot by uniform margin, which indicates the cumulative probability of the marginal distribution. Pairs of annual maxima are not always due to the same storm; thus by taking into account that this fact represents the dependency, Kitano et al. [2] define accordance A as a new index of the dependency and the sample value obtained by the following:

$$\hat{A} = \frac{\text{(Number of the pairs of the annual maxima due to the same storm)}}{\text{(Total number of the years of recorded length)}} \tag{3}$$

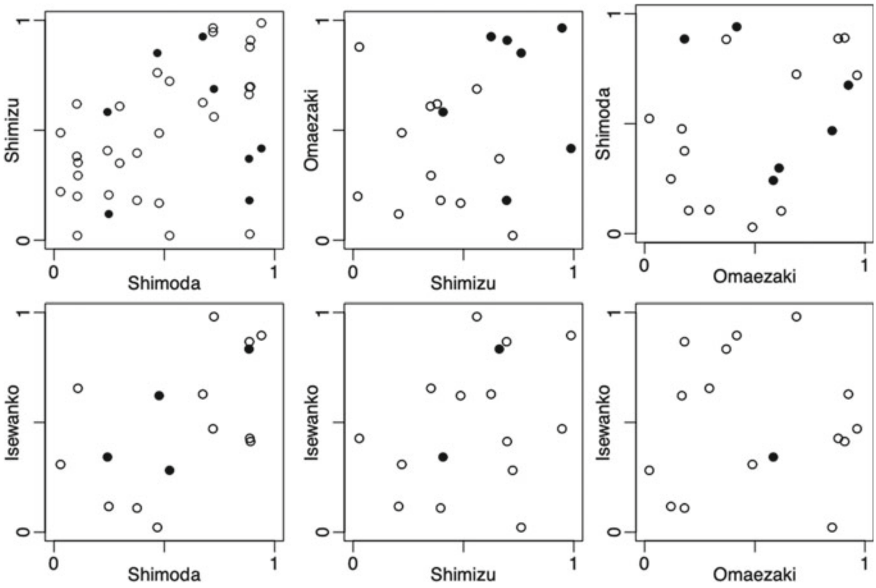

Fig. 3 Scatter plots by copula representation with the accordance

which is noted to be defined not only for bivariate but also for higher dimension.

3 Models for Multivariate Extreme Value Statistics

3.1 *Husler-Reiss Model—A Brief But Essential Introduction*

Original derivation [3] of Husler-Reiss model (hereafter it is abbreviated as HR model) is based on the limiting form of the following joint occurrence rate:

$$\lambda_{\mathrm{AB}} \approx \int_{x_{\mathrm{A}}}^{\infty} P(X_{\mathrm{B}} > x_{\mathrm{B}} | X_{\mathrm{A}} = x_{\mathrm{A}}) dP(x_{\mathrm{A}}) \approx \int_{\log x_{\mathrm{A}}}^{\infty} \overline{\Phi}\left(b + \frac{\log x_{\mathrm{B}}\Delta - z_{\mathrm{A}}}{2b}\right) e^{-z_{\mathrm{A}}} \mathrm{d}z_{\mathrm{A}} \tag{4}$$

where Φ with overline stands for the exceedance probability of the standard normal distribution. The integration by parts can evaluate the above, then by setting $\lambda_A = 1/x_A$ and $\lambda_B = 1/x_B$, we get the rate in the analytical form:

$$\lambda_{AB} = \lambda_A \overline{\Phi}\left(b + \frac{\log(\lambda_A/\lambda_B)}{2b}\right) + \lambda_B \overline{\Phi}\left(b + \frac{\log(\lambda_B/\lambda_A)}{2b}\right) \tag{5}$$

which is a bivariate case. When the value of parameter b decreases to zero, the exceedance probability behaves like the step function as shown in Fig. 4 (left), and as the limiting case of $b = 0$, we have the joint rate of perfect dependent case

$$\lambda_{AB} = \lambda_A \wedge \lambda_B = \frac{1}{x_A \vee x_B} \tag{6}$$

where $\lambda A \Lambda \lambda_B = \lambda A$ for$\lambda A < \lambda B$ and xA V $xB = xA > xB$, etc. And the value of the joint rate is also found to vanish as the value of parameter b is large, which means to be independent. Another rate can be defined for bivariate extremes by the principle of inclusion and exclusion (PIE), and it shows the exceedance rate at least one of both

$$\lambda_{(AB)} = \lambda_A + \lambda_B - \lambda_{AB} = \lambda_A \Phi\left(b + \frac{\log(\lambda_A/\lambda_B)}{2b}\right) + \lambda_B \Phi\left(b + \frac{\log(\lambda_B/\lambda_A)}{2b}\right) \tag{7}$$

Figure 4 (right) shows that the cumulative probability takes constantly almost 1 around $z = 0$ when b is enough large. For infinity of b, λ(AB) =$\lambda A + \lambda A$, which became independent.

The univariate case can be obtained also in the above by giving the lowest bound of x_B to zero as the conditional probability becomes 1, thus

$$\lambda_{AB}(x_B = 0) = \int\limits_{\log x_A}^{\infty} e^{-z} dz = \frac{1}{x_A} (= \lambda_A) \tag{8}$$

The bivariate HR model contains a parameter b which is the value given by

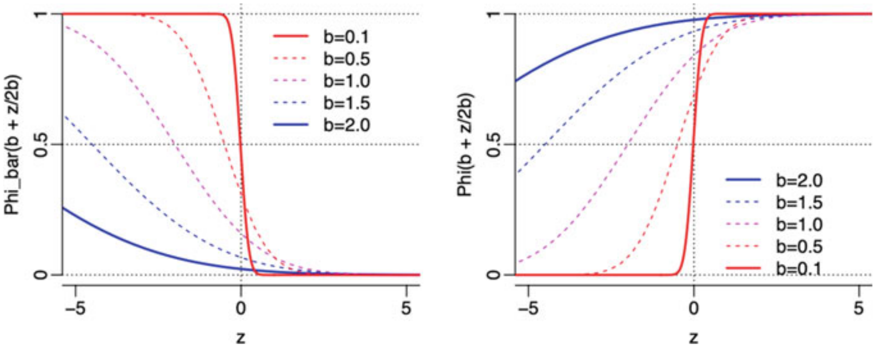

Fig. 4 Exceedance probability and cumulative distribution functions of the normal distribution appearing in MR model (use $z = \log(\lambda A/\lambda B)$)

$$b = b_n\sqrt{\frac{1-\rho_n}{1+\rho_n}} \approx b_n\sqrt{\frac{1-\rho_n}{2}}, \quad \rho_n = 1 - \frac{b^2}{\log n}, \quad b_n^2 = 2\,\log n \tag{9}$$

That is to say, the asymptotic process is so special that the value of correlation coefficient changes to approach 1, while bn increases. Sibuya [4] shows that the pair of maxima from the normal distribution is asymptotically independent. Therefore in the practical application we need the different interpretation to use another derivation. As the exceedance rate of at least one threshold is obtained according to the principle of inclusion and exclusion, here we use the log-normally distributed variables ξA and ξB to make the occurrence rate like as

$$\lambda_{(AB)} = \exp\left(-\frac{\sigma^2}{2}\right)\int\int_0^\infty\left(\frac{\xi_A}{x_A} \vee \frac{\xi_B}{x_B}\right)d\Phi(\log\xi_A, \log\xi_B) \tag{10}$$

where the probability density is given by

$$d\Phi(s,t) = \frac{dsdt}{2\pi\sigma^2\sqrt{1-\rho^2}}\exp\left\{-\frac{s^2-2\rho st+t^2}{2\sigma^2(1-\rho^2)}\right\} \tag{11}$$

and the constant value in front of the integration in Eq. (10) is the reciprocal of the mean of the univariate log-normal distribution

$$\int_{-\infty}^{\infty}\frac{e^s ds}{\sqrt{2\pi}\sigma}\exp\left(-\frac{s^2}{2\sigma^2}\right) = \exp\left(\frac{\sigma^2}{2}\right) \tag{12}$$

After some manipulation, we attain the joint occurrence rate of the same result as Eq. (7), except for the parameter b which is just given by

$$b = \sigma\sqrt{\frac{1-\rho}{2}} \tag{13}$$

This does not contain any asymptotic quantity but constant values σ and ρ, which means that we deal with it conveniently in the normal sense of asymptotical extremes.

For the trivariate and the higher-dimensional multivariate HR model, they can be obtained also by the multivariate normal distributions. For trivariate case, we have

$$\begin{aligned} c\lambda_{ABC} &= \lambda_A\overline{\Phi}\left(b_{AB} + \frac{\log(\lambda_A/\lambda_B)}{2b_{AB}}, b_{CA} + \frac{\log(\lambda_A/\lambda_C)}{2b_{CA}};\ \rho_{AB,C}\right) \\ &\quad + \lambda_B\overline{\Phi}\left(b_{BC} + \frac{\log(\lambda_B/\lambda_C)}{2b_{BC}}, b_{CA} + \frac{\log(\lambda_B/\lambda_A)}{2b_{CA}};\ \rho_{BC,A}\right) + \lambda_C\overline{\Phi}(\cdot) \end{aligned} \tag{14}$$