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Supplement of

The value of visualization in improving compound flood hazard communication: a complementary perspective through a Euclidean geometry lens

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S1. Survey for compound flood hazard communication

S1.1 Informed Consent

Please read this informed consent carefully before you decide to participate in the study.

Project title: CIROH: Coastal Nature Based Solutions to Mitigate Flood Impacts and Enhance Resilience

Consent Form Key Information:

- Participate in a 10-minute survey about compound flood risk communication tools.
- No information collected that will connect identity with responses

Purpose of the research study: The purpose of the study is to deepen our understanding of how effective our proposed compound flood risk communication tools would be among stakeholders and academic researchers. In addition, this study will help us understand how useful our proposed risk communication tools would be to the stakeholders and academic researchers to communicate with the public.

What you will do in the study: You will answer a list of multiple-choice questions about the proposed compound flood risk communication tools. At the end, you will be asked about your profession and years of experience in the profession.

Time required: The study will require about 10 minutes of your time.

Risks: The physical, social, and legal risks to participants are minimum.

Benefits: There is no direct benefit to the participants. The study may help us understand how effective the proposed compound flood risk communication tools would be. Results of this study may help researchers design more effective research output to assist local stakeholders to make decisions for compound flood risk reduction. The community will benefit greatly from this.

Confidentiality: The survey will be anonymous. The data will be mostly reported in aggregate. No names will be attached to any specific quotes that will be included in reports. Data (i.e., notes, recordings, and transcripts) collected from the meeting will be stored in the UA Box.

Voluntary participation: Your participation in the study is completely voluntary Right to withdraw from the study: You have the right to withdraw from the study at any time without penalty.

How to withdraw from the study: If you want to withdraw from the study, you can leave the meeting. There is no penalty for withdrawing. If you would like to withdraw after your materials have been gathered, please contact Dr. Shao at wshao1@ua.edu.

Compensation/Reimbursement: You will receive no payment for participating in the study.

If you have questions about the study or need to report a study related issue please contact, contact:

Name of Principal Investigator: Wanyun Shao

Title: Associate Professor

Department Name: Geography & the Environment

Email address: wshao1@ua.edu

If you have questions about your rights as a participant in a research study, would like to make suggestions or file complaints and concerns about the research study, please contact: The University of Alabama Office for Research Compliance (205)-348-8461 or toll-free at 1-877-820-3066. You may also ask questions, make suggestions, or file complaints and concerns through the IRB Outreach Website at https://research.ua.edu/compliance/irb/. You may email the Office for Research Compliance at rscompliance@ua.edu.

S1.2 Questionnaire

Do you agree to participate in this survey?

- ◻ Yes (1)
- ◻ No (2)

Q1) Are you familiar with Coastal Compound Flooding?

- ◻ Extremely well (1)
- ◻ Very well (2)
- ◻ Moderately well (3)
- ◻ Slightly well (4)
- ◻ Not well at all (5)

Note:

According to Radfar et al. (2024):

"Coastal flooding may result from the *concurrent* or *successive* interaction of inland factors, such as precipitation and discharge, and coastal drivers, including storm surges, waves, and tides. This combination is known as **coastal compound flooding** (CCF)"

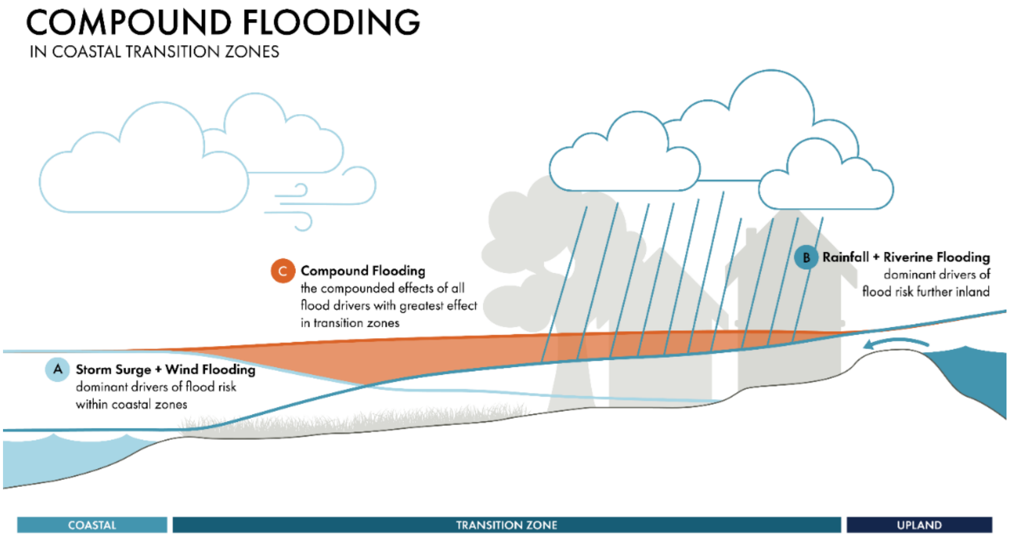

Fig. S1 Schematic of compound flooding (image source: https://thewaterinstitute.org/projects/compound-flooding)

Q2) How relevant do you think the study of compound flooding is to your work or area of interest?

- □ Extremely well (1)
- □ Very well (2)
- □ Moderately well (3)
- □ Slightly well (4)
- □ Not well at all (5)

Note:

Demonstrating the level of **interaction (dependence)** of different flood drivers helps better communicate the risk of compound flooding. A common practice is using **correlation coefficients**.

A **correlation coefficient** is a number that shows how closely two things are related. It ranges from -1 to 1. If the number is close to 1, it means the two things often happen together. If it's close to -1, it means when one thing happens, the other usually doesn't. If the number is around 0, it means there is no clear relationship between the two.

For example, if we find a high correlation between heavy rain and river flooding, it means these two events often occur together.

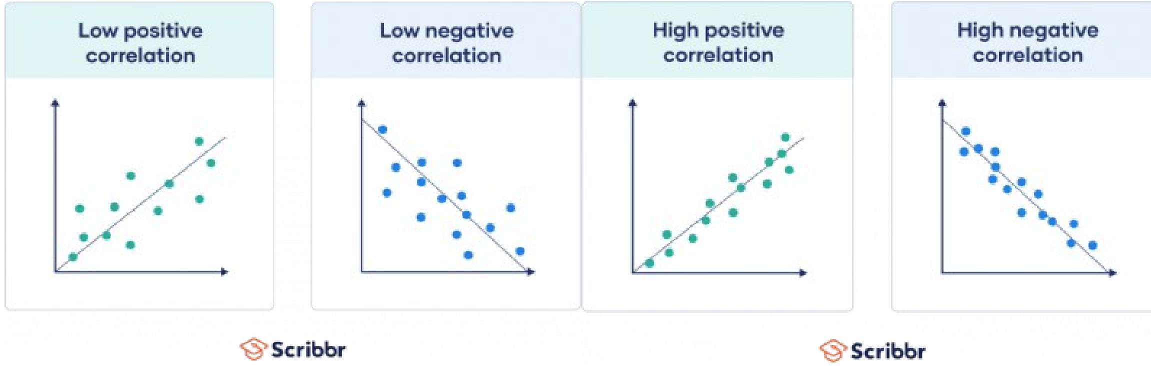

Fig. S2 Illustration of negative and positive correlations (image source: https://www.scribbr.com/statistics/correlation-coefficient/)

Note:

Fig. S3 illustrates the pairs of annual maximum discharge (Q) and respective maximum surge (S) for the two coastal cities.

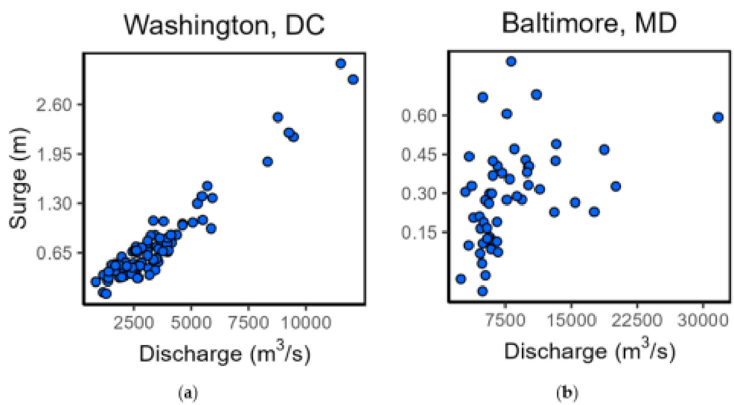

Fig. S3 Scatterplots of discharge annual maxima and surge maxima within +/- 1 day of the maximum-discharge timing for: (a) Washington, DC; (b) Baltimore, MD

Compound flooding, caused by the co-occurrence of **river discharge** and **storm surge** extremes (or, in general, extreme sea levels) can lead to devastating consequences for society.

To describe the **level of interaction (dependence)** between these two flood drivers to the **general public/non-experts**, suppose that we have two approaches:

First: Numerical description (conventional approach)

- At the **Washington** gauge, the correlation coefficient between river discharge and surge is 0.96. At the **Baltimore** gauge, the correlation coefficient is 0.41. Therefore, the interaction of compound flood drivers is ***stronger*** in Washington, DC.

Second: Graphical description (new approach)

- In the below graph, the **closer** the **arrows** of **q** (river discharge) and **s** (surge), the ***stronger*** their interaction. The farther apart the arrows are (higher angle), the weaker their interaction.

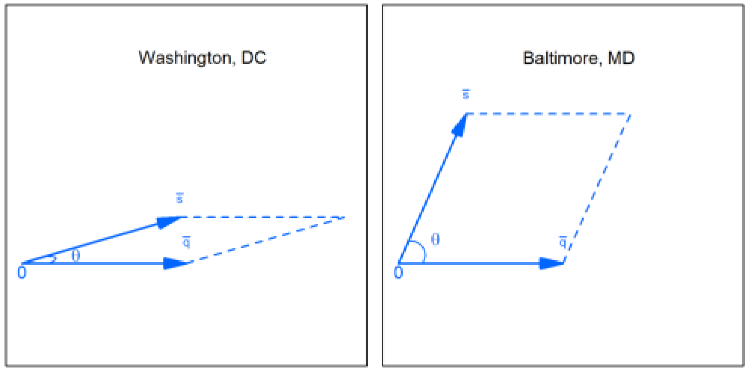

Fig. S4 Discharge and surge variables represented as unit-length vectors in the subject space for: Washington, DC and Baltimore, MD

Q3) Suppose you are a non-expert or a member of the public, how well would you understand the compound flooding risk based on numerical explanation?

- □ Strongly agree (1)
- □ Agree (2)
- □ Slightly agree (3)
- □ Neutral (4)
- □ Disagree (5)

Q4) Suppose you are a non-expert or a member of the public, how well would you understand the compound flooding risk based on graphical explanation?

- □ Strongly agree (1)
- □ Agree (2)
- □ Slightly agree (3)
- □ Neutral (4)
- □ Disagree (5)

Q5) How familiar are you with the concept of non-stationarity in the context of flooding?

- □ Extremely well (1)
- □ Very well (2)
- □ Moderately well (3)
- □ Slightly well (4)

- □ Not well at all (5)

Note:

Non-stationarity refers to **increasing variation** of flood drivers due to climate change. Natural climatic variability and anthropogenic climate change are among the most important drivers of non-stationarity.

Non-stationarity also influences the **dependence structures** among compound flood drivers over time. However, due to complexities in using this approach, existing literature commonly rely on moving window approach or simplifying assumption of stationarity of the dependence structure.

Public perception of this impact is even more challenging.

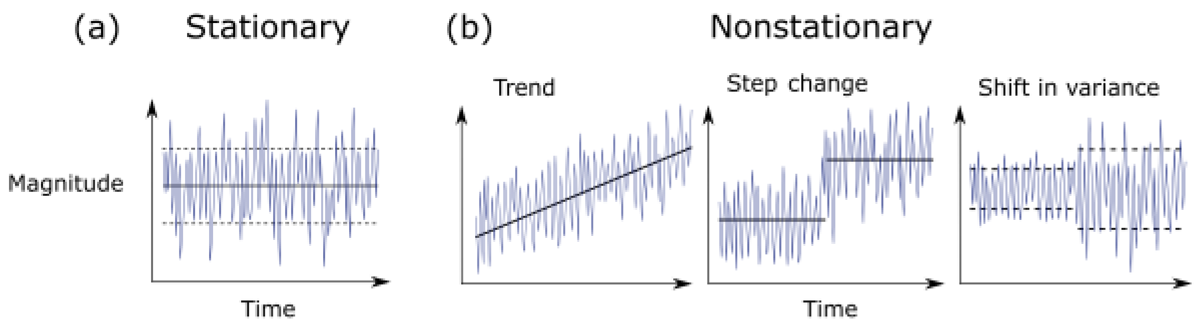

Fig. S6 Illustration of stationarity and nonstationaity (image source: https://hess.copernicus.org/articles/25/3897/2021/)

Fig. S7 shows a scatterplot of river discharge (Q) and sea level (S) samples in the Galveston Bay, TX, for three periods: "1946-1971", "1972-1996", "1997-2022"

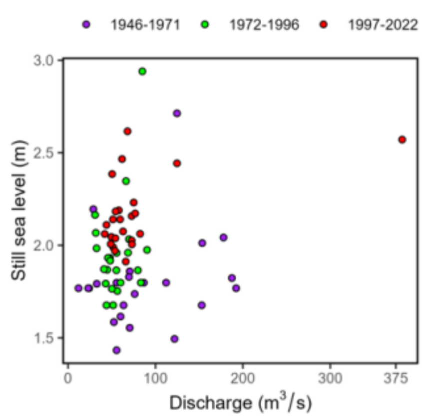

Fig. S7 Scatterplot of annual maxima sea levels and discharge maxima within +/- 5 days of the maximum-sea-level timing for Galveston Bay, TX. Pairs are colored based on period of observation

Q6) In your own opinion, how clear are the variations in the dependence between the two flooding drivers over time be from the above scatterplot?

- ◻ Strongly agree (1)
- ◻ Agree (2)
- ◻ Slightly agree (3)
- ◻ Neutral (4)
- ◻ Disagree (5)

Display this question:

If Q6 = Extremely well

Q6.1) Which period has the strongest correlation between Q and S, and which has the weakest?

____

Q7) Suppose you are a non-expert or a member of the public, How clear would the variations in the dependence between the two flooding drivers over time be from the above scatterplot?

- ◻ Strongly agree (1)
- ◻ Agree (2)
- ◻ Slightly agree (3)
- ◻ Neutral (4)
- ◻ Disagree (5)

Note:

Using the presented method (i.e. "Angles"), it is possible to demonstrate the **evolution of dependence**, as presented in Fig. S8:

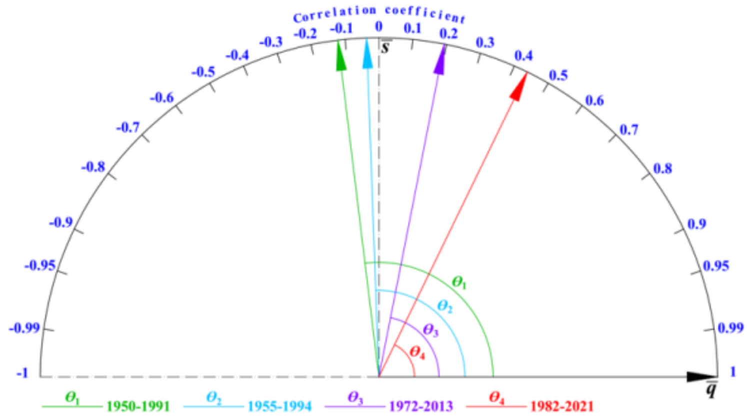

Fig. S8 Subject space showing a stronger dependence between sea levels and discharge across multiple overlapping time periods, i.e., a shrinking angle θ between the two vectors at Galveston Bay, TX. Observe how an obtuse angle, i.e., a negative correlation in the past, gradually transforms into an acute angle indicating strong positive correlation

Fig. S8 illustrates how non-stationarity in the dependence of the two variables over multiple, possibly **overlapping time periods**, can be visualized with the use of this method.

A sample takeaway messages from this figure:

- how θ shrinks from an obtuse angle in 1950-1991 (past) to an acute angle in 1982-2021 (present), indicating that the **negative correlation** between discharge and sea level extremes has **gradually evolved into a strong positive dependence over time**.

Q8) How well do you think this approach conveys the concept of variation (non-stationarity) in the dependence structure of compound flooding drivers?

- ☐ Strongly agree (1)
- ☐ Agree (2)
- ☐ Slightly agree (3)
- ☐ Neutral (4)
- ☐ Disagree (5)

Q9) How well do you think this approach enhances risk communication to a non-expert or a member of the public?

- ☐ Strongly agree (1)
- ☐ Agree (2)
- ☐ Slightly agree (3)
- ☐ Neutral (4)

- ◻ Disagree (5)

Q10) Overall, how would you rate the effectiveness of this new approach in the field of compound flooding risk assessment?

- ◻ Strongly agree (1)
- ◻ Agree (2)
- ◻ Slightly agree (3)
- ◻ Neutral (4)
- ◻ Disagree (5)

Q11) How likely are you to apply this new approach in your own work or research?

- ◻ Strongly agree (1)
- ◻ Agree (2)
- ◻ Slightly agree (3)
- ◻ Neutral (4)
- ◻ Disagree (5)

Q12) How likely are you to apply this new approach for public risk communication?

- ◻ Strongly agree (1)
- ◻ Agree (2)
- ◻ Slightly agree (3)
- ◻ Neutral (4)
- ◻ Disagree (5)

Q13) Which one of the following best describes your role as a coastal community stakeholder? Select all that apply.

- ◻ Academia (1)
- ◻ Emergency manager (2)
- ◻ Building code official (3)
- ◻ Engineer (4)
- ◻ Floodplain manager (5)
- ◻ Planner (6)
- ◻ Natural resource manager (7)
- ◻ Project manager (8)
- ◻ Local governmental agency (e.g., city/county/local utility authority) (9)

- ☐ State government agency (10)
- ☐ Federal government agency (11)
- ☐ Private company/organization (12)
- ☐ Non-governmental organization (13)
- ☐ Other (14)

Display this question:

If Q13 = Other

Q13.1) Please specify your role:

____

Q14) What is your highest level of education? Select all that apply.

- ☐ Less than a high school diploma (1)
- ☐ High school graduate or equivalent (e.g., GED) (2)
- ☐ Some college credit, but no degree (3)
- ☐ Professional degree (e.g., MD, JD) (4)
- ☐ Bachelor's degree (5)
- ☐ Master's degree (6)
- ☐ PhD or higher (7)
- ☐ Prefer not to say (8)

Q15) How would you describe your level of experience with hydrological or hydrodynamic fields (e.g., flooding)?

- ☐ More than 5 years (1)
- ☐ 3-5 years (2)
- ☐ 1-3 years (3)
- ☐ Less than 1 year (4)
- ☐ No experience (5)