Reservoir Computing-based Advance Warning of Extreme Events

T. Wang[1], H. Zhou[1], Q. Fang[2], Y. Han[1], X. Guo[1], Y. Zhang[1], C. Qian[3], H. Chen[3], S. Barland[4], S. Xiang[1], and G. L. Lippi[4]

[1]State Key Laboratory of Integrated Service Networks, Xidian University, Xi'an 710071, China
[2]School of Electronics and Information, Hangzhou Dianzi University, Hangzhou 310018, China
[3]Interdisciplinary Center for Quantum Information
College of Information Science and Electronic Engineering, Zhejiang University, Hangzhou 310027, China
[4]Institut de Physique de Nice, UMR 7010 CNRS, Université Côte d'Azur, France

Abstract— Extreme events (EEs), such as very rare and large amplitude fluctuation events, have been a topic of great interest among different fields due to their significant impact on society [1]. One example of such events is giant waves that unexpectedly emerge on a relatively calm ocean surface [2]. Since their high amplitude and sudden appearance, they have posed significant challenges in terms of observation and tracing. However, after a decade, researchers discovered a phenomenon in an optical system called fiber supercontinuum generation that showcased statistical behavior resembling these EEs [3]. The advantage of being able to study EEs within the controlled environment of a photonics laboratory generated immense interest and prompted scientists to rapidly search for similar occurrences in various other systems [4].

Another crucial aspect is the predictability of EEs, which is of great practical significance to determine whether the occurrence and characteristics of an EE can be predicted in advance [5]. Numerous studies have been dedicated to unravelling this question. However, a definitive answer that can be applied under general conditions has yet to emerge. Researchers have made progress in this area, with studies attempting to tackle this question [6]. Nonetheless, there remains a crucial requirement for additional research in order to develop more advanced techniques for forecasting these events.

In this work, we present one innovative method to generate EEs by using a microcavity laser. The intensity pulses associated with EEs exhibit a longer tail distribution, indicating the rare feature of the EEs. Their observation is corroborated by numerical modelling, based on a standard spin-flip model, which confirm the presence of EEs whose number can be tuned by a suitable choice of modulation parameters. We show that reservoir computing is capable of predicting the emergence of EEs with good accuracy. In addition, we compare the performance of different reservoir computing implementations, in hybrid forms, to identify the most successful one. Our work provides a new platform for studying EEs in a microcavity system and beyond, thus opening up a new field of investigation for EEs prediction.

REFERENCES

1. Grassia, M., M. De Domenico, and G. Mangioni, "Machine learning dismantling and early-warning signals of disintegration in complex systems," *Nat. Commun.*, Vol. 12, 5190, 2021.
2. Kharif, C. and E. Pelinovsky, "Physical mechanisms of the rogue wave phenomenon," *European Journal of Mechanics B-Fluids*, Vol. 22, 603–634, 2003.
3. Solli, D. R., C. Ropers, P. Koonath, and B. Jalali, "Optical rogue waves," *Nature*, Vol. 450, 1054–1057, 2007.
4. Dudley, J. M., F. Dias, M. Erkintalo, and G. Genty, "Instabilities, breathers and rogue waves in optics," *Nat. Photon.*, Vol. 8, 755–764, 2014.
5. Erkintalo, M., "Predicting the unpredictable?," *Nat. Photon.*, Vol. 9, 560–562, 2015.
6. Pathak, J., B. Hunt, M. Girvan, Z. Lu, and E. Ott, "Model-free prediction of large spatiotemporally chaotic systems from data: A reservoir computing approach," *Phys. Rev. Lett.*, Vol. 120, 024102, 2018.