Understanding turbulence through artificial intelligence

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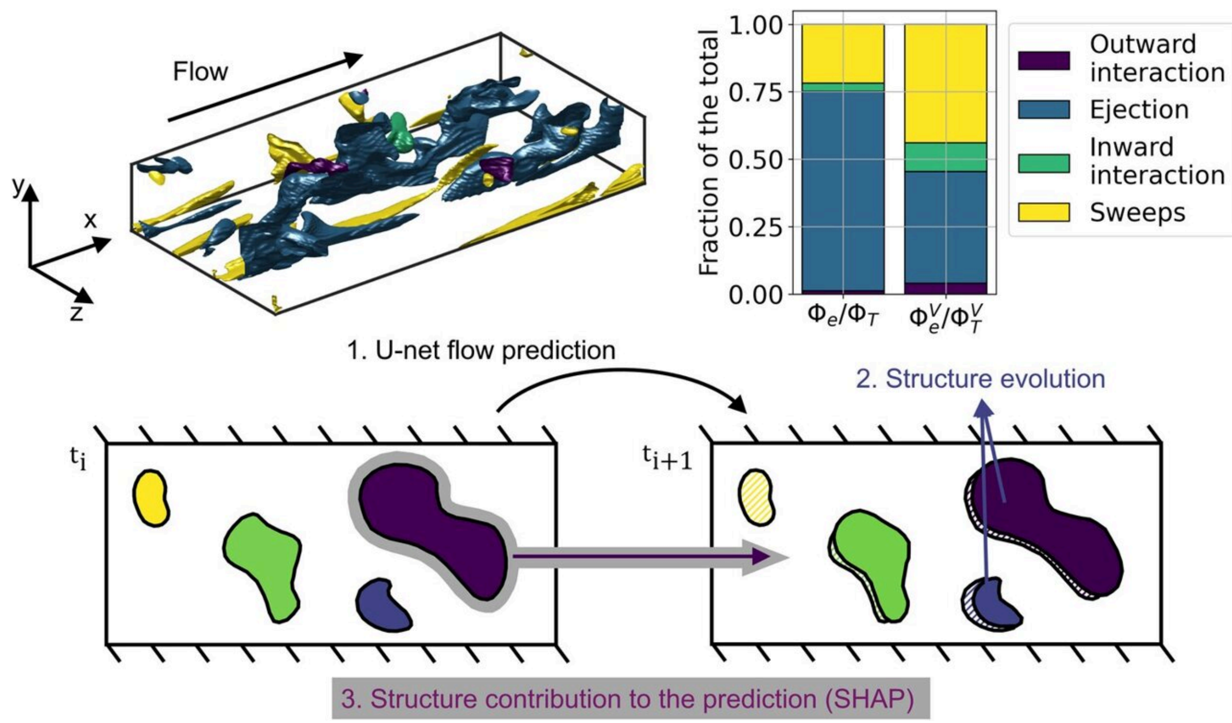

Conceptual map of the workflow employed in this study. (Top-left) Instantaneous Reynolds stress (Q) events identified in a turbulent channel. (Top-right) Total contribution and total contribution per unit volume of each event type to the U-net prediction. Workflow comprising three steps: 1 A U-net is used to predict the next instantaneous flow field (time t_{i+1}) based on the current one (t_i); 2 The structures evolve, so some may dissipate in the next field (yellow), others may be convected (rest of colors), and some may even merge into larger ones (not shown); 3 Calculation of the contribution of each structure (gray shade) to the prediction of the next field. Credit: *Nature Communications* (2024). DOI: 10.1038/s41467-024-47954-6

When hearing the word turbulence, the first association that springs to mind is often the uncomfortable jostling experienced during airplane travel. However, turbulence denotes the irregular and chaotic behavior exhibited by fluids, gases, and liquids in a wide array of scenarios. Think of the swirling air in our cities, the waters of seas and rivers, or within engines and around vehicles like cars, ships, and airplanes.

Actually, turbulence is a significant factor in energy dissipation within these modes of transportation, accounting for up to 15% of the annual CO_2 emissions generated by humanity.

Now, an international team composed of scientists from the Universitat Politècnica de València and the universities of Edinburgh and Melbourne, led by Ricardo Vinuesa from the Flow Institute of the Royal Institute of Technology, KTH, has developed a new technique that allows us to study turbulence in a completely different way from that used in the last 100 years. Their work has been published in *Nature Communications*.

The main difficulty of fluid mechanics is that "although the equations of fluid mechanics are about 180 years old, the problem remains open. These equations are unsolvable algebraically or numerically for practical cases, even for the world's largest computers. For a typical jetliner, we would need a memory equivalent to a month of the internet just to configure the simulation," says Sergio Hoyas, professor of aerospace engineering at UPV and researcher at IUMPA.

"We need to understand turbulence to improve the simplified models used in daily life. And there is a new tool: artificial intelligence," says Vinuesa.

For the first time

Although several works already apply artificial intelligence to fluid mechanics, the great novelty of this study is that it allows, for the first time, not to simulate or predict but to understand turbulence.

From a database of about one terabyte, the researchers trained a neural network that allows for the prediction of the movement of a turbulent flow. Using this network, they have managed to track the evolution of the flow by individually removing small structures, subsequently evaluating the effect of these structures using the SHAP algorithm.

"The most important thing is that the results of this analysis exactly match the knowledge acquired in the last 40 years and extend it. Our method has managed to reproduce this knowledge without the neural network knowing anything about physics," says Andrés Cremades, a postdoctoral researcher at KTH and the article's first author.

"Experimental validation with data from the University of Melbourne indicates that our method applies to realistic flows and opens up a novel path for understanding turbulence," Vinuesa says.

More information: Andrés Cremades et al, Identifying regions of importance in wall-bounded turbulence through explainable deep learning, *Nature Communications* (2024). DOI: 10.1038/s41467-024-47954-6

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