Large Deviations and Rare Transitions in Turbulent flows

Results in Brief

Understanding the extreme events in turbulent flows

A researcher in France is studying how the extreme events and abrupt transitions found in turbulent flows can impact weather and climate.
Turbulent flows, also known as turbulence, are fluid motions characterised by rapid changes in pressure and flow velocity. Turbulent flows such as planetary atmospheres, oceans and flow around an air foil or wind turbine undergo strong fluctuations in their mean state. In some cases, they might even suddenly switch to an entirely different flow configuration.

“Although these extreme events are crucial for weather, climate and a range of engineering applications, many aspects remain poorly understood,” says Corentin Herbert, a physics researcher at ENS de Lyon.

“Because turbulent flows have, in general, several metastable attractors, it can be expected that abrupt transitions exist in the ocean and atmosphere due solely to their turbulent nature.”

Under TransTurb, a research project supported by the Marie Skłodowska-Curie Actions, Herbert set out to better understand such extreme events and abrupt transitions in turbulent flows.

**A tipping point for global climate**

The scientific aim of the project was to investigate whether spontaneous transitions between bi-stable states existed at all in the atmosphere and whether they were like noise-induced transitions studied in statistical physics.

“Although it is impossible to know when the transition will happen, the dynamics are generally predictable as the system always follows the same path to produce the rare event,” explains Herbert.

The phenomenon the project focused on, called equatorial superrotation, is a reversal in the direction of tropical surface winds.

“While easterlies prevail on Earth, westerlies are observed on many planetary atmospheres like Venus,” says Herbert. “Abrupt transitions to superrotation might provide a new example of a tipping point for global climate, or more speculatively, for anthropogenic climate change.”

Using theoretical computations and numerical simulations, the project has unambiguously shown that a feedback mechanism between equatorial waves in the atmosphere and the background wind lead to bi-stability and abrupt transitions. The project also clarified under which conditions this happens.
Adapting algorithms

According to Herbert, there are major technical difficulties in studying extreme events in complex systems. “The main challenge is that we are interested in rare events, for which, by definition, we have few observations,” he says.

“Direct numerical simulations of the system do not really alleviate the problem because models for turbulent flows or the climate system are computationally expensive.”

To solve this sampling problem, efficient numerical algorithms have been developed by several groups. “The second goal of the TransTurb project was to show that these algorithms can be adapted to address relevant questions for rare events in turbulent flows,” explains Herbert.

“Relying on the expertise of rare event algorithms, we demonstrated that such algorithms allow for the evaluation of the typical time between two occurrences of a rare event, called the ‘return time’.”

Tools available to other researchers

Many of the numerical tools developed during the project are now available to the public via Github. “This should make it easy for other researchers to improve and extend our methods and apply them to other systems,” adds Herbert.

“I hope the project showed the physics community that there are many fascinating problems in climate science for which their skills can be of use.”

Keywords

TransTurb, turbulent flows, turbulence, atmosphere, weather, climate, physics, equatorial superrotation, climate science
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