ENS DE LYON

IMT Atlantique
Bretagne-Pays de la Loire
École Mines-Télécom

PhD PROPOSAL

CHARACTERIZATION OF CAUSALITY RELATIONSHIPS BETWEEN THE SCALES OF TURBULENCE

Keywords : Turbulence ; Ocean dynamics ; Signal and Image processing ; Multiscale analysis ; Information Theory ;

1. Context

Turbulence is an omnipresent phenomenon in nature, which intervenes in processes as diverse as chemical reactions, atmospheric flows or galactic dynamics. However, numerous unknowns continue to surround it, making it a challenge for science. The very known works of Kolmogorov and Obukhov described a statistical theory showing the multi-scale behavior of turbulence and the existence of an energy cascade from large to small scales [1]. During this PhD we want to go further and develop a multiscale characterization of turbulence based on causality relationships between scales. Thus, both the theoretical and methodological branches of this framework should be studied.

In the last years, a large number of causality measures have been developed presenting different advantages and counterparts [2], among them the Information Theory based approaches appear as promising [3]. However, turbulence is multi-scale, and consequently this Information Theory framework should be adapted to characterize relationships and interactions among scales. From several years the team composed by S. G. Roux, N. B. Garnier and C. Granero-Belinchon has been working on the development of a statistical description of multi-scale couplings and interactions based on Information Theory [4]. Since information can be directly linked to complexity and then to the structure and state of complex systems, and since multi-scale approaches of Information Theory started to emerge in the last years, this framework appears as novel and original.

The main goal of this PhD is the characterization of causality relationships between the scales of turbulence [4]. Thus, two main methodological aspects should be confronted: first, the definition and generation of scales from a time series [5], and second, the definition of an adapted measure of causality across scales. Furthermore, the theoretical framework of these causal interactions between scales of turbulence should be stablished and if possible related to previous multiscale descriptions of turbulence. Finally, this methodological study presents also an applicative section with relevance in the description of turbulence and ocean dynamics.

2. Main tasks

First, the student will make a bibliographic work to understand the different kind of causality measures existing in the literature with a focus on the Information Theory based approaches. Simultaneously, the student will familiarize with a set of existing codes developed within the team by N. B. Garnier to estimate causality relationships between time series. Then, the student will familiarize with multiscale analysis and multiscale decomposition methodologies. Finally, the student will study causality interactions between the scales of time series and will focus on two main problems : first, the analysis of the Kolmogorov cascade in three dimensional isotropic turbulence and second the description of the interactions between eddies of different sizes in the ocean.

3. Eligibility Criteria

Candidates are required to be in the Master 2 (or third year engineering school) level education in the field of either applied mathematics, physics, signal processing or earth sciences. Good knowledge of Python programming language with previous experiences in programming is required, as well as

previous experience in fluid dynamics and turbulence. Background in signal processing, information theory, oceanography and/or causality interactions will be a plus.

4. Supervision and research team

The PhD will be advised by Carlos Granero-Belinchon, Thierry Chonavel (IMT Atlantique), Stéphane G. Roux and Nicolas B. Garnier (ENS de Lyon). Thus, the supervision team is composed by physicists and signal processing researchers from the Laboratoire de Physique de l'ENS de Lyon and the Mathematical and Electrical Engineering department of IMT Atlantique, leading to a multidisciplinary project. Moreover, the internship will develop within the OSE research team at IMT which is a dynamic research group on image processing and artificial intelligence for Oceanography and Climate.

Motivated students should send a CV and a motivation letter to: carlos.granero-belinchon@imt-atlantique.fr.

The PhD is expected to start before Novembre 2022.

References

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[3] Schreiber, T. **Measuring Information Transfer**, Phys. Rev. Lett., 85, 461–464 (2000). https://link.aps.org/doi/10.1103/PhysRevLett.85.461

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[5] Cohen, L. **The scale representation**, IEEE Trans. Signal Process. 41 3275-3292 (1993). https://www.ee.columbia.edu/~dpwe/papers/Cohen93-scale.pdf