ENS DE LYON

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

PHD PROPOSAL

CHARACTERIZATION OF CAUSALITY RELATIONSHIPS BETWEEN SCALES OF TIME PROCESSES: APPLICATIONS TO EARTH SCIENCES

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

1. Context

Today, the huge amounts of collected data in the framework of Earth sciences is revolutionizing the way scientific advances are propelled in this field. Thus, analyzing the available datasets (remote sensing images, in-situ observations, models) with the suitable signal processing methodologies produce nowadays new understandings on topics such as climate change, ocean dynamics or ocean atmosphere interactions. These analyses also allow to call into question and/or validate existing physical models as well as to improve them.

Causality interactions are fundamental to correctly comprehend the connections between the parts of a complex system such as the Earth [1] and they can be crucial for the correct modeling and forecasting of such a system. Thus, the study of causality can be used for example in climate and meteorology for prediction purposes, but also to characterize ice concentration in the poles depending on stratospheric events or to measure the abundancies of anchovies depending on the sea surface temperature [1]. However, correlation and linear regression techniques are still used to characterize these causality interactions, so leading to incorrect conclusions (correlation is a measure of linear dependencies not causality) [2].

In the last years, a large number of causality measures have been developed presenting different advantages and counterparts [1], among them the Information Theory based approaches appear as promising [2]. However, complex systems, and more precisely the Earth, are most of the time 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 [3]. 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 a time process [3]. Thus, two main methodological aspects should be confronted: first, the definition and generation of scales from a time series [4], and second, the definition of an adapted measure of causality across scales. Furthermore, this methodological study presents also an applicative section with relevance in the understanding of Earth sciences.

Thus, different applications can be envisaged depending on the interests of the student. For example:

- characterization of the feedback of global warming (do small scale increases in temperature produce large scale effects?)

- analysis of the Kolmogorov energy cascade in turbulence (do large scale dynamics of chaotic processes cause small ones or the opposite?)
- description of the interactions between eddies of different sizes in the ocean (do small scale eddies produce the formation of large scale eddies? Or on the contrary large scale eddies break down into small ones?)

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. First, different applications within the field of Earth Sciences are possible depending on the interests of the student. In a second step, we will focus on causality characterization between scales with applications to ocean dynamics.

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 signal processing. Background in Information Theory, oceanography, causality interactions, fluid dynamics and/or turbulence 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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