PhD project, within the project Critical-Earth Horizon 2020 Marie Skłodowska-Curie Actions, Innovative Training Network.

Studying abrupt climate changes using machine learning and rare events algorithms

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Where: École Normale Supérieure de Lyon - Laboratoire de physique (ENSL-CNRS, Lyon, France).
When: Starting in 2021 (any time after March 2021).
Duration: A three-year PhD project.
Salary and condition: The PhD will benefit excellent salary conditions, training and networking plans, following the European Marie Curie ITN rules (see the 2019 allowance amount).

Scientific description:

The aim of this project is to study the possibility that the atmospheric circulation or climate may undergo abrupt transitions between coexisting stable states. Paleoclimate records indicate that abrupt changes have occurred in the past, on time scales compatible with atmospheric processes (e.g. dust in Greenland ice cores). Such abrupt transitions are also commonly observed in laboratory experiments of turbulent flows. The first example of interest is the bifurcation of the Atlantic Meridional Overturning Circulation (AMOC) due to interactions between turbulent ocean and atmosphere, and ice dynamics. The second is the bifurcation of the Earth atmosphere to a superrotation state [4]: it is a state for which the equatorial belt experiences strong eastward winds, and for which the Earth climate is strongly affected.

Studying those transitions is extremely important in order to understand possible future of the Earth. However, the scientific studies are strongly limited. One can use oversimplified models for which it is difficult to learn much about the real Earth dynamics. The alternative would be to use comprehensive and realistic climate models. But the complexity of those models prevents us to run them long enough and to make the required experiments to study those bifurcations.

In order to solve these problems, we will couple the use of realistic models, with rare event algorithms and machine learning approaches.

We have recently demonstrated that rare event algorithms can lead to a gain of a factor 100 to 1000 in the computational cost required to compute extreme events in climate models, for instance extreme heat waves over Europe [1]. We have also obtained similar results for the study of abrupt climate change in models of the geostrophic turbulence of atmosphere dynamics [2]. This technique will probably have a huge impact in future study of abrupt climate change.

The main interest of rare event algorithms is to produce large sets of extremely rare extreme events that cannot be obtained through reasonable numerical simulations. One of the risks of rare event algorithms, is that it would work only if the score function to select the trajectories is a good guess of what the model dynamics should actually do to produce the extremes. So far, we have been very successful to identify good score functions to produce extremely rare persistent heat wave, transition between different attractors in atmosphere jet turbulent flows. However, it is not clear whether this approach would simply generalize to abrupt transitions with more complex dynamics.

Using machine learning approaches, one can learn the optimal score function from data [3]. This will improve a lot the efficiency of a rare event algorithm and its versatility for studying large classes of abrupt transitions. Machine learning of optimal score function is thus a way to deal with the main drawback of rare event algorithms.

Machine learning requires a large data set with already observed rare events. This is the main drawback and limitation of a machine learning approach to study rare events in climate dynamics. A rare event algorithm is a perfect tool to obtain such a large data set. We thus conclude that rare event algorithms solve the possible weakness of machine learning and that machine learning solves the weakness of rare event algorithms. This motivates the main aim of this part of the project: We will couple rare event algorithms and machine learning in a way of a control feedback loop.

The developed methodological tool (coupled rare event algorithm/machine learning) will be applied to a hierarchy of models with different complexity in order to identify critical transitions in stochastic and deterministic dynamical models related to the bifurcation of the Atlantic Meridional Overturning Circulation and to supperotating states of the Earth atmosphere.

[1] F. Ragone, J. Wouters and F. Bouchet, 2018, Computation of extreme heat waves in climate models using a large deviation algorithm, Proceedings of the National Academy of Sciences, vol 115, no 1, pages 24-29, [pdf].
[2] F. Bouchet, J. Rolland, and E. Simonnet, 2019, A rare event algorithm links transitions in turbulent flows with activated nucleations, Phys. Rev. Lett. 122, 074502, *arXiv:1810.11057*, [pdf].
[3] D. Lucente, S. Duffner, C. Herbert, J. Rolland and F. Bouchet, 2019, Machine learning of committor functions for predicting high impact climate events, *Climate Informatics CI2019 proceedings*, *arXiv:1910.11736*, [pdf].
[4] C. Herbert, R. Caballero and F. Bouchet, 2020, Atmospheric bistability and abrupt transitions to superrotation: wave-jet resonance and Hadley cell feedbacks, Journal of the Atmospheric Sciences, vol. 77, no. 1, arXiv:1905.12401, [pdf].
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Candidates wishing to pursue a PhD degree in the field of climate physics are invited to apply.

The CriticalEarth project: Students will receive training within a pan-European academic sector research training network, specifically focused on research in abrupt transition for Earth climate.

The positions are posted as part of the CriticalEarth project – "Multiscale and critical transitions in the Earth system" -- funded through the Horizon 2020 Marie Skłodowska-Curie Actions programme. CriticalEarth will train young researchers in Europe to address key scientific problems for the study of abrupt transitions in the Earth system.

The CriticalEarth consortium comprises universities with researchers who are leading experts on study of theoretical physics, mathematics, and climate. In cooperation with the other 15 early stage researchers (ESRs) to be recruited, the researchers will generate, integrate and apply multidisciplinary knowledge from applied mathematics, statistical physics, climate science and numerical simulations.

The network will give them an excellent background for collaborating in cross-disciplinary teams in academia, industry, governmental and non-governmental institutions. CriticalEarth's main outcomes will be (i) a cohort of trained scientists within a research field with high demand for years to come; (ii) a ground-breaking understanding of multiscale dynamics in the Earth system and (iii) better foundations for understanding and better tools for assessing and avoiding irreversible climate change. In addition to training young researchers for the challenges of tomorrow CriticalEarth will provide from day one excellent research with impressive scientific and societal impact.

Eligibility: Applicants must not have resided and not have carried out their main activity (work, studies, etc.) in France for more than 12 months in the 3 years immediately before the recruitment date — unless as part of a procedure for obtaining refugee status under the Geneva Convention.

The applicant must be an Early Stage Researcher (ESR) i.e. at the time of recruitment he/she must be in the first 4 years (full-time equivalent research experience) of his/her research careers and must not have been awarded a doctoral degree.

Further requirements: Candidates should be able to demonstrate motivation and a strong eagerness to learn and have the ability to work both independently and as part of a team. Previous research experience will be a distinct advantage. The fellow must be willing to travel and will be required to complete international secondments.

Applications must include a cover letter, a CV and 2 recommendations letters and be sent directly to Freddy.Bouchet@ens-lyon.fr. The closing date is 31st January 2021. After 31st January 2021, please contact Freddy.Bouchet@ens-lyon.fr to know if the position has already been granted or not.