PhD thesis topic

Impact of climatic and anthropogenic disturbances on the dynamics of boreal forest ecosystems: a hybrid modelling approach

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Research project : TOUNDRA
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Research team: équipe VELO (Vérification pour l'Environnement et le LOgiciel)
Graduate school: MASTIC (`https://ed-mastic.doctorat-paysdelaloire.fr/`)

Context

In its most recent assessment report, the IPCC (Intergovernmental Panel on Climate Change) warns once again of the urgency of climate change and pays particular attention to the extreme events, their recent increase in frequency and intensity, and their impact on the equilibrium of forest ecosystems [PRA+22]. The preservation of forest ecosystems is therefore a major social and scientific challenge, which requires a better understanding of their dynamics, characterized by complex interactions between their biological evolution, climate and human activity. Despite the recent development of mathematical vegetation models that integrate several aspects of these interactions, modeling the dynamics of forest ecosystems remains particularly difficult, partly due to the high spatial variability of plant species, and the difficulty of obtaining long-term data on the parameters that characterize tree distribution, age and growth. However, forest management is considered essential for mitigating the effects of climate change and to preserve ecosystem services, in a context of intense deforestation and significant loss of biodiversity.

The TOUNDRA research project (*Mathematical modeling and analysis of boreal forests vulnerability to climate change: a hybrid approach*), funded by the French National Research Agency, proposes to study the stability of boreal forest ecosystems in response to climate change, using a hybrid modeling approach, aimed at reproducing the biological dynamics of forests disturbed by extreme climatic events and human activity. The project therefore revolves around a mathematical model obtained by coupling a system of differential equations describing the biological dynamics of the boreal forest, with a discrete probabilistic process modeling the impact of extreme events and deforestation. This model is described in detail in the following articles: [CDF23], [CDF21] and [KABA94]. This thesis is part of the TOUNDRA project.

Thesis topic

The objectives of this thesis are twofold.

The first axis concerns the comparison of the hybrid model of disturbed forest dynamics with the observation data produced by forest ecologists involved in of the TOUNDRA project. These data are of a paleo-ecological nature and describe the history of the boreal forest and fire over the Holocene period [AAL+08]. Parametric exploration and numerical simulations of the model will therefore be carried out in order to identify at least relevant parameter regimes. Feedback on the structure of the model may lead to certain modifications. This comparison of the model with the data should enable to a better understanding of the spatio-temporal mechanisms within the boreal forest ecosystem. For example, the observations of chaotic patterns in space, the impact of climatic and human disturbances on ecosystem stability ecosystem stability, the response of forest-tundra and temperate forest-boreal forest ecotones to climate change, will be examined in the light of the model's trajectories.

The second axis is more theoretical and concerns the study of the properties of the hybrid forest model. Built by coupling two formalisms, this hybrid model presents a rich dynamics. The properties of stability, the emergence of oscillations or chaotic regimes will be studied in line with very recent work in theoretical computer science on hybrid dynamical systems [Tab09]. An abstraction of the dynamic hybrid system corresponding to the disturbed forest model in the form of a Markov decision process will be studied, as well as the issues of bisimulation, decidability and and verification. For a broad scope, this theoretical analysis will be placed in a general framework, of which the study of forest dynamics will be the privileged application. However, other applications may also be envisaged, such as oceanography and epidemiology.

Profile of the candidate

To carry out this research work, the candidate must have solid skills in in computer science, both computational (numerical simulation, supercomputing) theoretical (formal methods of model checking) and in applied mathematics, in the field of differential equations. The candidate should also have an interest in environmental sciences, particularly in forest ecology. Experience in the study of models in the life sciences would be highly appreciated. Last but not least, the candidate should have good writing skills and an aptitude for teamwork.

Contract

- Status: paid thesis under agreement.
- Fields: computer science, modeling, applied mathematics, forest ecology.
- Contract duration: 36 months.
- Desired start date: first half of 2025.

Application procedure

- Application deadline: January 15, 2025.
- Send to Guillaume Cantin (`guillaume.cantin@univ-nantes.fr`) a cover letter and a CV.

References

[AAL+08] Adam A Ali, Hugo Asselin, Alayn C Larouche, Yves Bergeron, Christopher Carcaillet, and Pierre JH Richard. Changes in fire regime explain the Holocene rise and fall of Abies balsamea in the coniferous forests of western Québec, Canada. *The Holocene*, 18(5):693–703, 2008.

[CDF21] Guillaume Cantin, Arnaud Ducrot, and Beatriz M Funatsu. Mathematical modeling of forest ecosystems by a reaction–diffusion–advection system: impacts of climate change and deforestation. *Journal of Mathematical Biology*, 83(6):66, 2021.

[CDF23] Guillaume Cantin, Benoît Delahaye, and Beatriz M Funatsu. On the degradation of forest ecosystems by extreme events: Statistical model checking of a hybrid model. *Ecological Complexity*, 53:101039, 2023.

[KABA94] Yu A Kuznetsov, M Ya Antonovsky, VN Biktashev, and EA Aponina. A cross-diffusion model of forest boundary dynamics. *Journal of Mathematical Biology*, 32:219–232, 1994.

[PRA+22] Hans-O Pörtner, Debra C Roberts, Helen Adams, Carolina Adler, Paulina Aldunce, Elham Ali, Rawshan Ara Begum, Richard Betts, Rachel Bezner Kerr, Robbert Biesbroek, et al. *Climate change 2022: Impacts, adaptation and vulnerability*. IPCC Geneva, Switzerland, 2022.

[Tab09] Paulo Tabuada. *Verification and control of hybrid systems: a symbolic approach*. Springer Science & Business Media, 2009.