PHD POSITION

Remote sensing and forest inventory: towards a higher spatial-temporal resolution mapping of forest attributes in metropolitan France

- **Profile of the candidate:** Bac + 5 yrs (master level) in data science / geomatics / forest sciences or similar. Python skills required, as well as affinity for remote sensing, machine learning and forest.
- **Keywords:** Remote sensing, forest inventory, aerial biomass, wood volume, machine learning, deep learning, mapping, climate change.
- **Contract duration:** 3 years.
- **Workplace:** Laboratoire d'Inventaire Forestier (LIF - ENSG/IGN), Nancy, FR & Laboratoire des Sciences du Climat et de l'Environnement (UMR LSCE - IPSL), Gif sur Yvette, FR.
- **Supervisors:** Nikola BESIC (LIF - ENSG/IGN, nikola.besic[at]ign.fr), Philippe CIAIS (UMR LSCE - IPSL, philippe.ciais[at]lsce.ipsl.fr) and Cédric VEGA (LIF - ENSG/IGN, cedric.vega[at]ign.fr).
- **University - doctoral school:** Université Paris Sacley - École doctorale des sciences de l'environnement d'Ile-de-France.
- **Language:** Proficiency in English required, proficiency in French desirable.
- **E-mail application, containing a detailed CV, a motivation letter and contacts of at least two potential referees, should be sent to the supervisors, as soon as possible.**

Description of the project:

By contributing to the reduction of carbon emissions by substitution effect through the use of wood as energy and material as well as to the sequestration of carbon in biomass, dead wood, soils and wood products, forests represent an indispensable component of any climate change mitigation strategy (IPCC, 2021). The contribution of French forests to the national carbon balance is estimated by the IGN, as one of the indicators of their sustainable management, telling how much the forest sink offsets fossil emissions in France (Mérillon et al., 2021). A large part of these estimates is based on the modeling of forest attributes from measurements made on National Forest Inventory (NFI) plots, which then allows statistical inference by administrative division (department/region).

Forests, while being an extremely important lever in the fight against climate change, are also vulnerable ecosystems (Ciais et al., 2005). The intensification of temperature increase and recurrence of droughts (Bastos et al., 2020) (e.g. 2018, 2019, 2022) increasingly threatens the mitigating effects of climate change by forests, by slowing down the fertilizing effect of carbon dioxide and increasing their vulnerability to biotic (e.g. bark beetle) and abiotic (e.g. fires) factors.

In this context of rapid changes and given the localized nature of some forest threats (e.g., bark beetle, fire), it becomes imperative to be able to provide reliable high spatio-temporal resolution estimates of forest attributes in metropolitan France, following the example of what has been done in the USA (Yu et al., 2022). This is particularly true for those attributes that have direct and unequivocal links to the mitigating effects of forests, and that can be observed through a symbiosis of remote sensing and forest inventory. We are thinking first of all of total aerial biomass, total wood volume, or stem wood volume, whose high spatial resolution estimates at the end of this thesis should make it possible to establish at least part of the carbon balance at a scale significantly larger than the department or the region.

Since the reliability of these estimates can only be guaranteed by the NFI, and the high spatio-temporal resolution information comes from remote sensing, the direction to take is to use the two together - which is allowed by the multi-source inventory approach (MSI) (Tomppo et al., 2008). This approach integrates remotely sensed data into the spatial forest survey framework allowing the estimation of surveyed parameters at the larger scale than the classical NFI. Originally developed in Finland using Landsat optical images, it was not immediately applicable in France, where the diversity of forests, whether in terms of species, climatic contexts or management modes, could not be reproduced by the exclusive use of optical data. This has changed with the incorporation of photogrammetry and lidar data, allowing the development of the IMS at IGN (Irulappa-Pillai-Vijayakumar et al., 2019), whose performance in terms of spatial coverage and temporal frequency remains limited by the characteristics of the sensors used. The development of optical and radar sensors with high spatial resolution and higher revisit frequency (Sentinel 1 and 2), as well as the development of LIDAR missions (GEDI and Lidar HD) could change the situation - allowing the deployment of the IMS over the entire metropolitan territory at a significantly higher temporal frequency, which this thesis should demonstrate.

The thesis will be composed of three following research axes, corresponding to the principal objectives:

■ **Axis 1: remote-sensing data fusion** – Different remote sensing sensors containing information on the forest (GEDI, Lidar HD, Sentinel 1 and 2, etc.) and having a potential to allow through their combined employment a higher spatio-temporal mapping of forest attributes are not systematically coincident in space and time. This represents a major issue due to their complementary relevance: GEDI and Lidar HD inform us more directly, through the geometrical information contained in the cloud points, about a 3D structure of the forest, but are not characterized by both wide spatially continuous coverage and particularly high revisit frequency; Sentinel 1 and 2 missions cover simultaneously large sections of the metropolitan France every couple of days, but provide significantly less elaborated 2D information on the forest attributes. This axis foresees reconciling the benefits of these two groups of sensors through their spatio-temporal fusion, which basically implies generalizing the information-rich lidar measurements across space and time, using the Sentinel data as a sort of proxy. This is to be done by involving artificial intelligence techniques, in the setup based on increasing the complexity of the learning techniques used - from classical neural networks (machine learning) to convolutional neural networks (deep learning). A possible epilogue could be a sort of semi-supervised learning technique (Besic et al., 2016).

■ **Axis 2: models of forest attribute maps** - Once coincident, the remote sensing data from Axis 1 only provide us with electromagnetic or geometric information, which we will then need to transform into the parameter of interest - aerial biomass or wood volume. In this crucial part of the thesis we will combine the data from Axis 1 with the attributes estimated on the NFI plots and work on the construction of models mostly based on deep learning techniques (Li et al., 2022). The latter will combine remote sensing data and estimates of above-ground biomass or wood volume on NFI plots, allowing therefore spatial and temporal generalization of these estimates. Aside from constructing the IA model which could take form of a convolutional neural network with a U-shape architecture (Ronneberger et al., 2015), this part of the project foresees as well the work on the further processing of Sentinel remote sensing data (Cloude & Pottier, 1996) which will be used to feed the model together with the spatio-temporally generalized lidar data.

■ **Axis 3: statistical inference of forest attributes** - Since biomass or volume map models may not have expected statistical relevance, data from Axis 2 will be integrated into the NFI statistical inference framework or more specifically the multi-source inventory framework, where these models in conjunction with plot-level data will allow for unbiased estimation of forest attributes of interest on small domains - at the pixel level (bootstrapping) or at the level of domains much smaller than the department or region (Vega et al., 2021). This final step, involving important decisions concerning the trade-off between the precision and the final spatio-temporal scale is conceived as a joint undertaking of the PhD student, the supervisors and other colleagues.

All the axes, and in particular the axis 2, will contribute to the collaborative research efforts of the Targeted Project 1 of the PEPR FairCarbon, which gathers numerous partners, promising the synergy from which the thesis project will benefit.

Since total aerial biomass and wood volume cannot be measured directly at NFI plots, they are estimated from allometric models and measured trees height and diameters, some of which are under development. This thesis project is based significantly on collaboration with colleagues at IGN who, supported by the previously evoked PC1, are seeking to improve the estimation of total aerial biomass and wood volume on NFI plots. The underlying objective of the thesis will be to contribute, by means of its feedback, to the identification of the most adequate estimation methodology.

Bibliography:

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