RÉPUBLIQUE FRANÇAISE
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INRAE

UMR Silva

# PhD Thesis

## Measuring photosynthesis and respiration in high time-resolution with eddy covariance and wavelet analysis

Land vegetation currently feels unprecedented pressure of a changing climate. There is an increased pressure on crop production (Lin & Ma 2022), reduced productivity of forests (Chuine et al. 2023), and tree mortality such as the large-spread death of spruce in France since 2018 (Saintonge et al. 2022). A better understanding how plants respond to environmental pressures such as heat waves and droughts will enable to design better mitigation measures, will give better knowledge of which tree species will still thrive in a future climate, and will allow to better represent plant resilience in ecosystem and land surface models (LSM).

### The land carbon sink and the underlying gross fluxes

Land vegetation absorbs around 25% of anthropogenic $CO_2$ emissions, significantly influencing future climate change (Friedlingstein et al. 2023). The increase of the land sink is major component of the negative emissions foreseen in the French National Low-Carbon Strategy (Stratégie nationale bas-carbone). The land carbon sink is a fine balance between uptake by photosynthesis (gross primary productivity, GPP) and release by respiratory processes (ecosystem respiration, RESP). The future will be marked by how these underlying gross fluxes will change in the future. Understanding GPP and RESP and their responses to heat waves and droughts will be essential for designing sensible actions for a low-carbon strategy and for guiding adaptation of agricultural and forestry production in the face of climate change. Land surface models parameterize the gross fluxes GPP and RESP independently in their computer codes while observations are the net flux NEE. The latter are, however, the main calibration data for LSMs. Providing good estimates of the underlying gross fluxes GPP and RESP would be the ultimate constraint for LSMs and would lead to much more robust climate projections (Arora et al. 2020).

### Observation of carbon fluxes

Eddy covariance is a leading method for monitoring greenhouse gas fluxes, providing direct and continuous measurements relevant to climate change. The eddy covariance community has gathered in national, regional, and global networks such as AmeriFlux in the US, ICOS in Europe, and FLUXNET worldwide that share data and collaborate on synthesis studies. The products emanating from the eddy observations (Jung et al. 2020) have become the standard reference for all flux related research such as atmospheric inversions, satellite products, and the like.

Eddy covariance data products are also used to calibrate (Kuppel et al. 2014) land surface models (LSM). They often use the estimates of gross primary productivity (GPP) because this variable is sensitive to most parameters in LSMs (Göhler et al. 2013). These models estimate GPP and respiration RESP rather than the observed net flux NEE, so model developers seek to use data closest to the modelled processes. However, GPP is only modelled from net NEE fluxes (Sabbatini et al. 2018), leading to diverging estimates such as double the amount of GPP in boreal forests between estimates of the same group (Jung et al. 2020, Nelson et al. 2024).

Signals from sources (RESP) and sinks (GPP) have to be transported turbulently from (within) the canopy to the eddy covariance sensors above the vegetation. Relevant contributions of eddies of all different sizes and thus time scales have to be integrated to calculate the net ecosystem flux. “Relevant eddies” and hence the choice for the averaging period is based on determination of the so-called spectral gap, a frequency range that lies between turbulent scales and larger-scale disturbances. The spectral gap is, if ever, analysed once at the installation of the eddy system and the same averaging time is then used throughout the lifetime of the



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instrumentation. However, the width and position of the spectral gap changes with meteorological conditions (Von Randow et al. 2002). Post-processing tests (Integrated Turbulence Characteristics ITC, u*, $\sigma_w$) ensure that the measured turbulent fluxes represent well the ecosystem fluxes. If one of the tests fails, the whole half-hour is discarded, leading to a large number of missing half-hourly flux values often around 20%-50% of the total data (Vitale et al. 2019).

**Wavelet transforms to calculate net and gross carbon exchange fluxes**

Wavelet transforms, which analyze time series in time-frequency space, have been used in eddy covariance studies, such as on airplanes (Mauder et al. 2007) or to detect $CH_4$ flux outbursts from permafrost soils (Göckede et al. 2019). However, these applications were limited to specific campaigns and lacked comprehensive methods incorporating necessary data transformations and corrections for accurate ecosystem fluxes. Building on these earlier applications, Destouet et al. (2024) developed a wavelet-based method to continuously identify the spectral gap in time-frequency space, even under non-stationary conditions, and successfully applied it over a full year at the beech forest site FR-Hes. In parallel, Coimbra et al. (2023) addressed the challenge of estimating GPP and RESP directly from raw eddy covariance data. While traditional methods derive these fluxes from NEE using models (Tramontana et al. 2020), earlier attempts at direct estimation using $CO_2$-$H_2O$ similarity or conditional sampling (e.g., Scanlon & Kustas 2010, Zahn et al. 2022) have been inconsistent under varying environmental conditions (Klosterhalfen et al. 2019). Coimbra et al. (2023) integrated wavelet analysis into the partitioning process. This advancement provides a more stable and robust framework for deriving gross fluxes from high-frequency raw data.

This PhD project combines and enhances the developments of Destouet et al. (2024) and Coimbra et al. (2023) to provide an alternative to current eddy data processing, including the partitioning of gross fluxes. The method will be scrutinised with Large-Eddy Simulations and compared against existing methods at all European ICOS sites across ecosystems and countries. This PhD will enhance our understanding of agricultural and forest production by producing reliable observations that more accurately reflect climate impacts on plant and soil systems independently. These insights will support studies on topics such as water resources, droughts, extreme events, as well as long-term monitoring of greenhouse gas emissions.

**Objectives**

We propose a PhD project to investigate key assumptions in eddy covariance measurements, focusing on ensuring that observed signals represent ecosystem fluxes. The project will translate tests into the time-frequency domain and address three core questions:

1. Is a spectral gap consistently observed on tall forest towers? Detecting the spectral gap will validate the universality of the Destouet et al. (2024) approach for identifying turbulent regions.
2. Can individual eddies reliably partition fluxes directly from 20-Hz data? Using LES simulations and machine learning at ICOS sites, this will test and strengthen the methodology of Coimbra et al. (2023).
3. Can high time-resolution fluxes be provided across all European ICOS sites? Successful application across ICOS sites will position this method as a robust alternative to existing products, enabling new research possibilities.

This project combines turbulence analysis, modeling, and machine learning to advance ecosystem flux research.

**Methodology**

During this project, the PhD candidate will develop a new method for eddy covariance analysis that integrates key post-processing steps, such as turbulence testing (ITC, u*) and partitioning net fluxes into GPP and RESP, directly into raw data processing. Building on Destouet et al. (2024) and Coimbra et al. (2023), the method will



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be refined, validated with LES/DNS simulations, and tested against standard processing at all ICOS ecosystem sites.

The project includes:

1. Developing a comprehensive raw data processing chain to replace current methods (e.g., EddyPro®) by implementing frequency corrections, humidity adjustments, and density corrections directly on high-frequency data.
2. Validating flux quality and turbulence adequacy using time-frequency information to enhance ITC tests and confirm ecosystem flux accuracy.
3. Partitioning fluxes into GPP and RESP at high temporal resolution by refining methods to account for uncertainties in individual eddy fluxes and extending applicability to diverse ecosystems and tower heights.
4. Testing the method with LES/DNS simulations, providing a noise-free testbed to validate key assumptions, such as the confinement of eddy behaviors.
5. Applying the method to all ICOS sites, leveraging its scalability across various ecosystems to demonstrate its potential as an alternative to existing products.

The work will focus initially on managed sites FR-Hes and FR-Gri, and the tall SE-Svb forest tower, before scaling to the entire ICOS network, offering a robust, high-resolution tool for ecosystem flux research.

**Applications**

We are seeking a motivated candidate who is eager to work in an interdisciplinary setting at the intersection of signal processing, fluid mechanics, and ecophysiology. They should have strong computer skills, an aptitude for mathematics, have interest in research related to climate change, and an affinity to work with international partners.

The thesis will take place for three years at the UMR Silva on the campus of INRAE near Nancy (54280 Champenoux) from autumn 2025 onwards, with frequent visits to UMR Ecosys in Paris-Saclay.

To apply, please send a cover letter, a CV, the transcript of grades of the master (or of the 3 years of engineering school), a contact information of an academic reference, as well as a résumé (300 words) of the master topic (or of the end-of-study internship) to:

Matthias Cuntz – matthias.cuntz@inrae.fr
Pedro Coimbra – pedro-henrique.herig-coimbra@inrae.fr

Interviews will take place between the beginning of August and mid-September.

Do not hesitate to contact us for any further information.



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