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BenchFlux: Advancing Nature-Based Climate Solutions through Scale-Aware CO_2 Flux Benchmarks

Emma Izquierdo-Verdiguier[1], Álvaro Moreno-Martínez[2], Paul Stoy[3], Oliver Sonnentag[4], Christopher Pal[5], Yanghui Kang[6], Trevor Keenan[7], Ankur R Desai[3], Stefan Metzger[8], Jingfeng Xiao[9], Matthew Fortier[4,5], Maoya Bassiouni[7], Sadegh Ranjbar[3], Samuel Bower[8], Sophie Hoffman[3], Danielle Losos[3], and Nicholas Clinton[10]

[1]University of Natural Resources and Life Sciences Vienna (BOKU), Austria (emma.izquierdo@boku.ac.at)
[2]University Valencia, Spain
[3]University of Wisconsin-Madison, USA
[4]Université de Montréal, Canada
[5]École Polytechnique de Montréal, Canada
[6]Virginia Tech, USA
[7]University of California-Berkeley, USA
[8]AtmoFacts, USA
[9]University of New Hampshire, USA
[10]Google, Inc., Mountain View, CA, USA

Addressing the escalating climate crisis necessitates precise tools for evaluating nature-based climate solutions (NbCS). The BenchFlux project represents a significant advancement by developing scale-aware benchmarks for carbon dioxide (CO_2) fluxes, leveraging flux tower measurements and Earth Observation (EO) data. Unlike existing scale-agnostic approaches, BenchFlux introduces a methodology that explicitly accounts for the emergent, nonlinear behaviors inherent in carbon flux dynamics across spatial and temporal scales.

The objective of this project is to harmonize bottom-up CO_2 inventories with top-down atmospheric inversions, thereby providing substantial tools for precise carbon accounting on global-to-local scales. By integrating flux tower ground-truth data and multi-source EO datasets, BenchFlux employs machine learning (ML) and cloud computing tools to develop ML-ready benchmarks with enhanced precision and uncertainty quantification. By transitioning from scale-agnostic to scale-aware data joins, the project optimizes the statistical power of flux tower measurements while maintaining consistency across various scales.

BenchFlux is built on three pillars:

- **Observational Inputs**: Nested integration of flux tower ground-truth and EO predictors to produce a harmonized, ML-ready dataset. This includes multi-resolution, spatialized CO_2 flux data with uncertainties across spatial-temporal scales, enabled by Google Earth Engine and cloud-optimized workflows.

- **Models**: Development of advanced ML models, such as Bayesian and knowledge-guided approaches, to improve predictive accuracy and functional consistency for carbon flux estimation.
- **Benchmark Outputs**: Comprehensive datasets, baseline models, and uncertainty-aware evaluation metrics to foster collaboration and inform NbCS policies from local to global scales.

BenchFlux is a collaborative project across six international research teams, integrating expertise in flux tower data processing, remote sensing, and ML. By fostering open science practices, the project will provide accessible tools, tutorials, and datasets to empower the global scientific community. The project outcomes will catalyze the adoption of NbCS, ensuring accountability in net-zero pledges and advancing climate solutions grounded in scientific rigor.