Project: **1240**

Project title: Potentials and vulnerabilities of future terrestrial carbon sinks under different pathways

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Allocation period: **2023-01-01 to 2023-12-31**

Text: Maximum of two pages including figures. Reports for joint projects may be longer.

Overview

The main purpose of this project is to analyse the role of natural disturbances, climate variability and land-use on the terrestrial carbon cycle under various future greenhouse gas concentration pathways. The project is embedded in the project "High-resolution monitoring of avoided carbon emissions and carbon restoration potentials from land use change", funded by the Stifterverband/Volkswagen AG that aims at quantifying the variability of sub-component carbon fluxes (e.g. forest degradation) and their drivers (anthropogenic vs. natural). In a first step, we developed a new model-data integration approach that allows us to disentangle observed changes in terrestrial biomass carbon into anthropogenic (land-use) and environmental flux contributions (Bultan et al. 2022). This distinction is crucial for understanding how the terrestrial carbon sinks evolve under direct human influences versus climate change and climate variability. Here, we focus our analysis on the Amazon rainforest, as it constitutes one of the main carbon sinks on land, storing around 150-200 PgC in vegetation and soils (Brienen et al. 2015). There has been growing scientific evidence that the Amazon rainforest might be approaching a tipping point, where continued deforestation and climate change could trigger a large-scale dieback of the rainforest, which could lead to a carbon release of ca. 30-75 Pg to the atmosphere and would therefore have severe consequences for the global climate system (Armstrong McKay et al. 2022). However, a systematic analysis of the probability of an Amazon tipping point in the current generation of Global Climate Models (CMIP6) and how this might be mediated by land-use, climate change and climate variability under realistic greenhouse gas concentration pathways is currently lacking. We report here on the progress of the project proposed in the request for DKRZ resources for end of 2021 to the end of 2022. Note that we did not conduct the simulations that were planned in the initial request for project bm1240, as new opportunities to study tipping points and fill current scientific gaps opened up as part of the AIMES (Analysis, Integration, and Modeling of the Earth System) community. However, our analysis is still in line with the scientific goals for project bm1240 and required and will require substantial HPC resources, as we are analysing a large amount of CMIP6 datasets and employing novel, computationally extensive algorithms to study tipping behaviour, which requires full parallelisation to ensure time-efficiency.

Development of an algorithm for automatic detection of abrupt transitions of the forest carbon sink

Our algorithm for the automatic detection of abrupt transitions in vegetation state partly builds on recent scientific work (Smith, Traxl, and Boers 2022; Boulton, Lenton, and Boers 2022b), but was adapted substantially to capture state transitions. We tested the algorithm for carbon stored in vegetation. Our algorithm combines a linear fit approach (i.e., fitting linear trends over moving windows of different sizes) to detect the strongest (identified through a percentile threshold) declines in vegetation carbon within the time series with surrogate data testing to analyse whether the decline in vegetation carbon during an abrupt transition is statistically significant. Fig. 1 shows that the algorithm successfully detects abrupt transitions in the vegetation carbon sink.

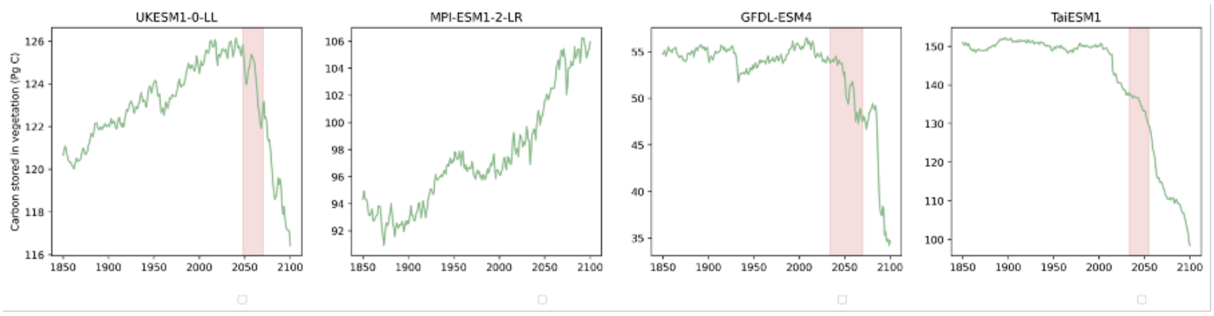

Figure 1: Timing of abrupt transitions (red frames) of the vegetation carbon sink in the Amazon rainforest under the ssp370 scenario.

Disentangling drivers of abrupt transitions

To better understand the causes of abrupt transitions in vegetation state, we separate abrupt transitions due to deforestation from those due to climate change and climate variability. We do this by using multiple climate realizations (i.e., ensemble members) for each model. The ensemble members differ due to climate variability only and are independent from each other at each time step. However, the land-use forcing is the same for all ensemble members. Consequently, we assume that an abrupt transition that occurs in all ensemble members at the same time step must be caused by land-use. We tested this hypothesis spatially (Fig. 2) and found that the timing of abrupt transitions is the same for multiple ensemble members in grid cells that are strongly affected by land-use change (i.e., grid cells with the 5% highest emissions from land-use change), while the timing of abrupt transitions differs between ensemble members in areas that are not or barely affected by land-use change. The quantification of the percentage of abrupt transitions caused by deforestation versus climate change and climate variability is work in progress.

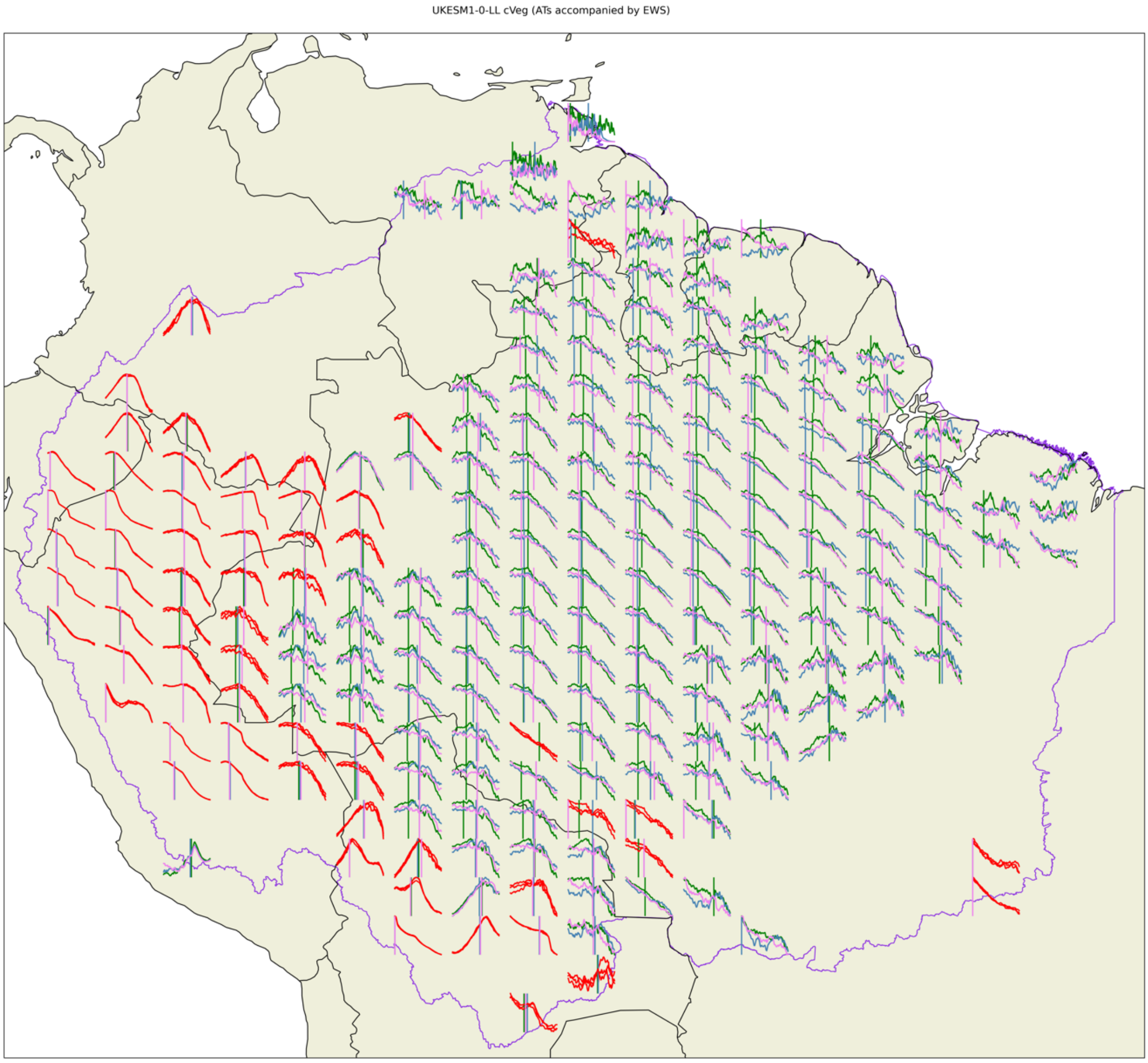

Figure 2: Time series of 21st century vegetation carbon in grid cells with abrupt transitions. The different colored lines show different ensemble members (i.e., climate realizations), whereas the vertical lines are the timing of abrupt transitions. Red lines are grid cells where emissions from land-use change exceed the 95th percentile of all emissions from land-use change.

Early Warning Signals for detecting abrupt transitions

We tested various statistical and ecological indicators (vapor pressure deficit, precipitation) that could potentially serve as 'Early Warning Signals' (EWS) for upcoming abrupt transitions in the state of the Amazon rainforest (Hu, Dakos, and Rietkerk 2022). The statistical indicators include Variance and lag-1 Autocorrelation (AR1) that have been shown to robustly increase close to an abrupt transition due to a loss in ecosystem resilience (Smith, Traxl, and Boers 2022; Boulton, Lenton, and Boers 2022a). Our preliminary results suggest that abrupt transitions in vegetation are often forewarned by a statistically significant (tested with surrogate data testing) increase in variance and/or AR1 and/or vapor pressure deficit.

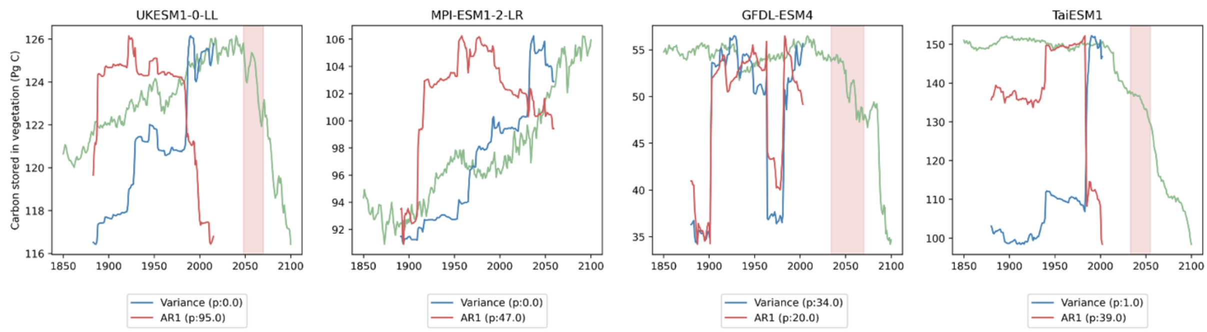

Figure 3: Timing of abrupt transitions (red frames) of the vegetation carbon sink in the Amazon rainforest under the ssp370 scenario and statistical early warning signals. P-values of Variance and Autocorrelation (AR1) indicate whether there is a statistically significant increase in Variance and/or AR1 prior to the abrupt transition.

References

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