Simulating anthropogenic fire over the Holocene using an updated fire module in the LPJ-DGVM

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Introduction

Fire is one of the most important disturbance processes that affects the terrestrial biosphere by altering vegetation composition and distribution, biomass productivity and plant diversity. Moreover, biomass burning is a key process controlling the spatial and interannual variability in the emissions of climatically relevant trace gases, such as CO_2, CH_4, CO and NO_x. Changes in biomass burning throughout the Holocene are also likely to have affected the global carbon budget and were influenced by vegetation, weather, climate and human activities.

Reasons for anthropogenic burning include landscape management, e.g. promotion of habitat and resource diversity, alteration of natural fire regimes, the usage of fire as a hunting tool, landscape clearing and agricultural burning of harvest remainders. Evidence for a purposeful extensive use of fire by hunter-gatherer societies has been documented , e.g. for Native Americans and Australian aboriginal tribes (Lewis 1973, 1982; Bowman 1998), and suggests that these societies may have greatly changed ecosystems for their use and survival using fire as a management tool. However, global-scale quantification of natural and anthropogenic biomass burning during the Holocene remains challenging. Integrative methods such as modeling of vegetation dynamics combined with process-based modeling of fire dynamics are suitable to quantify the effect of natural and anthropogenic burning on vegetation, carbon pools and trace gas emissions over extensive temporal and spatial scales.

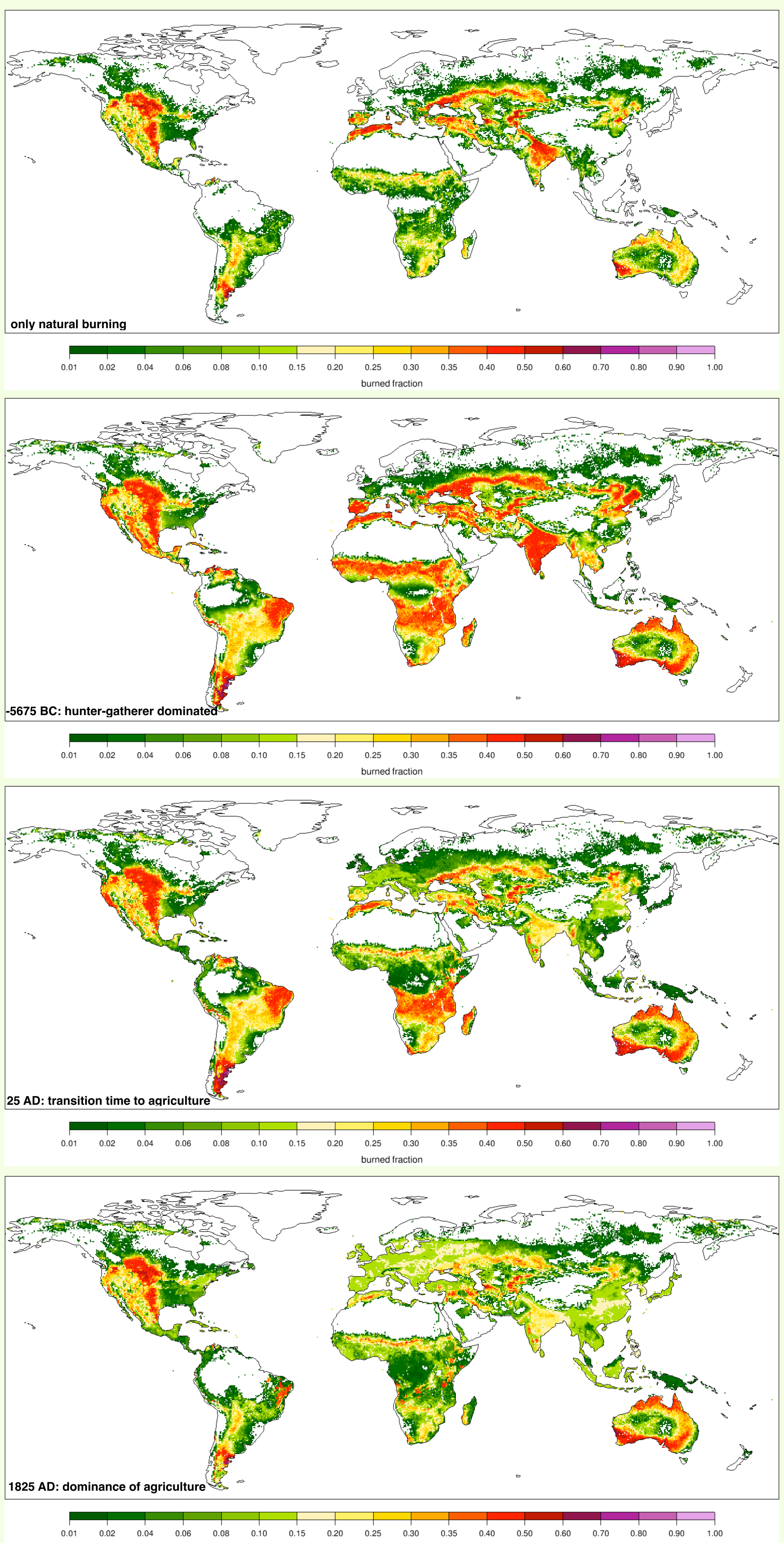
Methods

We combine the dynamic global vegetation model LPJ with an updated process-based fire module (based on SPITFIRE) and a new scenario of global preindustrial human population and land use in order to quantify Holocene changes in burned area, trace gas emissions and terrestrial carbon storage. Fire is simulated for three different cases:

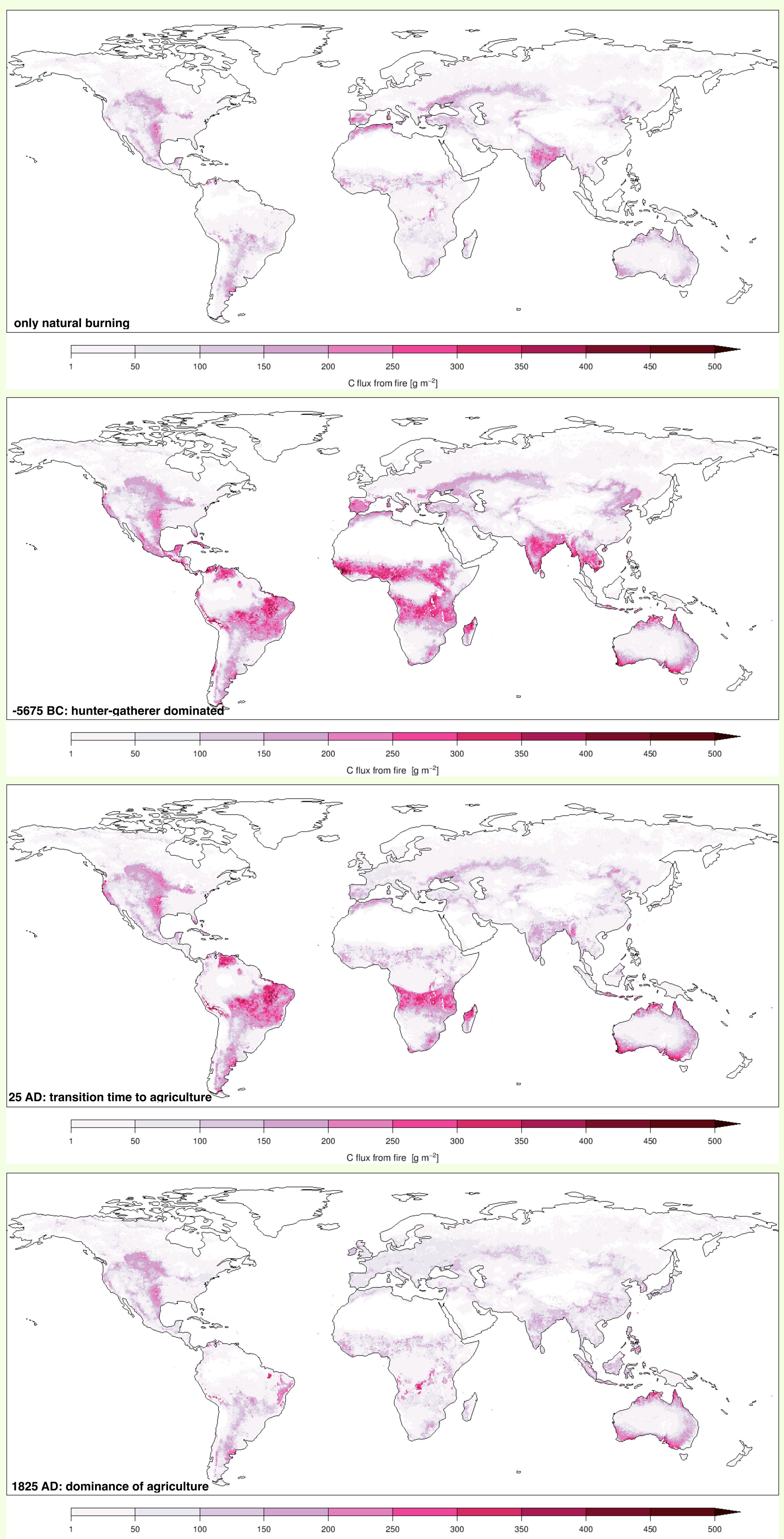
a) wildfire as a result of natural processes (lightning as ignition source)
b) wildfire ignited by humans (intentionally, accidentally)
c) managed fire for conversion and maintenance of agricultural land

We distinguish three different human lifestyle strategies - hunter-gatherers, pastoralists and farmers - and assign each group different baseline ignition rates for intentional burning on natural land. Timing of intentional burning is set to a maximum rate up to moderate fire risk (FDI of 0.25), and decreases as risk for severe wildfire increases. Farmers are currently set to burn an equivalent of 20% of cropland after harvest every year. Landscape fragmentation by increasing landuse is taken into account, leading to a reduction in the maximum possible average size of individual fires based on the average natural patch size at a given landuse fraction. Burning by hunter-gatherer societies is set to reach a target of 10% of the landscape, which will only be achieved if fire weather conditions allow for enough burning, i.e. where the dry season is long enough.

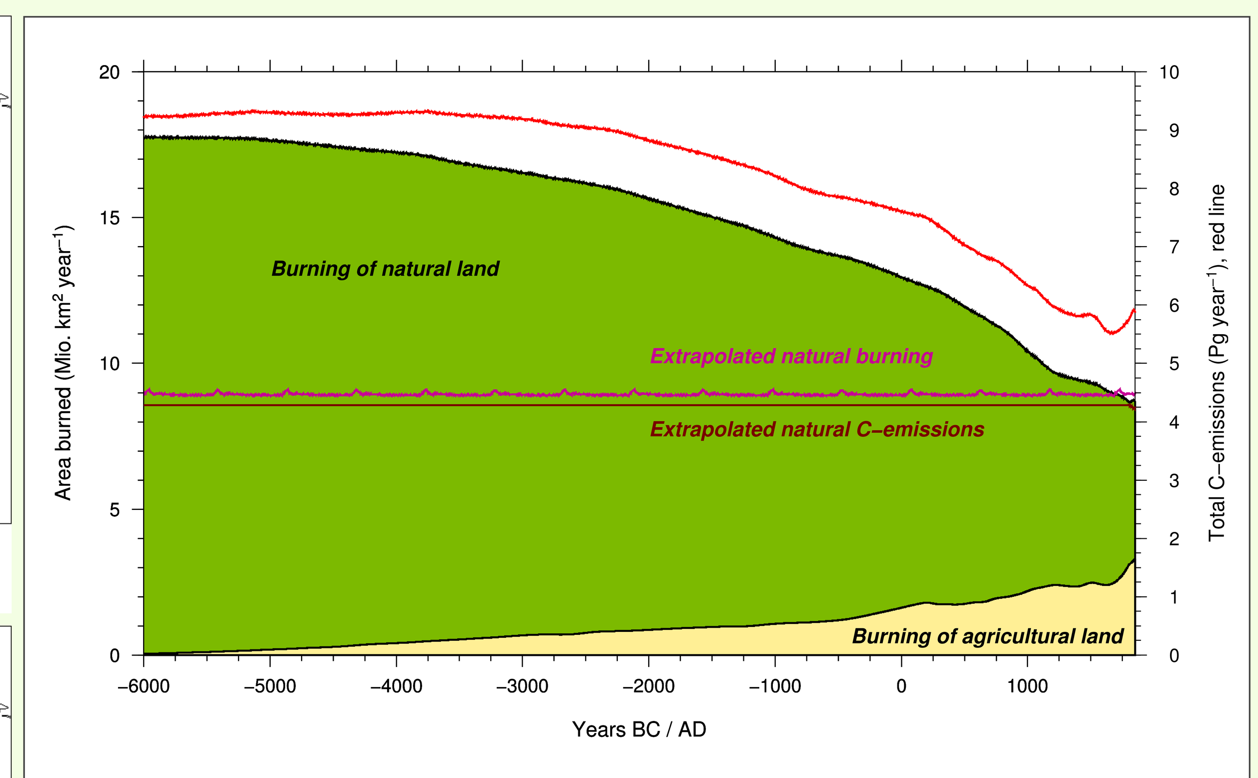
Burned area fraction

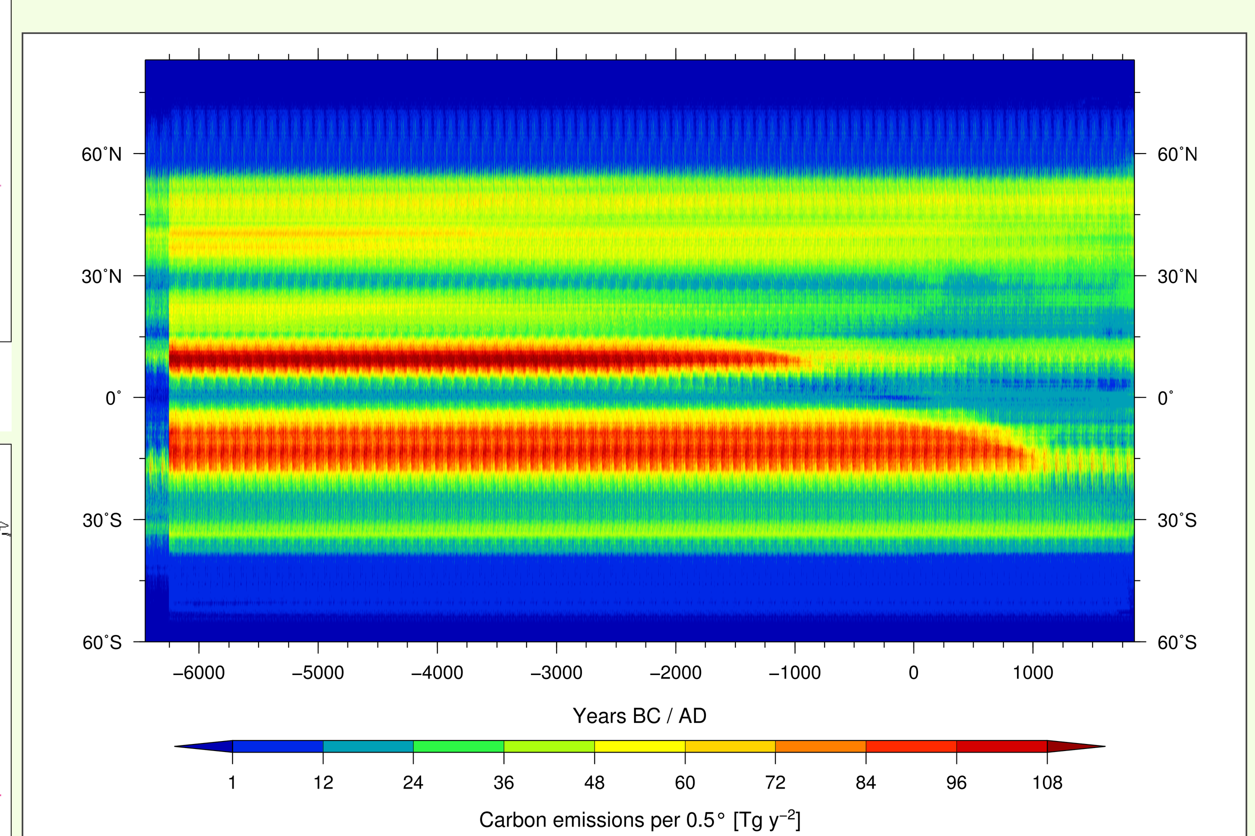


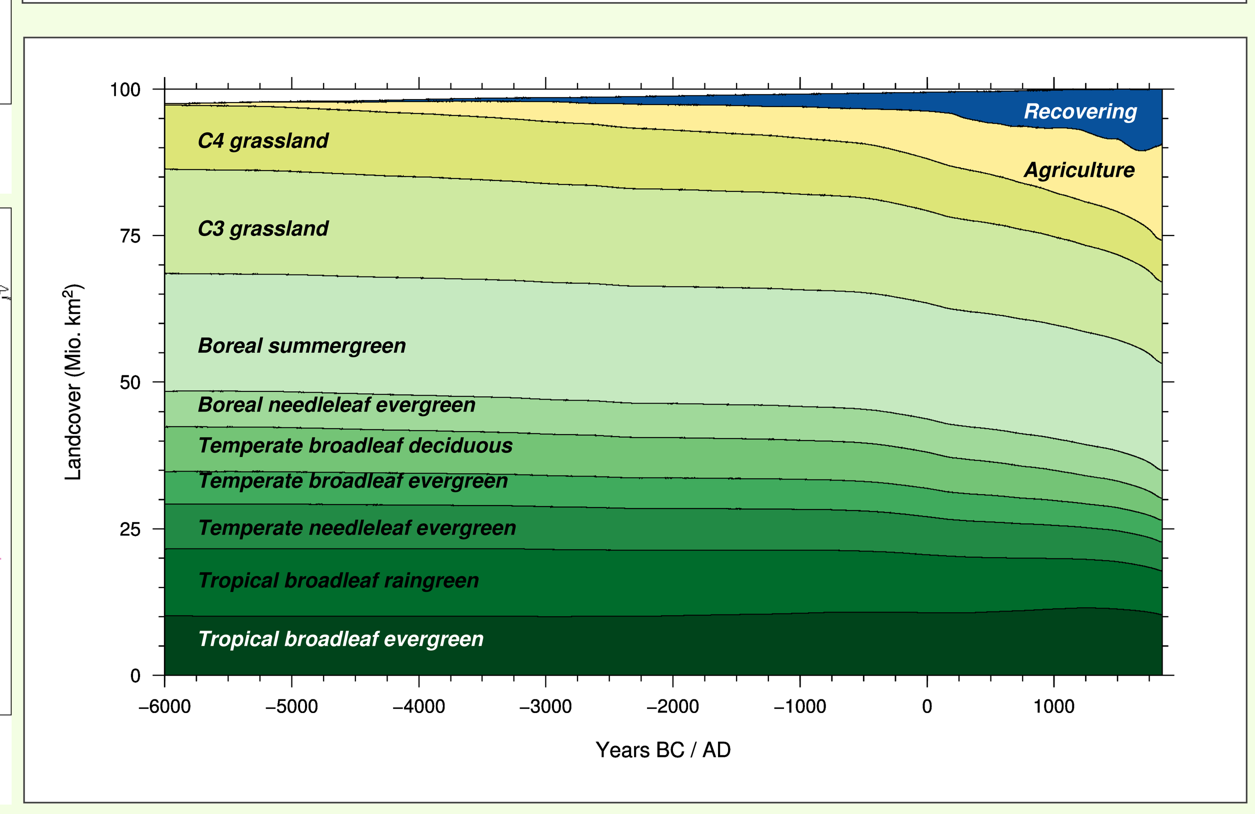
Carbon emissions



Time series







Conclusions

Our results indicate that increasing population densities, changes in lifestyle strategies and intensification of agriculture over the later part of the Holocene led to decreases in fire activity due to indirect and direct suppression of fire by humans. Fire suppression results from a reduction in fuel loading, landscape fragmentation due to landuse intensification and changing agricultural practices. This fire suppression led to a gradual decline in trace gas emissions from biomass burning over the last 8000 years. Changes in total carbon storage within biosphere and soils, however, were more influenced by conversion of forests to cropland and pasture. Therefore, the overall Holocene carbon balance was a large transfer of carbon from the terrestrial biosphere to the atmosphere and oceans. Extensive burning practices of early hunter-gatherer populations are likely to have contributed to significant releases of climatically relevant greenhouse gases (CO_2, CH_4, NO_x) and may support the early anthropogenic hypothesis.

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