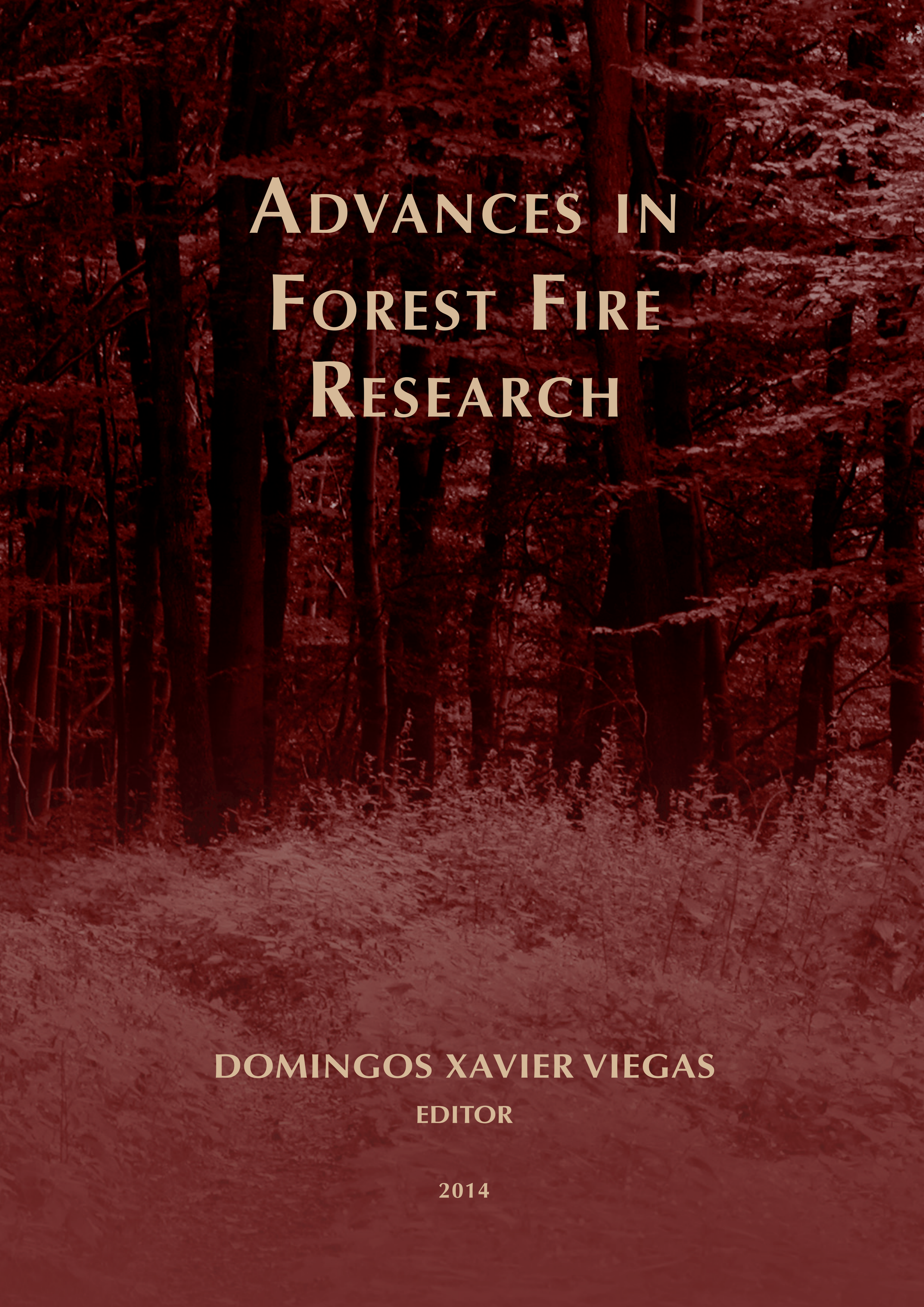

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Fire and deforestation processes represented in vegetation models for the Brazilian Amazonia

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Abstract

Dynamic global vegetation models need to be improved to accurately represent fire and land-use change in Amazonia. To this end, we are working on improving existent dynamic vegetation models to account for such strong disturbances, and aim to perform new analyses to quantify how fire, deforestation and climate change may combine to affect the distribution of major biomes and climate in the region. At present, we concentrate the development and implementation of new fire models on the simulation of fire probability and effects on vegetation dynamics, based on methods already tested in global dynamic vegetation models where fire potential is driven by the combination of presence of fuel, flammability, and sources of ignitions. To account for fire disturbance we assumed that the fraction of the vegetation affect by fires is proportional to the fire probability. Deforestation is directly interpreted as a fraction of the affected vegetation, and it is assumed to disturb tropical, temperate and conifer broadleaf, evergreen and deciduous trees. Both disturbances affect biomass, leaf area index, and total ecosystem aboveground net primary productivity, modifying the fractional cover of forest and herbaceous canopies. These implementations represent important steps towards the development and use of vegetation models that can account for major contemporary disturbances in the study region.

Keywords*: Fire, deforestation, model, Amazonia*

1. Introduction

Dynamic global vegetation models with improved representation of surface process are being developed to access the impacts of fire and land-use change in Amazonia. In addition to represent major features such as vegetation distribution, terrestrial carbon cycle and links between land surface and atmosphere, the models need to be improved to account for major disturbances in the region. Fires and deforestation have substantial impacts on the ecosystems of Amazonia, causing rapid shifts in surface cover, atmospheric emissions of greenhouse gases, and modifications fluxes of moisture and energy from the surface. To this end, we are working on improving existent dynamic vegetation models to account for fires and deforestation in Amazonia.

The current developments for representing fire and deforestation processes in vegetation models for Amazonia were implemented in a revised version of the IBIS model (Integrated Biosphere Simulator), which has the ability to simulate land-surface processes such as vegetation dynamics and terrestrial carbon cycle, based on dominant climate and soil properties (Foley *et al*. 1996, Kucharik *et al*. 2000). The model offered the possibility of performing global and regional simulations from common input datasets, and was tested using several experiment configurations and evaluations of model outputs. One test was the compatibility between model and observed values of evapotranspiration globally (Baumgartner and Reichel, 1975).

Our improvements of IBIS evolved into the Brazilian Integrated Land Surface Processes Model (Inland), first released on November 2012 during a workshop at INPE (http://www.ccst.inpe.br/inland). The development of the model aims global applications with emphasis on improvements and performance for ecosystems in South America and Brazil, and is part of a broad effort in Earth System modelling in Brazil [ref BESM]. From Inland 1.0, we have implemented a new fire scheme and the ability of the model to account for deforestation disturbances, including the assimilation of deforestation scenarios for Amazonia, as summarized below.

2. Methods

2.1. Fire occurrence and effects

The development of the new fire model implemented in Inland was based on methods already tested in global dynamic vegetation models (Cardoso *et al*. 2013). From the methods considered, we adopt the work of Arora and Boer (2005) (AB2005) where fires are simulated as burning occurrence (probability of fire) and effects (burned area and emissions). At this initial stage, we concentrated the development and implementation of the fire model for Inland on the simulation of fire probability and effects on vegetation dynamics only. For that, we implemented the fire occurrence probability equations of AB2005, where fire potential is driven by the combination of presence of fuel, flammability, and sources of ignitions.

Presence of fuel is represented as in AB2005, which determines that a minimum of 200 gC/m2 of plant biomass is required to sustain a fire. In the Inland implementation, plant biomass was considered the sum of stem and leaf biomass from all vegetation types over land. Flammability, as described in AB2005, increases exponentially as soil moisture at the root zone approaches the wilting point. In Inland, we calculate flammability based on the moisture at the model's first soil layer, where most of roots are located. Our approach to represent ignitions sources from lightning differed from AB2005 as we assumed that lightning activity is simply random. Final fire occurrence probability is calculated by multiplying these three estimates, as in AB2005.

To account for fire disturbance, we propagated the fire occurrence probability estimation into the calculation of vegetation dynamics, following the original IBIS formulation for considering disturbances. That was done by assuming that the fraction of the vegetation affect by fires is proportional to the fire probability. As disturbances (fraction of affected vegetation) were considered in IBIS, Inland considers that fires affect biomass, leaf area index, and total ecosystem aboveground net primary productivity, which in turn modify the fractional cover of forest and herbaceous canopies.

2.2. Deforestation processes

Based on a similar approach used for fire, deforestation processes were considered in Inland also by accounting for this disturb when calculating the dynamics of the vegetation. In this case, no additional assumptions were made, and input deforestation data is assimilated by directly interpreting it as a fraction of affected vegetation. However, we assume that the grid-cell fraction of vegetation affected by deforestation only impacts tropical, temperate and conifer broadleaf, evergreen and deciduous trees. For these classes, deforestation changes plant biomass, leaf area index and net primary productivity.

In Inland, the treatment of the fire and deforestation consequences follows the original IBIS formulation, and the possibility to consider a general natural disturbance rate is also maintained. In order to avoid overly-high (greater than 100%) fractions of affected vegetation, the balance between disturbance rates is evaluated in each grid cell by assuming precedence of natural causes, than fires, and finally deforestation, and by limiting the overall annual disturbance rate for each model grid cell to a maximum of 100%.

3. Results

The new implementations of fire and deforestation processes in the Inland model were tested in simulations where the model was run for a total of 699 years (1400-2099), to allow for equilibrium of the slow carbon pools and to test the model stability. There was an initial spin-up period of 366 years (from 1400-1765) under constant pre-industrial atmospheric CO2 value (278 ppm). The runs were continued from 1766 to 2005 with increased prescribed atmospheric CO2 concentrations (from 278 to

378 ppm), and from 2005 to 2099 with atmospheric CO2 concentrations following the Coupled Model Intercomparison Project 5 (CMIP5) protocols. From 1400 to 2005, climate data was applied cyclically, and after 2005 from CMIP5 models. Deforestation data is based on the work of Aguiar *et al*. (2012). The results presented here represent only contemporary conditions of the study region.
Figure 1 below shows the effect of considering fires in Inland. Top panels (a, b) show the spatial distribution of evergreen trees (tropical and temperate broadleaf trees, and boreal and temperate conifers) biomass. The bottom panels (c, d) show the spatial distribution of grasses (warm and cool grass) biomass. On the left the maps show simulation results without fires, and on the right considering fires. As shown, the simulation of the transition between forests and grasslands in the Brazilian Amazonia (approximately highlighted by the dotted ellipsis) is affected by the consideration of fire in the formulation of the model. As simulated, there is an expansion of grasses over forest areas noticeable in the border between the two regions dominated by these types of vegetation.

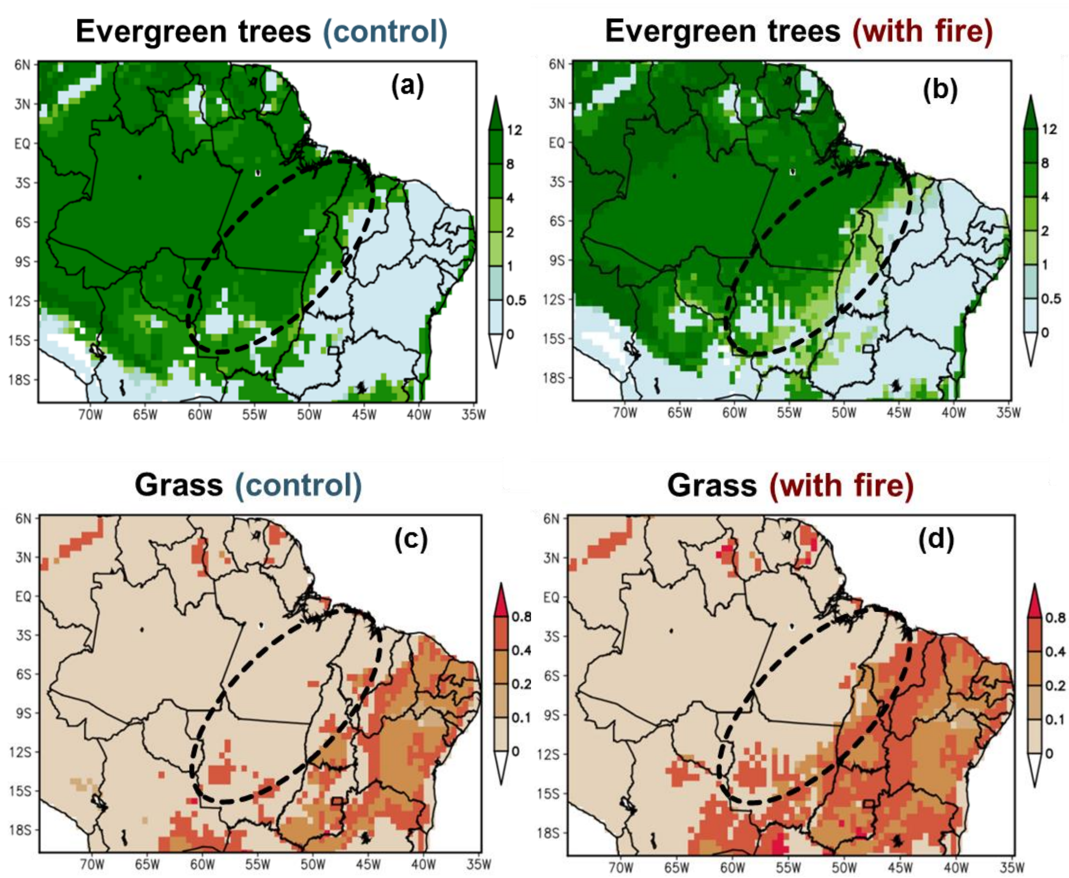

Figure 1. Contemporary distribution of evergreen trees and grasses biomass over the Brazilian Amazonia as simulated by the Inland model. Top panels (a, b) show the spatial distribution of evergreen trees (tropical and temperate broadleaf trees, and boreal and temperate conifers) biomass, and bottom panels (c, d) show the spatial distribution of grasses (warm and cool grass) biomass. On the left the maps show simulation results without fires, and on the right considering fires. The black dotted ellipsis approximately highlights the transition between forests and grasslands in the Brazilian Amazonia.

Figure 2 below shows the effect of considering deforestation on the contemporary distribution of evergreen tropical and temperate broadleaf trees biomass over the Brazilian Amazonia simulated by the Inland model. Panel (a) shows the spatial distribution of biomass without considering deforestation effects. Panel (b) shows the spatial distribution of the simulated biomass considering disturbance from deforestation based on Aguiar *et al*. (2012). As shown, the simulated biomass differs substantially by considering deforestation. In relation to panel (a), (b) shows patterns of reduced tree biomass that resembles the observed contemporary maps of forests distribution in the study region.

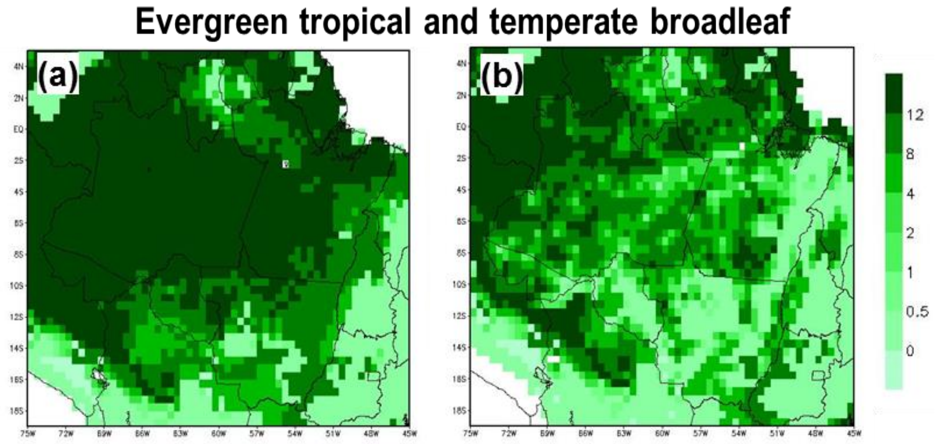

Figure 2. Effect of deforestation on the contemporary distribution of evergreen tropical and temperate broadleaf trees biomass over the Brazilian Amazonia simulated by the Inland model. Panel (a) shows the spatial distribution of the simulated biomass without considering deforestation effects. Panel (b) shows the spatial distribution of the simulated biomass considering disturbance from deforestation based on Aguiar et al. (2012).

4. Conclusions

At present, our implementations of major contemporary disturbances to ecosystem in Amazonia (fires and deforestation) are very simple, but they represent important steps towards the development and use of vegetation models for the study region. These new features are also important for broader analyses, where connections with prevailing environmental conditions such as climate can be considered. In specific, our preliminary results (not shown here) from offline and coupled vegetation-climate projections under current (5th Assessment Report of the Intergovernmental Panel on Climate Change) protocols of evaluations of future climate, indicate that the impacts of climate change in Amazonia will potentially intensify when combined to fires and deforestation. It is expected, for example, increase in dry season length, and reduction in the upper-canopy biomass related to an increase of the biomass in grasses from replacements of tropical forest by seasonal forest and savanna. These effects can have important implications for the distribution and stability of the vegetation in the region. Our future research activities include further model improvements and runs to understand the potential for changes and the connections between the ecosystems of the region and global environmental conditions and processes, such as carbon cycling and climate dynamics.

5. Acknowledgments

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