1. **Materials and Methods**
2. **3.3. CAETE: an overview**

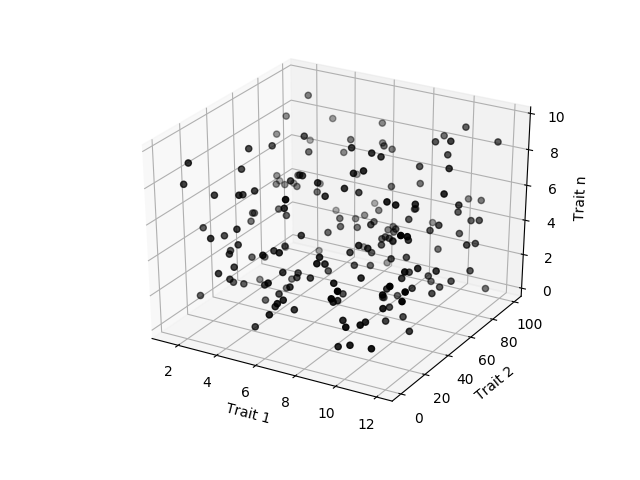
Here we present, for the first time, the Vegetation Model CAETÊ (Carbon and Ecosystem Functional Trait Evaluation Model). As a trait-based model, it focus on represent more reliably the variability of plant functional traits and, as full as possible, the range of functional diversity found in plant communities. For this, different from the the majority of current models, the vegetation representation is no longer through PFTs with its fixed parameters; instead, the vegetation is represented by a set of ecological strategies (called as plant life strategies (PLS) in CAETÊ model) generated by a unique combination of functional traits values. These values combination intend to describe the ecophysiological behavior of plants and their relationship with the environment. For this, they control, for example, differential acquisition of carbon, light and water, ultimately, determining how the strategy copes with the environment.

The underlying premise is that the range of values of a functional trait observed in nature can be seen as an axes of a multidimensional hypervolume formed by the combination of *n* chosen functional traits (VILLÉGER; MASON; MOUILLOT, 2008)⁠. In that sense, each point of this hypervolume is a unique combination of values for each functional trait and the volume that all points together occupy can be seen as a functional trait space (Figure XXX). It recalls the concept of the Hutchinsonian multidimensional niche in which the hypervolumes characterize phenotypic space occupied by a set of species (CARMONA et al., 2016; HUTCHINSON, 1957; LAMANNA et al., 2014; VILLÉGER; MASON; MOUILLOT, 2008). Each combination of functional traits (i.e. PLS) within the trait space performs differently in different regions depending on the environmental variables, analogously to the mechanism of environmental filtering (DIAZ; CABIDO; CASANOVES, 1998; WEBB et al., 2010). Since functional traits both respond to and affect the ecosystem (DÍAZ et al., 2013; FUNK et al., 2017; LAVOREL; GARNIER, 2002)⁠, these spatially different performance generates spatially different outputs (e.g. biogeochemical fluxes, stocks and functional diversity). These differential survival in a climatic condition depending on trait combination is possible because each functional trait is related to a trade-off (cost-benefit relationship) then different value combination leads to different "fitness"; the trade-offs also impedes that the model creates Darwinian demons (i.e. maximizing all the functions that contribute for fitness; (SCHEITER; LANGAN; HIGGINS, 2013)⁠ . Also the trade-offs permits a srategy perform different relativety to other strategies and occupy differente proportions of the grid-cell. ecosystem effect is possible because each functional trait is related to one or more ecosystem process⁠

Uma versão simplificada de competição.

This approach enables to analyze, as standard DGVMs, the biogeochemical cycles and as a standing out point the spatial distribution of the traits and its combinations as well as the different functional diversity facets. As the environmental changes (with the different climate change scenarios, for example) some PLSs would be favored and could increase its abundance, others may no longer be able to deal with new conditions and may be excluded. It changes the distribution of functional traits what can affect functional diversity, biogeochemical cycles, ecosystem functioning and hence resilience. Then, we are able to access compositions and abundance changes on PLS, and hence traits and functional diversity changes, in each community.

SEMI RANDOM



It opens the opportunity to analyse beyond the biogeochemical cycles, what is not possible with the PFT scheme.

FUNCTIONAL TRAIT-SPACE: FITNESS -> cope with the environment

TRADE-OFFS

Environmental filtering

THE NOVELTIES

1.1) **Generating and sampling the plant life strategies**

With the CAETÊ approach is possible to combine any number of any chosen functional traits to generate the potential functional space. This allows to investigate a plethora of ecological questions related to the more variate ecosystem and ecological processes, and as a standing out point, functional diversity question, including the ones concerned about the effects of climate change on natural ecosystems. The vallues that will compose this functional trait space are sampled from the range of values of the selected traits. This sampling can be uniform, according to a theoretical curve or following a distribution curve obtained from empirical studies.

The combination of all sampled values generate a great number of combinations within the functional space what can turn the modeling computationally impracticable. Then, we presume that sampling an appropriate number of PLS from the potential functional space combined with the environmental filtering mechanism is possible to produce reasonable biogeochemical and functional diversity patterns (PAVLICK et al., 2013)⁠. The problem that emerges is to determine how many PLS are necessary to be sampled. For this we performed analysis of how the CAETÊ's outputs change with the number of sampled PLS both regarding to biogeochemical variables and functional diversity variables (see section XXX for the CAETÊ's representation of functional diversity). The inclusion of functional diversity variable analysis is necessary because different traits combination can generate same values of biogeochemical variables (e.g. biomass) and analyzing only this variables could underestimate the necessary number of PLS. Then, a set of 6 ensembles with different numbers of sampled PLS (number of PLS = 50, 100, 200, 500, 1000, 3000) was ran to test the model sensitivity. Each ensemble contains 10 runs; this is required because of the random nature of the sampling process. The only difference between the ensembles is the number of initialized PLS.

Our analysis focused on NPP (biomassa prediz melhor), the different facets of FD (the dissmilarity index), hypervolume. For this, we separated the globe in three latitudinal zones: tropical zone (between 23.25ºN and 23.25ºS), temperate zone [north temperate zone (between 66.25ºN and 23.75ºN) plus south temperate zone (between 66.25ºS and 23.75ºS)] and polar zone [north polar zone (between 66.75ºN and 80ºN) plus south polar zone (between 66.75ºN and 80ºN)]. This zonal separation is needed because a global analysis could introduce an artificial variation, especially when dealing with functional diversity, since is expected a great degree of functional diversity between different latitudinal zones (LAMANNA et al., 2014)⁠ .

Our evaluation was regarding to the stabilization of the number, variance and dissmilarity index (in the case of functional diversity). We hypothesized that as the number of PLS increase the value of the chosen variables would tend to stabilize, the variance within each ensemble would tend to decrease as well as dissimilarity between ensembles.

For this analysis we have only considered the multi-traits framework

Quais estratégias não são inicializadas?

Porcentagem de gramíneas e herbáceas

Primeiro cria o espaço potencial e depois amostra?

**1.3) Gridcell occupation: the differential survival and the trade-offs role**

In a given environment many possible species, with its different characteristics, can survive. However they occupy different proportions of the ambient and contribute differently to the ecosystem functioning. A PFT scheme cannot capture it.

For capturing it the strategies arre simulated simultaneously using the g the same ecophysiolog- ical parameterizations under the same atmospheric forcing. The only part in which the plant growth strategies differ is in their values for fifteen functional trait parameters (t1, . . . , t15; Table C2).

"Each trait parameter is associated with costs and benefits,

leading to functional trade-offs because no trait value (or set of trait values) can be optimal for plant fitness in all environ- ments. For example, a particular growth strategy may allo- cate a relatively high fraction ofcarbon to fine roots, enhanc- ing the rate at which it can extract moisture from the soil matrix. This may be beneficial in terms of higher productiv- ity. However, it also comes with both real and opportunity costs. That growth strategy would incur the real metabolic costs of growth and maintenance respiration for the addi- tional fine root biomass."

All the grid cells are initiated with the same amount and the same identity of PLS in a bare soil this means that all trait combinatios are equally probable to occupy the grid cell. Since each grid cell has its particular climatic conditions some PLS will survive and some will not. A strategy is considered as survivor if it present (i) a positive carbon balance and (ii) present, concomitantly, at least 100 g of carbon in fine roots and in leaves. This is necesary because the model still do not have a storage compartment (what could enable the survival of a strategy because it could provide carbon compounds even in periods when the plant loses the leaves or has low water supply ). Since the CAETÊ is, yet, not a DGVM but an equilibrium model, the strategies which did not survive and were excluded from the gid cell are not able to be reseated in the grid cell.

Besides a strategy survive or not, is also important to understand what is its predominance within a grid-cell, this is, what is the fraction of the grid cell that a specific strategy occupies? The majority of vegetation models calculates the fractional coverages of PFTs through considering the bioclimatic limits (ARORA; BOER, 2006; PAVLICK et al., 2012a)⁠ or though competition relationship computed by Lotka-Volterra equations (ARORA; BOER, 2006; PAVLICK et al., 2012a)⁠. However these two approaches are not suitable for CAETÊ model because it do not define bioclimatic limits *a priori* and because Lotka-Volterra equations require a *n*-by-*n* matrix of competition coefficients (SCHEITER; LANGAN; HIGGINS, 2013)⁠ what turns the model CAETÊ computationally impracticable because the matrix size increases with the square of the considered PFTs (or PLS, in our case; PAVLICK et al., 2013; SCHEITER; LANGAN;HIGGINS, 2013).

Instead, CAETÊ model uses the biomass contribution of a strategy related to the total gridcell biomass to calculate the occupation fraction. This procedure has support in the biomass-ratio hypothesis (GRIME, 1998) that predicts that the immediate effects of a species functional traits are proportional to the species relative contribution to the total biomass of the community.

This approach is also necessary because the COMPETITION SCHEME in CAETÊ model is not mechanistic. It is still not possible to simulate the competition process mechanistically because the model is not a individual-based model yet (i.e. it do not consider demography, establishment, growth and mortality rates, nor age classes). Entretanto, a captura diferencial de

carbono, água e luz através da combinação diferencial dos atributos funcionais é capaz

de conduzir a uma diferença de abundância (GRIME, 1998) entre os PFTs/PLSs dentro

46de uma célula de grade. Deste modo, a competição é considerada indiretamente através

da derivação das abundâncias relativas (GRIME, 1998).

Therefore, the relative abundance of a PLS *i* in a grid-cell *j* is assumed to be proportional to its relative contribution to the total grid-cell biomass (; Eq. (XX)) , in its turn determined by the sum of biomass of all the survival PLS (*S*) in that grid-cell:

(XX)

**1.3) Scaling up the biogeochemical variables**

From the relative abundances is possible to calculate the grid cell occupation and also scale up the biogeochemical fluxes from the PLS to the grid cell scale and then to the ecosystem scale. This approach also assume the biomass-ratio hypothesis and is supported by the evidences both theoretical and experimental that the extension that a plant species affect the ecosystem processes is predictablef\_{4}^{sun}

from its relative contribution to the community total biomass. For example, the gross primary productivity of a grid cell *j* () is determined by the sum of the (Eq. XX) of all the grid cell survival PLS () weighted by their relative abundance (; Eq. (XX)): (XX)

**1.3) The chosen functional traits: related ecosystem processes and its associated trade-offs**

One of the focus of this paper, besides presenting the CAETÊ model, is to present a first application of it as a case study. In this work, we were interested in understand if the inclusion of a trait-based framework could lead to different results regarding to biomass and global carbon stock in face of some simple scenarios of change in temperature, CO2 concentration and precipitation patterns. For understanding this ecosystem process the traits related to the percentage of the carbon compounds distributed to plant compartments and the residence time of these compounds on each compartiment is of primary importance (CHAMBERS et al., 2012; FATICHI; LEUZINGER, 2013; MALHI, 2012; NORBY et al., 2005)⁠. The CAETÊ model considers three plant compartments: leaves, aboveground woody tissues (including stem and branches) and fine roots. Hence, six functional traits are considered as variants: allocation to leaves (), allocation to aboveground woody tissues (), allocation to fine roots (), carbon residence time in leaves (), carbon residence time in aboveground woody tissues () and carbon residence time on fine roots (). The allocation traits seeks to represent the percentage of the net primary productivity (; Eq. (XX)) distributed to each compartment; the carbon residence time traits seeks to represent the carbon length stay in each compartment. Together these functional traits ultimately define the amount of carbon in each compartment of a PLS (; Eq. (XX)) , and then, the total plant biomass of a PLS (; Eq. (XX)). Each functional trait is associated to, at least, one trade-off so that the amount of carbon in each compartment results in costs and benefits to certain strategy. In that sense, the allocation and the residence influence other model processes, for example, the solar radiation absorption, that provides energy for photosynthesis is dependent of the leaf biomass (derived from allocation and carbon residence time in leaves). In its turn the allocation and carbon residence time for fine roots determines the fine roots biomass, associated to water uptake. A greater allocation to leaves is a plant investment in capturing light but at the expense of investing in water uptake. So, in a given environment some combinations of allocation and residence time will maximize the productivity based on a balance between costs and benefits.

The table XXX summarizes the six traits, their units, corresponded trade-offs and linked equations.

The traits assume different values, the sampling strategy

**1.2) Functional diversity representation**

Here, functional diversity, following Díaz et al. (2007), is considered as the values, ranges of values and relative abundance of functional traits in a given community. Also, functional diversity is view both from the perspective of its single-trait component as well as its multi-trait component. The single-trait component allows to interpret more precisely how the different traits interact (affects and responds) with the environment (LEPŠ et al., 2006; RICOTTA; MORETTI, 2011)⁠, while the multi-trait component gives information about the ecological strategy as a whole (i.e. as a syndrome) and incorporates the relations between the traits, including the trade-offs. Also,the multi-trait component tell more precisely about the contribution and vulnerabilities of organisms (DÍAZ et al., 2013).

For measuring functional diversity we used the method developed by Carmona et al. (2016). It estimates functional diversity based on the Hutchinsonian concept of niche as a probabilistic hypervolume. This approach is based on trait probability density (TPD) which can be described as a probability density function: considering an ecological unit (e.g. population, community, region), the values of the TPD are directly proportional to the relative abundance of their corresponding trait values within that unit integrated to 1. From the TPDs is possible to calculate the functional differences between two of them by computing their dissimilarities, in other words, through the overlap degree of these distributions (CARMONA et al., 2016)⁠. It permits to calculate spatial (e.g. between regions) and/or temporal (e.g. before and after a disturbance) functional differences and gives important information about how the ecological unit changes in terms of functional diversity in its different facets. The dissimilarities was also used to infer the ideal number of PLS to be sampled from the potential trait space.

Functional diversity was characterized by four facets following Carmona et al. (2016) definitions: (i) functional richness: the portion of the functional trait space that is occupied by the organisms (PLSs in our case); (ii) functional evenness: how regular is the distribution of the PLSs in the functional trait space; (iii) functional divergence: the degree to which the abundance of PLSs is distributed towards the extremes of their functional volume within the entire functional trait space and (iv) functional redundancy: the degree to which traits are represented by multiple PLSs.

As addition the functional identity (only for the single trait metric): the dominant trait computed by the Community Weighted Mean (CWM); this metric provides information about the dominant traits (i.e. functional identity) in an ecological unit and is based on the idea that states that the traits of the dominant species in a community are the main determinants of ecosystem functioning (DÍAZ et al., 2007; GRIME, 1998)⁠. In this metric the mean values of functional traits are weighted by the relative abundance of the species in the considered ecological unit, in our case the PLSs. Then, the CWM of a functional trait in an ecological unit (that can be a grid-cell, a set of grid-cells, a region and so on) is computed throughout the number of survival PLS () in the ecological unit, the relative abundance of survival PLS (; Eq. XXX) and the functional trait value of the PLS ( ; Table XXX):

(Eq. XXX)

Hypervolume

**PCA: in order to reduce complexity and because of computational issues. And because we saw that some traits were highly correlated.**

**1.4) Ecophysiological processes: biogeochemical fluxes and stocks**

The following overview of the model's ecophysiological processes focuses on describing the main ecosystem processes related to the variant traits considered in this work (carbon allocation fractions and residence times) as well as its trade-offs. The full description with the detailed parameterizations is provided in Appendix XXX.

Dois tipos de forma de crescimento: gramínea/herbácea e árvore

Não lembro se tem c3 e c4

The photosynthesis equations are based on Farquhar et al., (1980) that consider three limiting factors: Rubisco carboxylation (; Eq. (XX)), light (; Eq. (XX)) and electron transport (; Eq. (XX)). Therefore, the gross primary productivity(are functions, and constants summarized in auxiliary table XX):

(XX)

Leaf level gross photosynthesis is calculated as the minimum (smallest root) between the three limiting rates (, , ) multiplied by a water stress function (; Eq. (XX)):

(XX)

where (Eq. XX) is the minimum between and .

(XX)

The response to water stress is a function of the ratio between the potential supply for transpiration (; Eq. XX) and the atmospheric demand of transpiration (; Eq. XX). This approach is based on Pavlick et al. (2013) and aims take into account the role of fine roots allocation on water uptake:

(XX)

The variable is calculated in function of a constant water uptake capacity by fine roots equal to 0.0005 mmH2OkgC-1day-1 (PAVLICK et al., 2012b)⁠, the amount of carbon present in the fine roots compartment (; Eq. XX) and the degree of water saturation in soil (; Eq. XX) ressaltando que o

w utilizado no modelo de fotossíntese e de respiração é o do dia anterior ao do cálculo:

(XX)

The photosynthetic active radiation () that hits the canopy represents 50% of the short wave radiation that hits the terrestrial surface ():

(Eq. XXX)

Because CAETÊ do not represent mechanistically the ecological process of competition, it can not represent the shading of understory strategies by the dominant canopy strategies and the consequent light competition. For this, we have used a simplified approach in order to represent the differential light acquisition and the role of the aboveground woody tissues on it: 5% of the PLS that presented the relative higher biomass in aboveground woody tissue compartment ( ; Eq. XXX) in a given grid-cell captured 100% of the IPAR while the others captured 80%. This approach was necessary because it included a trade-off associated to the allocation and residence time of aboveground woody tissue. Without the benefit of capturing more light the aboveground woody tissues would lead only to respiratory costs and would failure to represent woody strategies with consequences for the final computation of biogeochemical fluxes and stocks as well as of functional diversity. Thus:

The amount of carbon () in each compartment in a given PLS in a given time is determined by fraction of NPP allocated (; Table XXX) and the carbon residence time (; Table XXX) in this PLS' compartment:

(Eq. XXX)

Then, the total biomass () of a PLS is the sum of all compartments' carbon amount in a given time:

(Eq. XXX)

**1.4.2)Other ecophysiological processes**

(H) Are the state variables, forcing functions, and the parameters clearly defined and dimensionalized

(preferably in a table)?

(I) Are the equations presented in sufficient detail? Should they be presented in an appendix (or

on-line)?

**1.5)Inputs**

**2) Validation**

**2.1. Biogeochemical cycles**

**2.2. Functional traits**

**2.3. Functional diversity**

There is still several impediment for validate functional diversity. Despite it is a growing body of knowledge. Several methods for measuring it. There is not a "map" for functional diversity. The different trait utilization (since it depends on the study subject).

Validar com o do Lamana? Apesar de serem difrentes traits dá uma indicativa?

CWM: represents the functional identity of the community. It shows o valor preponderante

**1.3)The low functional diversity version**

**2) The inclusion of functional diversity improves the representation of biogechemical cycles and functional diversity?**

**3)A first model application. What are the effects of climate for biogeochemical cycles and functional diveristy ? In what extent The inclusion of funtional diversity changes the results?**

**4) What are the effects of climate change on functional traits of carbon allocation and residence time? What are the implications for global carbon stock and for biomass? A consideração leva a resultados contraditórios com a presente literatura?**

We identify the most likely ranges of biomass change as the maximum value of the PDFs (modal value) and the corre- sponding interquartile range. These values are good indicators for the shift in biomass change projections (modal value) and the underlying uncertainty of predictions (interquartile range). In the results section, the modal value and its inter- quartile range are denoted as ‘most likely range’. (RAMMIG et al., 2010)⁠