Estimation of CO2 emissions from deforestation and land use change in the Amazon: nested coupling of atmosphere, dynamic vegetation, LUCC and fire spread models.

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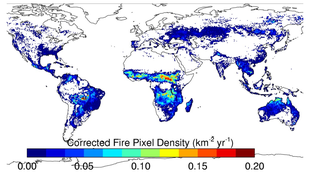
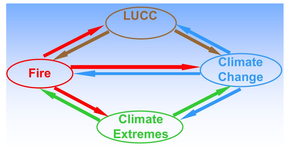
Introduction and motivation



Fire occurence based on satellite observations (Giglio et al., 2006)



Feedbacks between fire, LUCC and

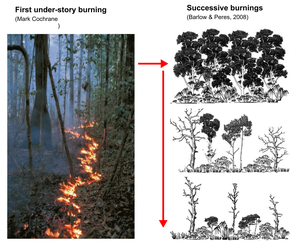
Deforestation of tropical forests for logging and agriculture, associated to slash-and-burn practices, is a main contributor of CO2 emissions, both immediate due to biomass burning and future due to the elimination of a potential CO2 sink. Moreover, climate change in the Amazon during the 21st century is projected to decrease the resilience of the Amazon forest and possibly replace large parts of tropical forests with savannas, adding to the direct anthropogenic deforestation. The **potential feedbacks** between LUCC (Land-Use and Land-Cover Change) and climate change are thought to further increase the loss of tropical forests and increase the rate of CO2 emissions, through mechanisms such as land and soil degradation and the increase in wildfire occurrence and severity. However, current understanding of the processes of fires (including ignition, spread and consequences) in tropical forests and feedbacks with climate are poorly understood and need further research. As the processes of LUCC and associated fires occur at local scales, linking them to large-scale atmospheric processes requires a **means of up-scaling higher resolutions processes to lower resolutions**.

Typical deforestation patterns (Cochrane, 2004)

Our approach is to **couple models which operate at various spatial and temporal scales**: a Global Climate Model (GCM) (and possibly a Regional Climate Model; RCM), Dynamic Global Vegetation Model (DGVM) and local-scale LUCC model and fire behavior model. The climate model(s) resolve larger scale atmospheric processes and forcings, which are felt by the surface DGVM and fed-back to the climate. Higher-resolution processes such as deforestation, land use management and associated (as well as natural) fires are resolved at the local level. Anthropogenic LUCC (such as deforestation and pasture burning) is modeled using Geographical Information Systems (GIS) and spatially-explicit models. Modifications to the land surface are imposed on the land model, which has a potential feedback on the land surface properties through processes resolved by the atmospheric and land models. Fire behavior is modeled at the regional scale (~100m) to represent the detailed landscape using semi-empirical or empirical fire spread models.

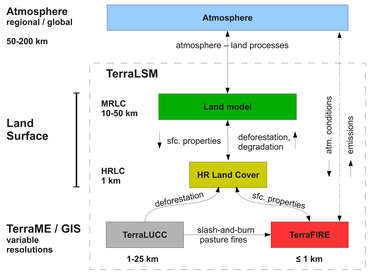
Slash-and-burn deforestation for agricultural purposes

Improved parametrizations from our fully-coupled experiments, for use in atmospheric and land surface models, will allow for a better understanding and evaluation of CO2 emissions from LUCC and feed-backs with climate change.



Successive understory fires lead to ecosystem

Model overview and components



Model structure

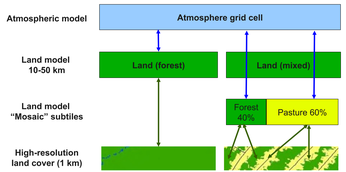
MODEL OVERVIEW - TerraLSM

1) Atmospheric Model at regional/global resolution

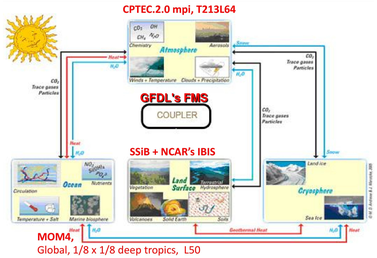
2) Land surface:
   MRLC: Land Surface Model (IBIS) at medium resolution
   HRLC: High resolution (1km) land surface type map
   Up- and down-scaling mechanisms for interractions between MRLC and HRLC
   Sub-grid variability accounted with mosaic tiles

3) LUCC model driving deforestation and fires

4) Semi-empirical fire spread model



Subgrid scale variability: mosaic tiles of different vegetation types



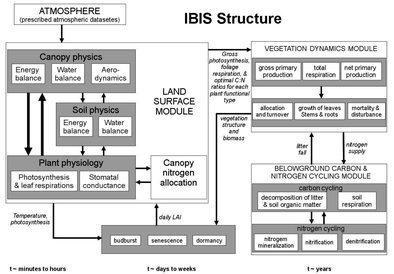
Brazil's Global Climate Model

Brazil's Global Climate Model

1) Atmospheric Model: CPTEC
2) IBIS Dynamic Vegetation Model
3) MOM3 OGCM
4) GFDL's FMS Flux coupler

Spatially Explicit Fire Spread Model

- FARSITE from USDA Forest Service (http://firemodels.fire.org)
- Fuel and vegetation conditions from the land model
- Fuel models for the Amazon tropical forest from field experiments in Acre and Mato Grosso



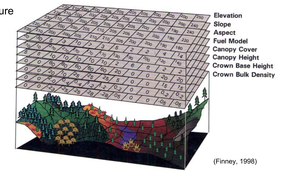
IBIS Dynamic Global Vegetation Model overview

Fire Modelling across different temporal and spatial scales

FARSITE Fire Area Simulator, by the USDA Fire Service

Simulates fire spread on a GIS landscape, using Rothermel's model, needs:

- **GIS raster data** including:
  - terrain elevation, slope, aspect
  - fuel type
  - canopy structure
- **Fuel model** describing fuel behavior, for use in Rothermel's equations (none for Amazon yet)
- **Weather data**:
  - wind
  - temperature
  - RH
  - rain



(Finney, 1998)

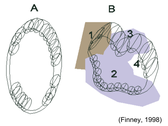
FARSITE semi-empirical model overview

Fire spread

Modeled using Huygen's wavelet principle, using the analogy of wave propagation.

Fire advance is modeled using an elliptical wavefront.

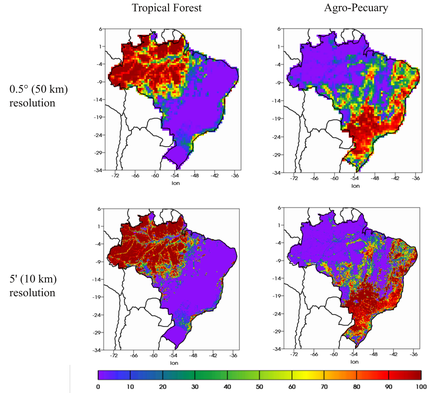
Wind, slope and fuel modulate fire spread rate.



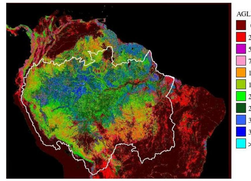
(Finney, 1998)

FARSITE fire spread

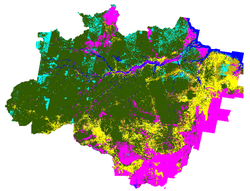
Data input and validation



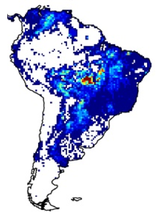
Vegetation types of Brazil : Proportion of Topical Forest and Agro-Pecuary at various resolutions showing sub-grid variability. Source: PROVEG map (1km) based on PROBIO land types



Aboveground Live Biomass in the Amazon bassin used to estimate CO_2 emissions due to biomass burning (Saatchi et al. 2007)



INPE/PRODES yearly maps of deforestation in the Amazon forest



MODIS Active Fire Product, to drive the fire spread model (Giglio et. al, 2006)

MODIS/AVHRR Global Burn Areas (fire scars), to evaluate simulated fire spread extent and timing (Carmona-Moreno et. al, 2005 ; Roy and Boschetti, 2009)