Meeting with EFI and COCOBOD – June 08, 2023

forestatrisk: a Python package for modelling and forecasting deforestation

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Plan

1. Introduction
   - Context
   - Software
2. Methods
   - Data
   - Models
   - Forecast
3. Applications
   - ForestAtRisk in the tropics
   - Other case-studies

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Context

Risk mapping

- Need for estimating the spatial risk of deforestation in the tropics.
- At high resolution, on large spatial scale.

Usage

- Conservation planning (hotspots of deforestation).
- Jurisdictional REDD+ :
  - Allocating deforestation.
  - Building reference scenario of deforestation and carbon emissions.

State-of-the-art

- Existing software : Dinamica-EGO, Land Change Modeller, and CLUE.
- Limitations :
  - Might not be open source, cross-platform, scriptable, and user-friendly.
  - Do not account for the spatial autocorrelation of the residuals.
  - Algorithms (genetic algorithms, artificial neural networks, or machine learning algorithms) having the tendency to overfit the data.
  - Applications to large spatial scales (e.g., at the country or continental scale) with high resolution data (e.g., $\leq$ 30 m) has not yet been demonstrated.

Software

- `forestatrisk` Python package.
- Process large rasters by blocks (no memory issues).
- Several statistical models : iCAR, GLM, RF, etc.
- Set of functions for sampling, modelling, forecasting, validating.

`forestatrisk` Python package

Article : **Vieilledent** 2021, *JOSS*, doi : 10.21105/joss.02975
Website : https://ecology.ghislainv.fr/forestatrisk

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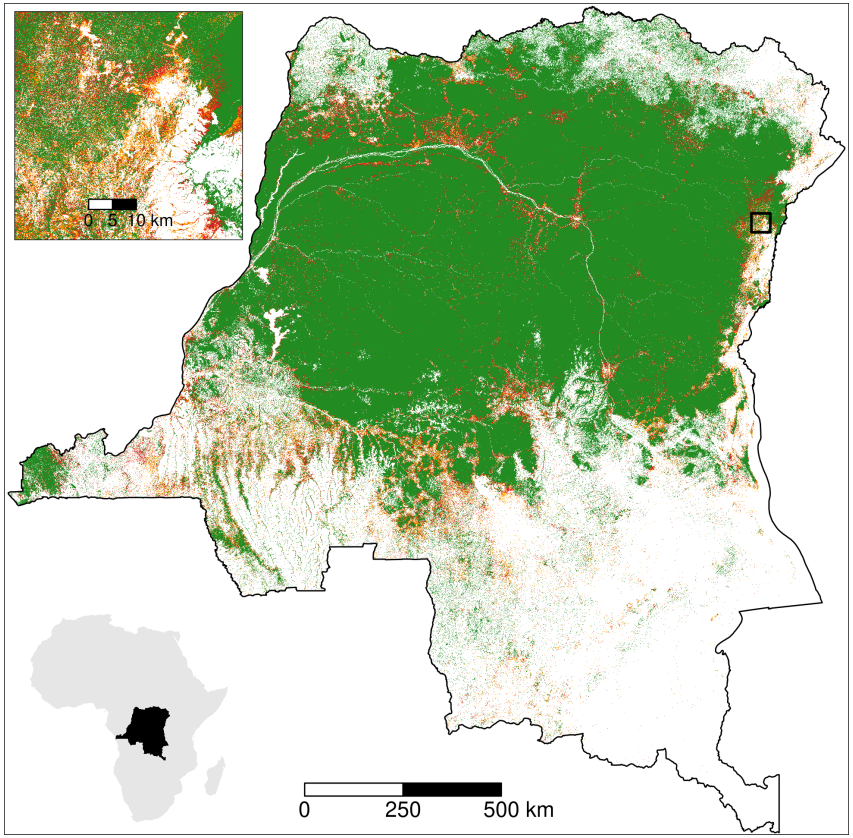
Historical deforestation maps

- We need an historical deforestation map.
- At least between two dates.
- Possible sources :
  - Global Forest Change (GFC).
  - Tropical Moist Forest (TMF).
  - Map provided by National Authorities.

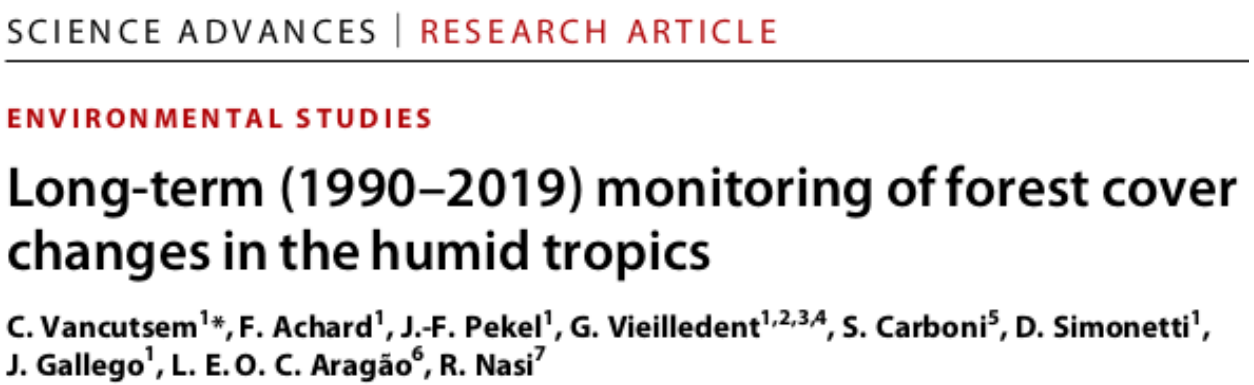
Example for DRC

- Example for DRC
- Using the Tropical Moist Forest (TMF) dataset.
- Three dates : 2000–2010–2020.
- Makes it possible to account for the distance to past deforestation.



Past deforestation 2000–2010–2020 in DRC

TMF dataset



SCIENCE ADVANCES | RESEARCH ARTICLE

ENVIRONMENTAL STUDIES

Long-term (1990–2019) monitoring of forest cover changes in the humid tropics

C. Vancutsem[1]*, F. Achard[1], J.-F. Pekel[1], G. Vieilledent[1,2,3,4], S. Carboni[5], D. Simonetti[1], J. Gallego[1], L. E. O. C. Aragão[6], R. Nasi[7]

Vancutsem et al. 2021, *Science Advances*, doi :10.1126/sciadv.abe1603

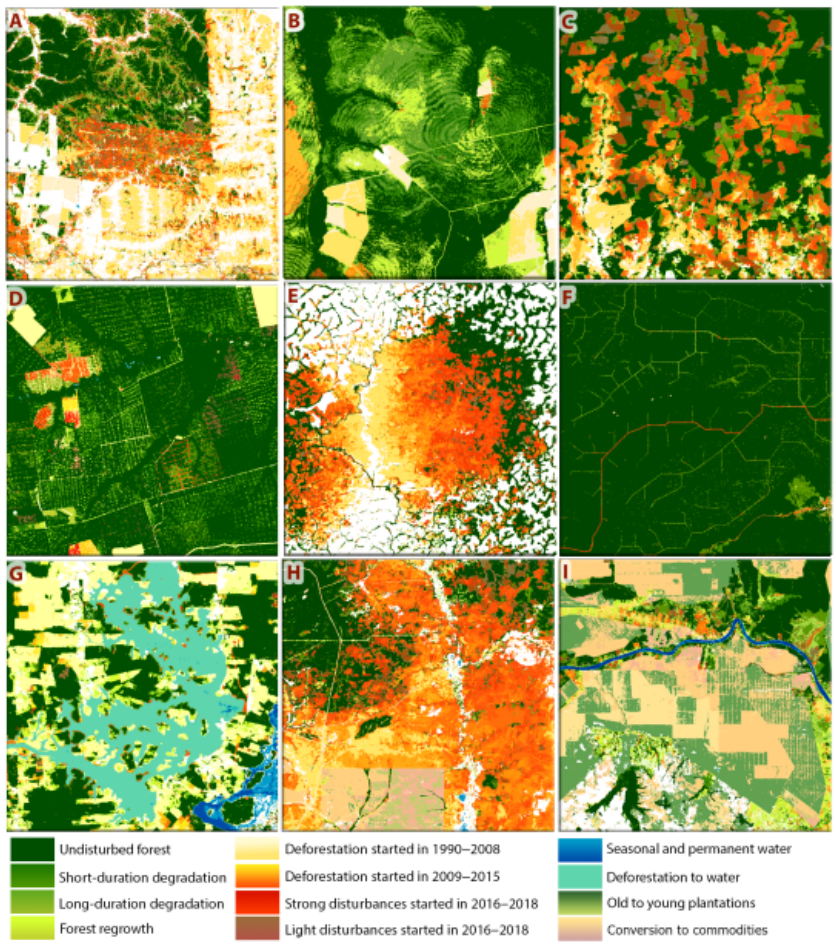
- Tropical Moist Forest (TMF)
- 1990–2022 : Annual deforestation, degradation, regeneration

TMF dataset

- Full Landsat archive (1982–2022), 30m pixel, time-series analysis.
- Classification tree based on expert knowledge.
- Tropical deforestation was underestimated (-33% in 2000–2012, Hansen et al. 2013).
- Maps and data : https://forobs.jrc.ec.europa.eu/TMF/.

TMF dataset

- Precise enough to visually identify the causes of deforestation (logging, fires, agriculture)

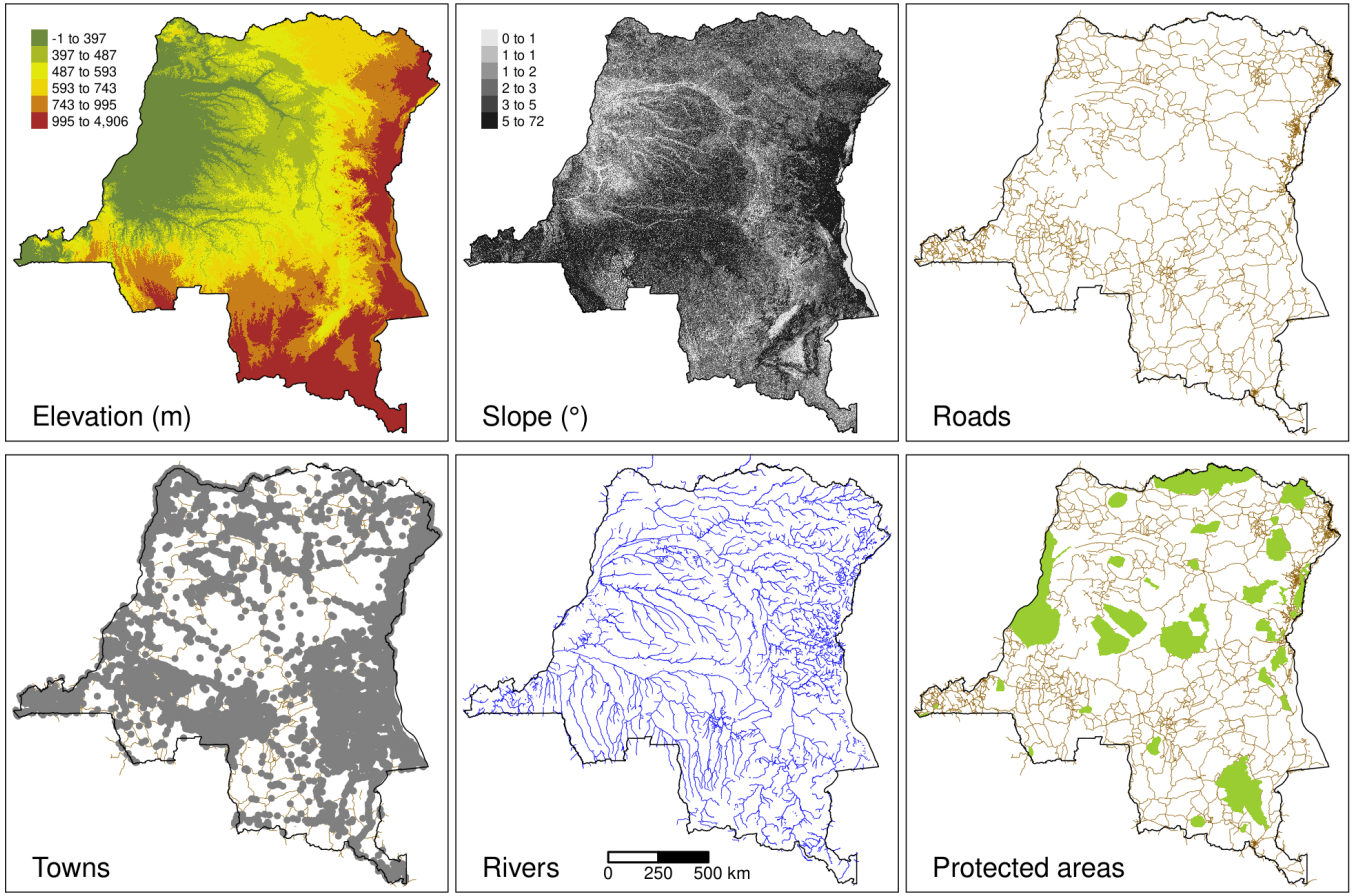


Spatial variables

- Height explanatory variables

Product	Source	Variable derived	Unit	Resolution (m)	Date
Forest maps (2000-2010-2020)	Vancutsem et al. 2021	distance to forest edge	m	30	–
		distance to past deforestation	m	30	–
Digital Elevation Model	SRTM v4.1 CSI-CGIAR	elevation	m	90	–
		slope	degree	90	–
Highways	OSM-Geofabrik	distance to road	m	150	March 2021
Places		distance to town	m	150	March 2021
Waterways		distance to river	m	150	March 2021
Protected areas	WDPA	presence of protected area	–	30	March 2021

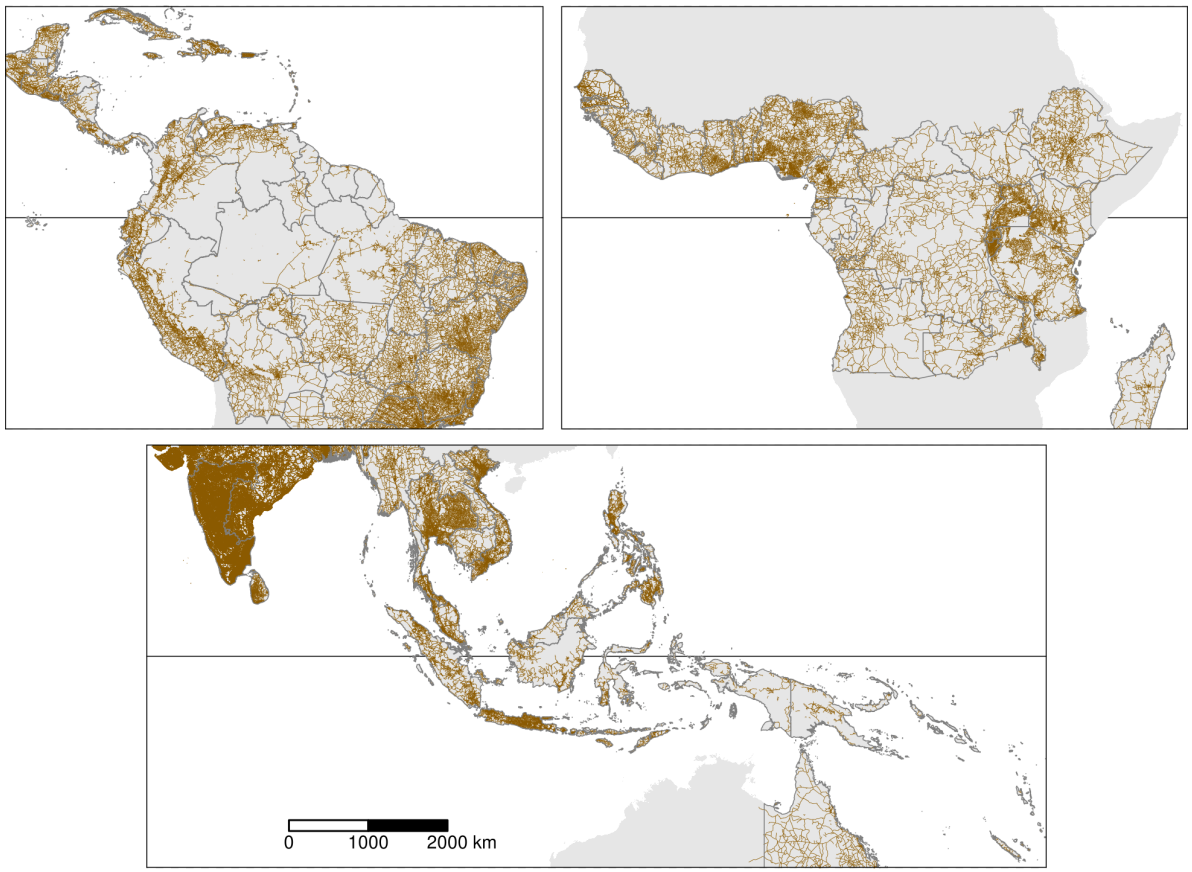
Spatial variables



Spatial explanatory variables in DRC

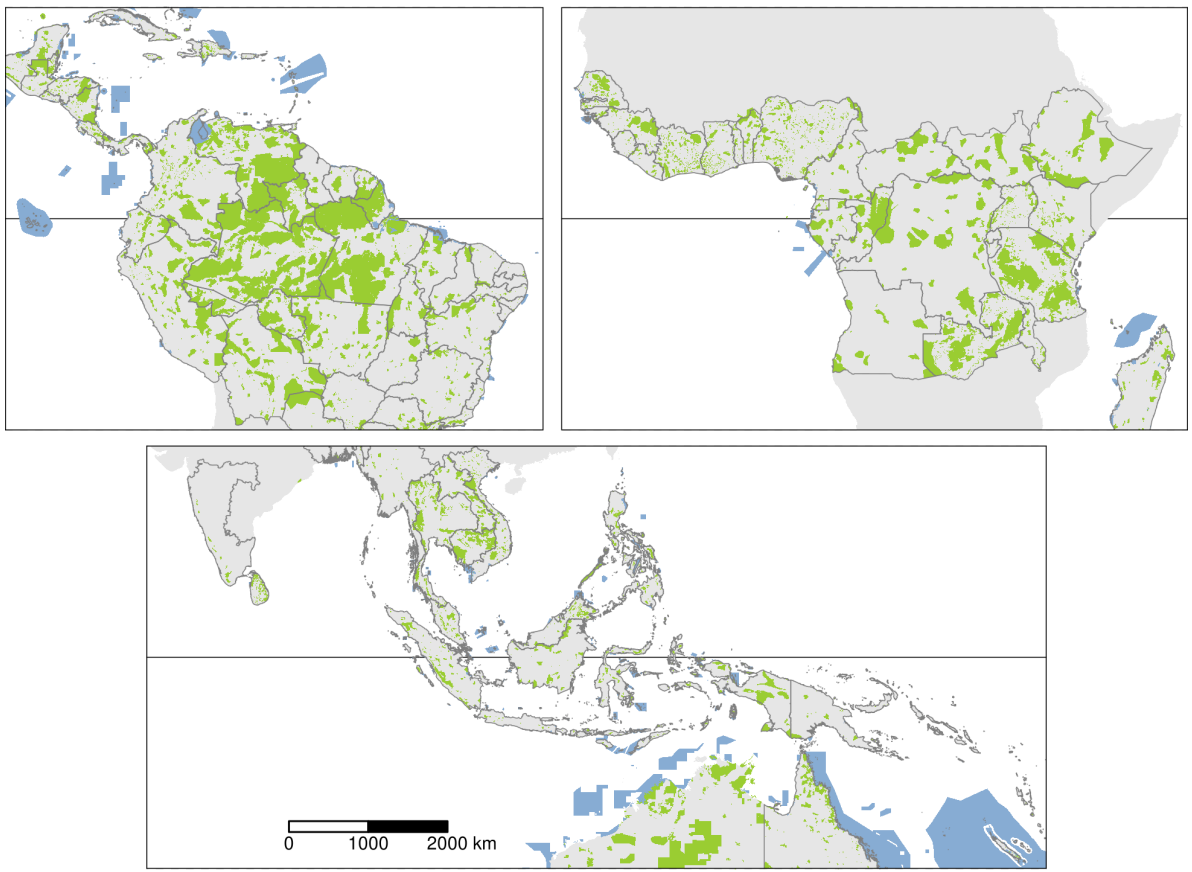
Roads

- OpenStreetMap (OSM)
- “motorway”, “trunk”, “primary”, “secondary” and “tertiary” roads
- 3.6 million roads from OSM



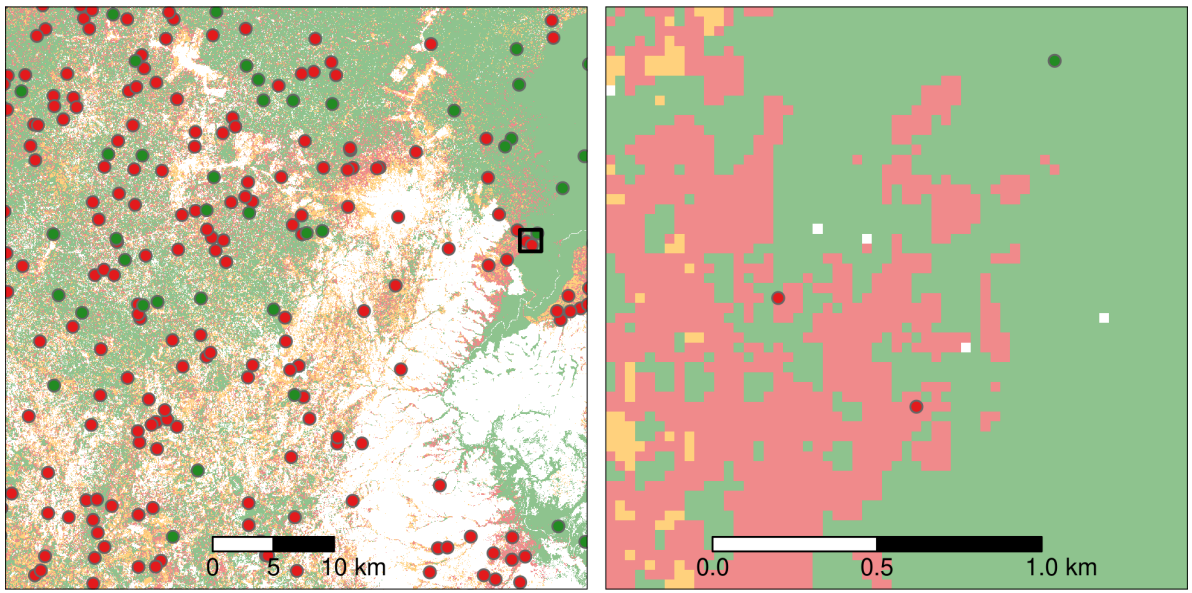
Protected areas

- PA status : “Designated”, “Inscribed”, “Established”, or “Proposed” before 1st January 2010
- 85,000 protected areas from WDPA



Sampling

- Stratified sampling between deforested/non-deforested pixels in 2010–2020
- Total number of points proportional to the forest cover in 2010 (from 20,000 to 100,000 points per study area)

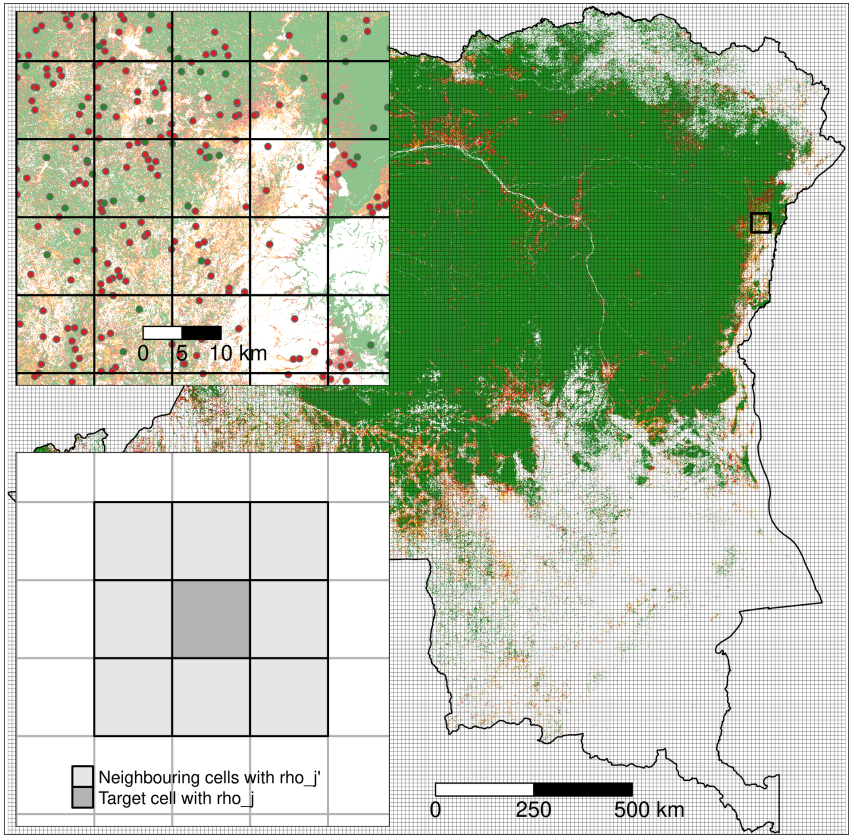


Spatial risk of deforestation

A logistic regression model with iCAR process

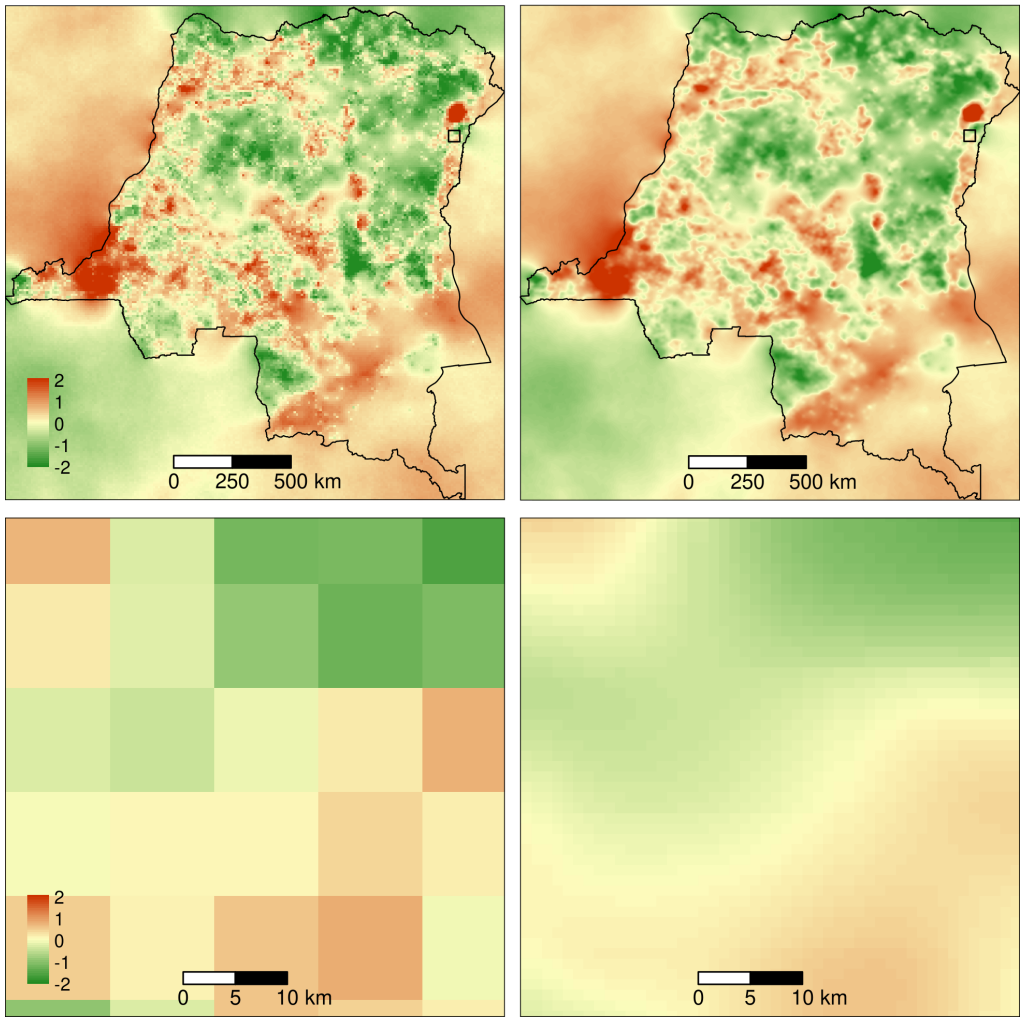
$$y_i \sim \mathcal{B}ernoulli(\theta_i)$$
$$\text{logit}(\theta_i) = \alpha + X_i\beta + \rho_{j(i)}$$
$$\rho_{j(i)} \sim \mathcal{N}ormal(\sum_{j'} \rho_{j'}/n_j, V_\rho/n_j)$$

(NB : We can compare this model with a simple GLM and a Random Forest model using a cross-validation procedure)



Square grid of 10km cells over DRC

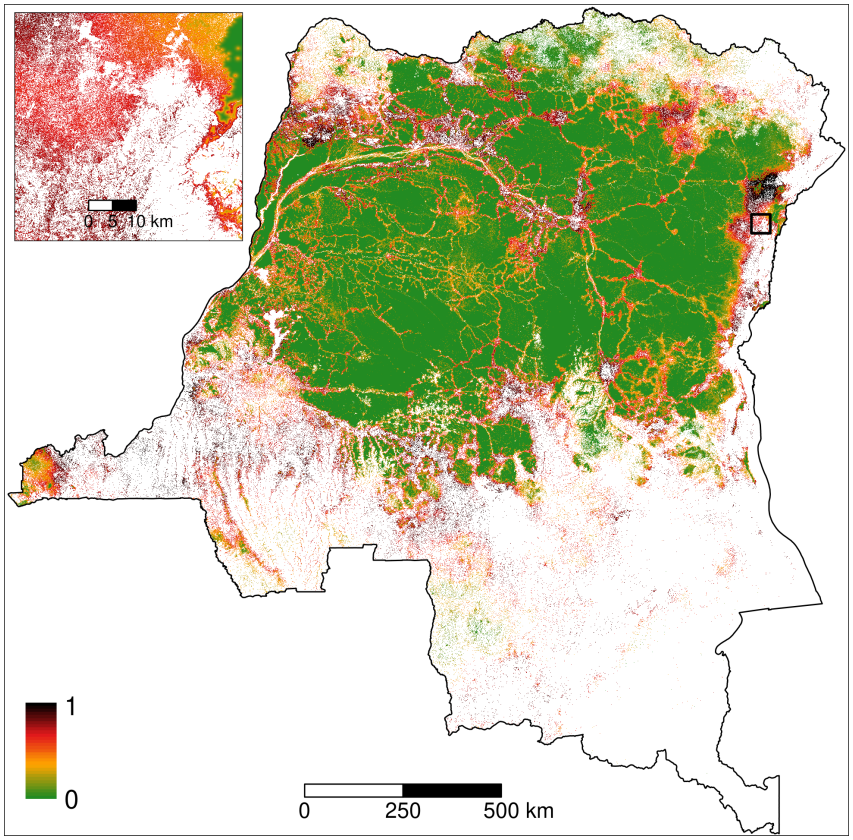
Spatial random effects



Interpolation of spatial random effects at 1km in DRC

Spatial probability of deforestation

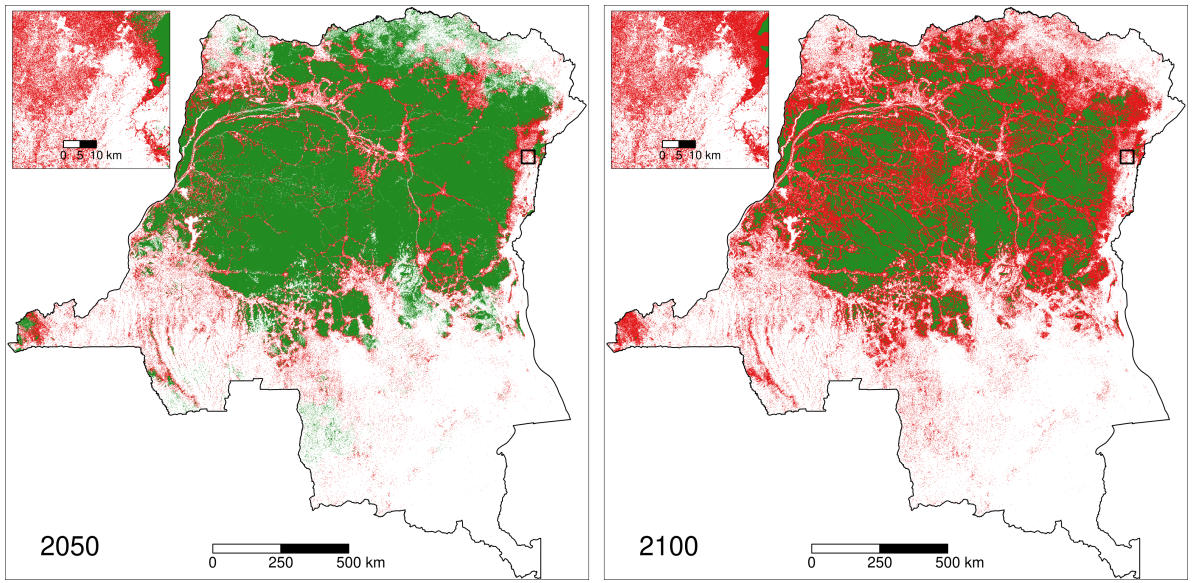
We use the fitted model to compute the spatial probability of deforestation.



Relative spatial probability of deforestation in DRC for the year 2020

Future forest cover

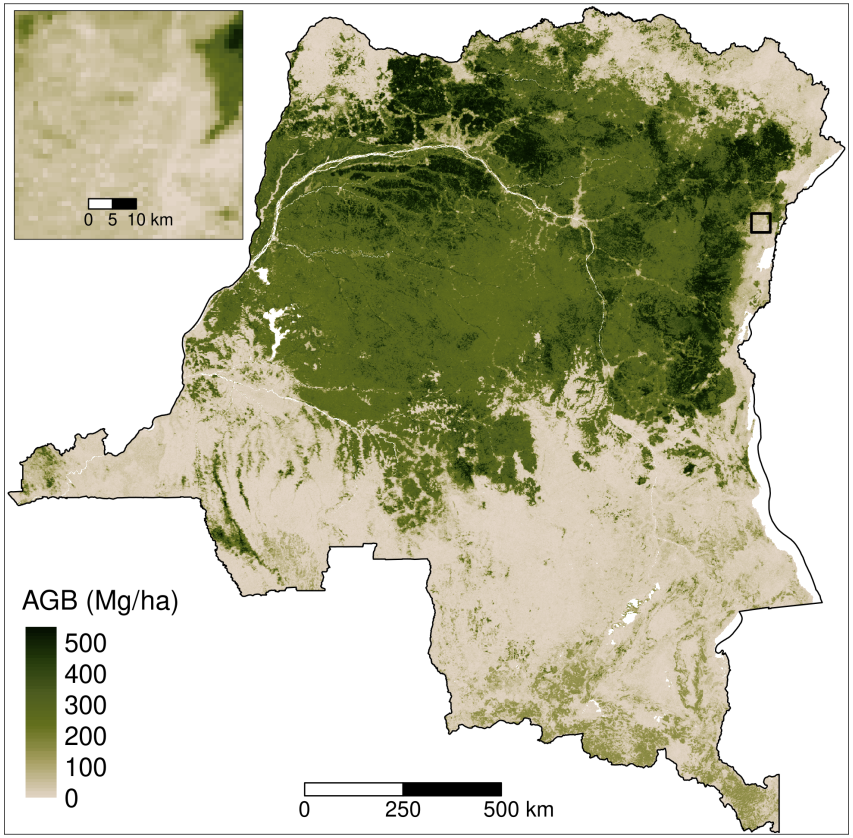
- Various deforestation scenarios can be considered
- Total deforested area D (ha) in a given period of time Y (yr).
- Number of pixels to be deforested : $n = D/\text{pixel area}$.
- Deforestation n pixels with the highest deforestation probabilities.



Projected deforestation in 2020–2050 and 2020–2100 in DRC

Future carbon emissions

- We can combine the map of the projected deforestation with a forest carbon map to compute emissions.
- Example for DRC with map by Avitabile et al. (2016) at 1km resolution.



Aboveground biomass in DRC

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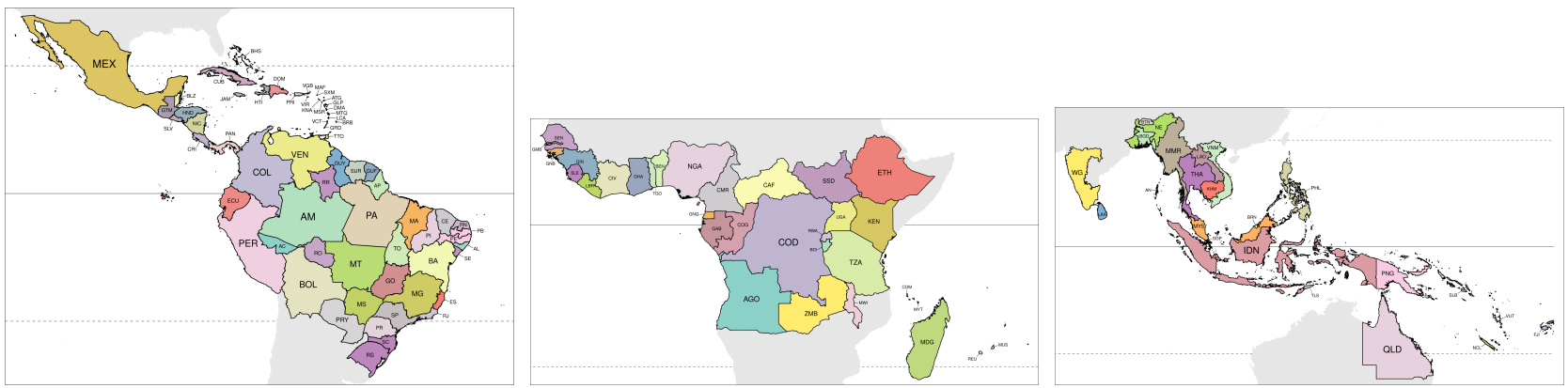
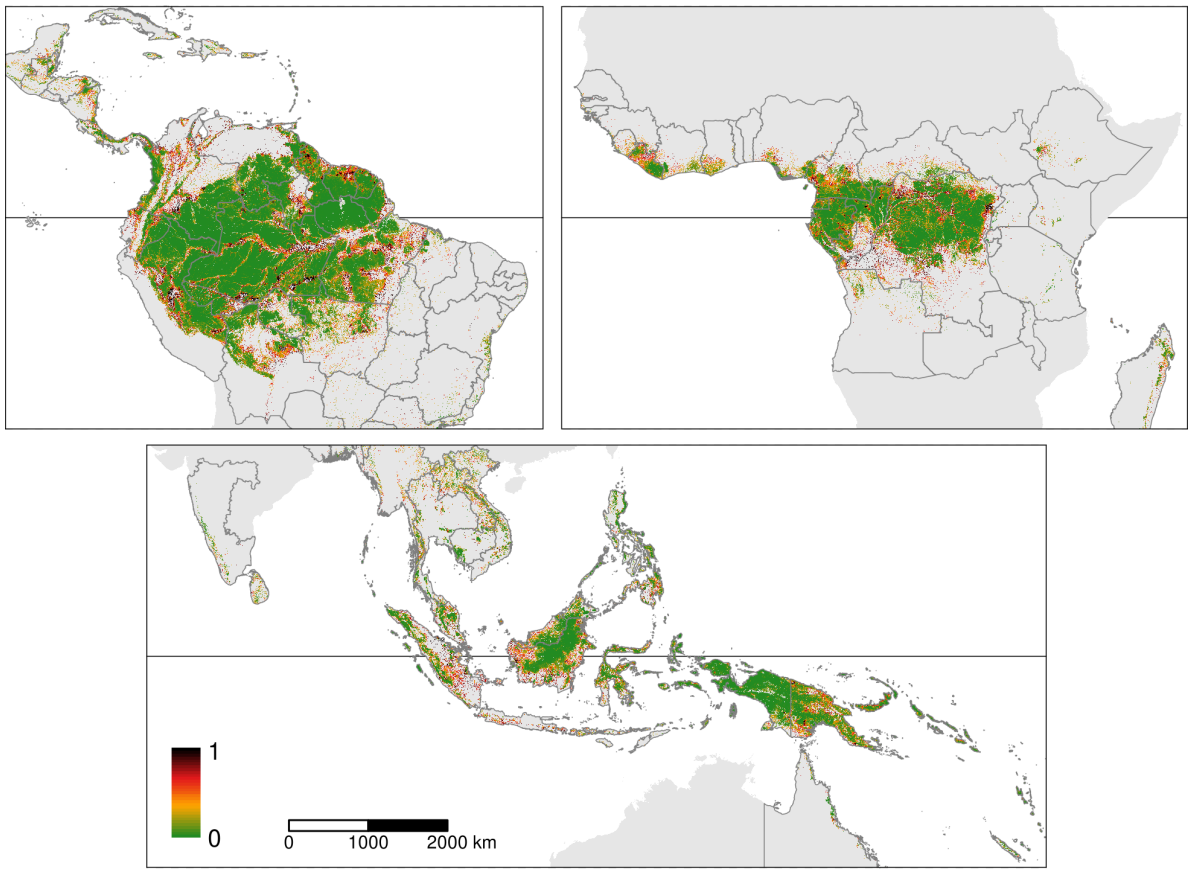
Study areas

- i. Consider tropical moist forest in 92 countries (119 study areas)
- ii. Estimate the current deforestation rate and uncertainty in each country
- iii. Model the spatial risk of deforestation from environmental factors
- iv. Forecast the deforestation assuming a business-as-usual scenario
- v. Consequences in terms of carbon emissions



The 119 study areas in the 3 continents

Spatial probability of deforestation



Pantropical map of the spatial probability of deforestation

Article in review : 10.1101/2022.03.22.485306

https://forestatrisk.cirad.fr/maps.html

Other case-studies

- Impact of mining activities in New-Caledonia.
- National Parks vs. Community Managed Forests in Madagascar.
- ...

. . . Thank you for attention . . .

https://forestatrisk.cirad.fr

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