The dynamics of the Amazon forests and the role of forest structure
- linking remote sensing and vegetation modelling -

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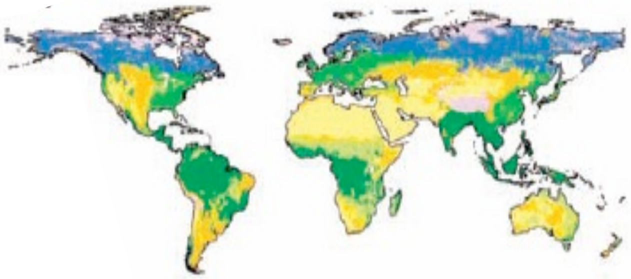
Forests in the global carbon cycle



Currently vegetation is a carbon sink! 2.6 Gt C / yr
(increase of carbon in atmosphere 4 Gt C/ yr, IPCC 2021)

Climate change can modify productivity of vegetation:

- Europe 2003 drought:
  30 % decrease of productivity, vegetation changed from C-sink into C-source:
  from 0.3 to -0.5 GtC
  (Cias et al. 2005, Nature)
- Amazon 2005/2010/2015 drought:
  forests transform from C-sink into C-source,
  from 0.4 to -1.2 GtC
  (Phillips et al. 2009, Science, Lewis et al. 2011, Nature, Qin et al. 2021, Nature CC)
- Higher mortality rates of trees:
  no global quantification
  (van Mantgem 2009 Science, Anderegg PNAS 2012)

Does vegetation act as a carbon sink also in future ?

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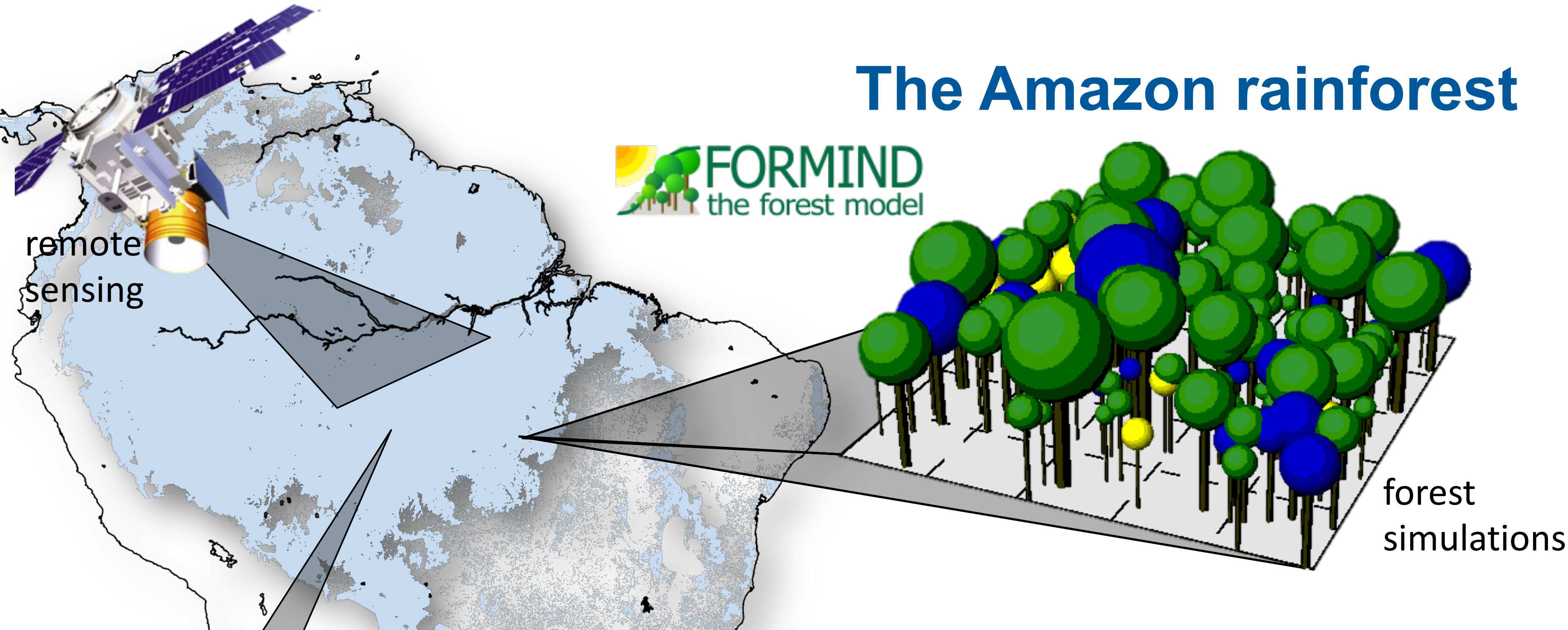
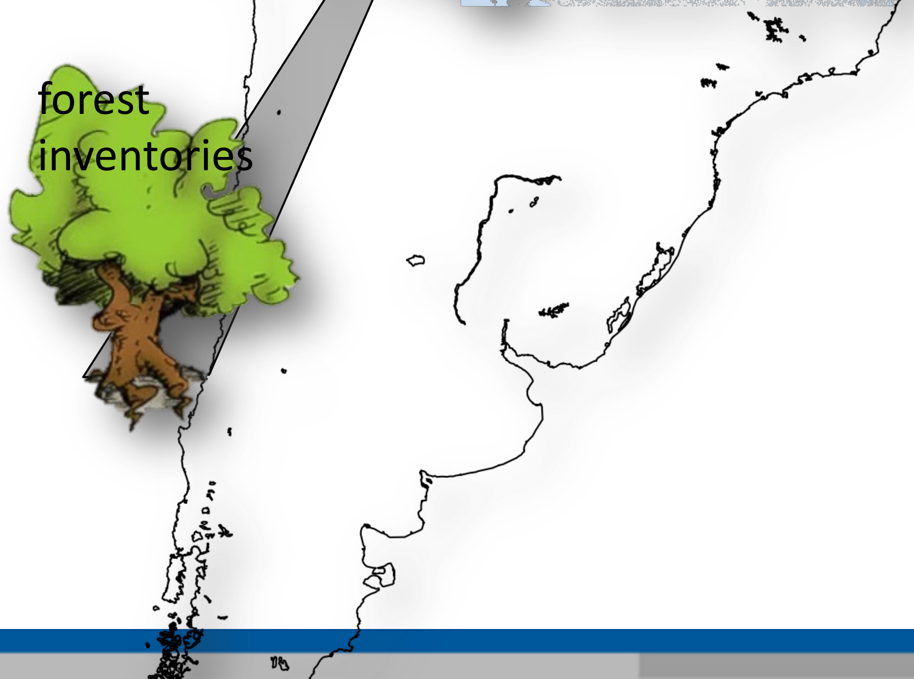
The Amazon rainforest



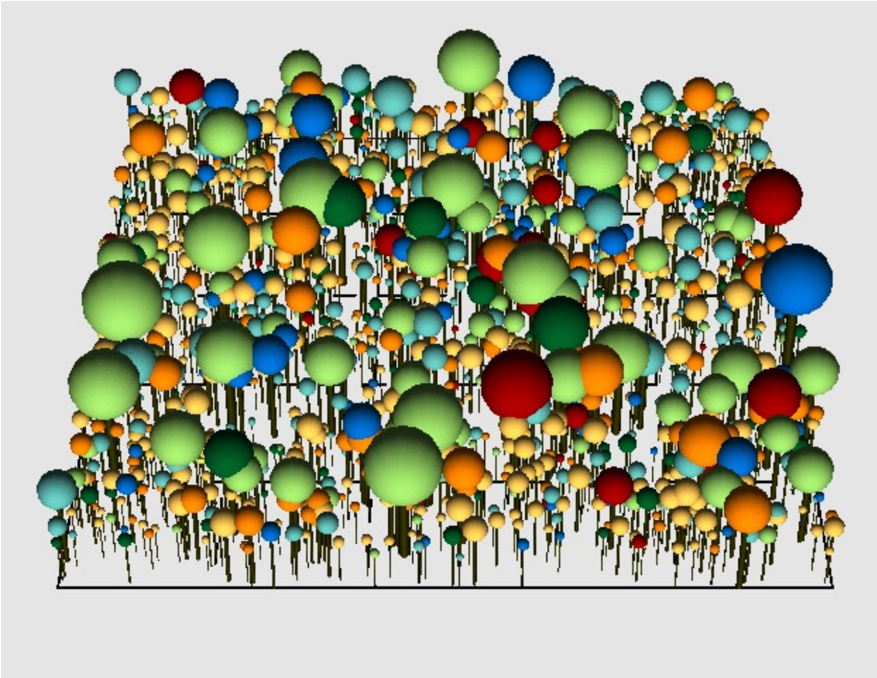


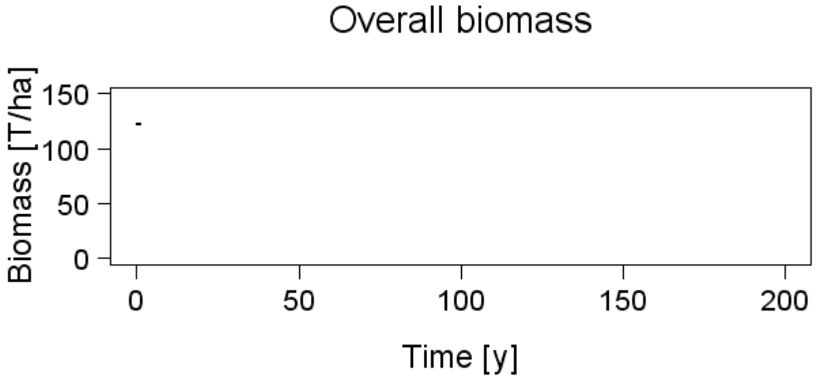
50 years tradition of forest gap models exploring:

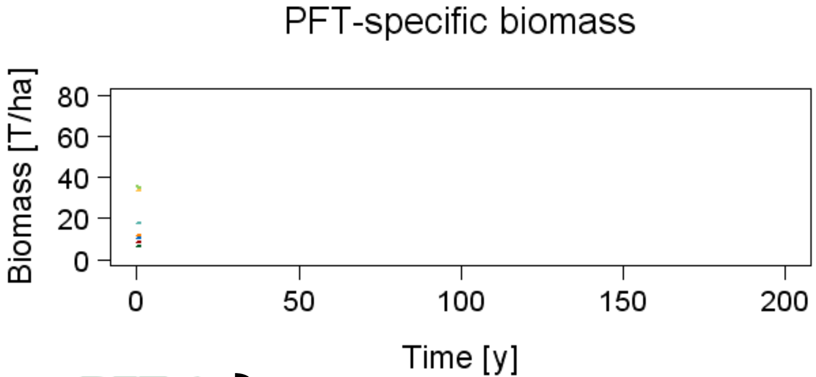
- forest dynamics and growth
- forest biomass, forest structure and species compositions
- impact of disturbances

forest gap models : Shugart 1998, CUP
Shugart et al. 1918, ERL
review Formind: Fischer/Huth… 2016, Ecol Mod

Tropical mountain forest (Ecuador, FORMIND simulations)







Ridge forest 1900-2100 m asl (forest type II, J. Homeier)

www.FORMIND.org

PFT 1
PFT 2 } fast growing species

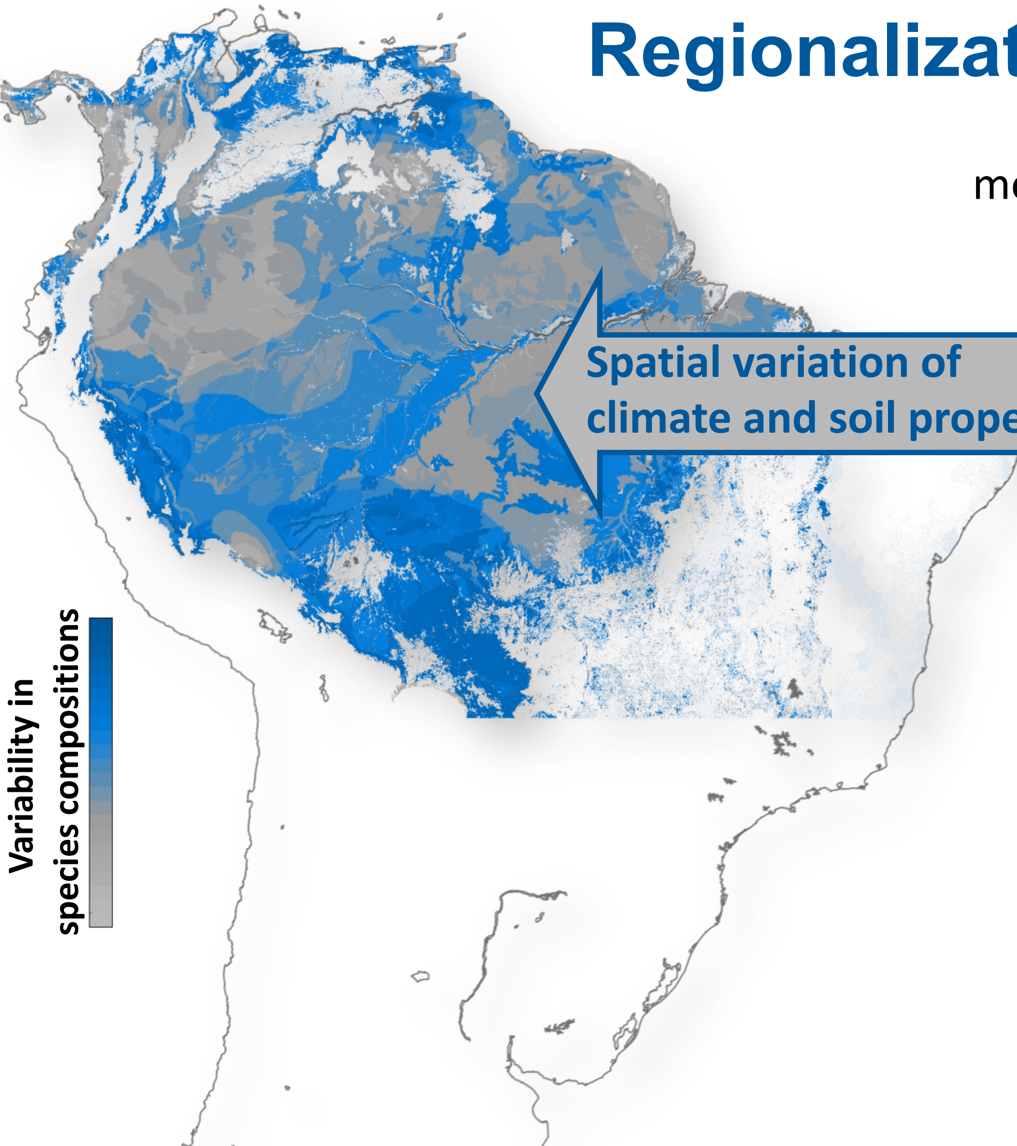
PFT 3
PFT 4 } medium growing species

PFT 5
PFT 6
PFT 7 } slow growing species

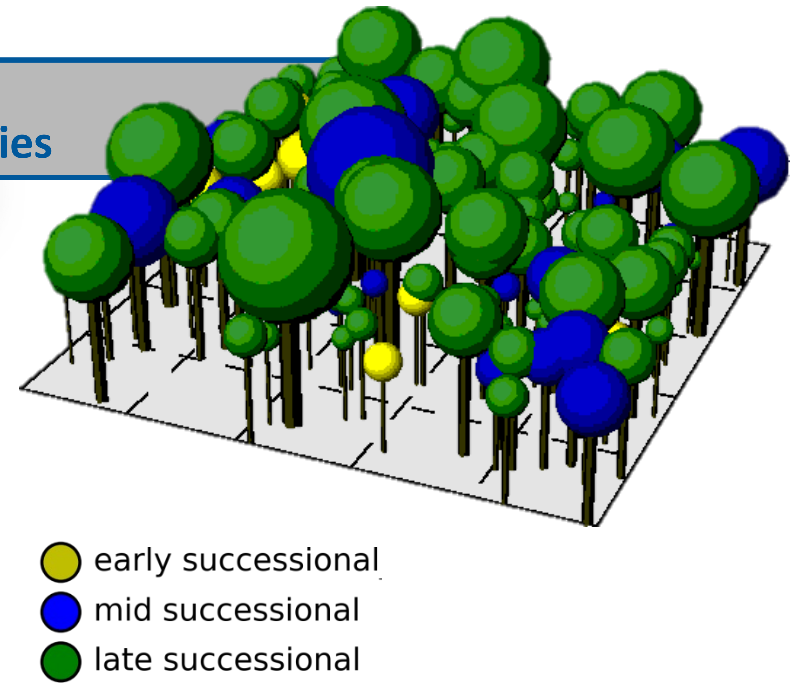
Puetz et al. 2014, Nat Comm
Snell, Huth et al. 2014, Ecography
Dislich ét al. 2013, Ecol Model

Regionalization of the forest model

based on field data analysis
mortality rates depend on local climate and soil properties



Spatial variation of climate and soil properties

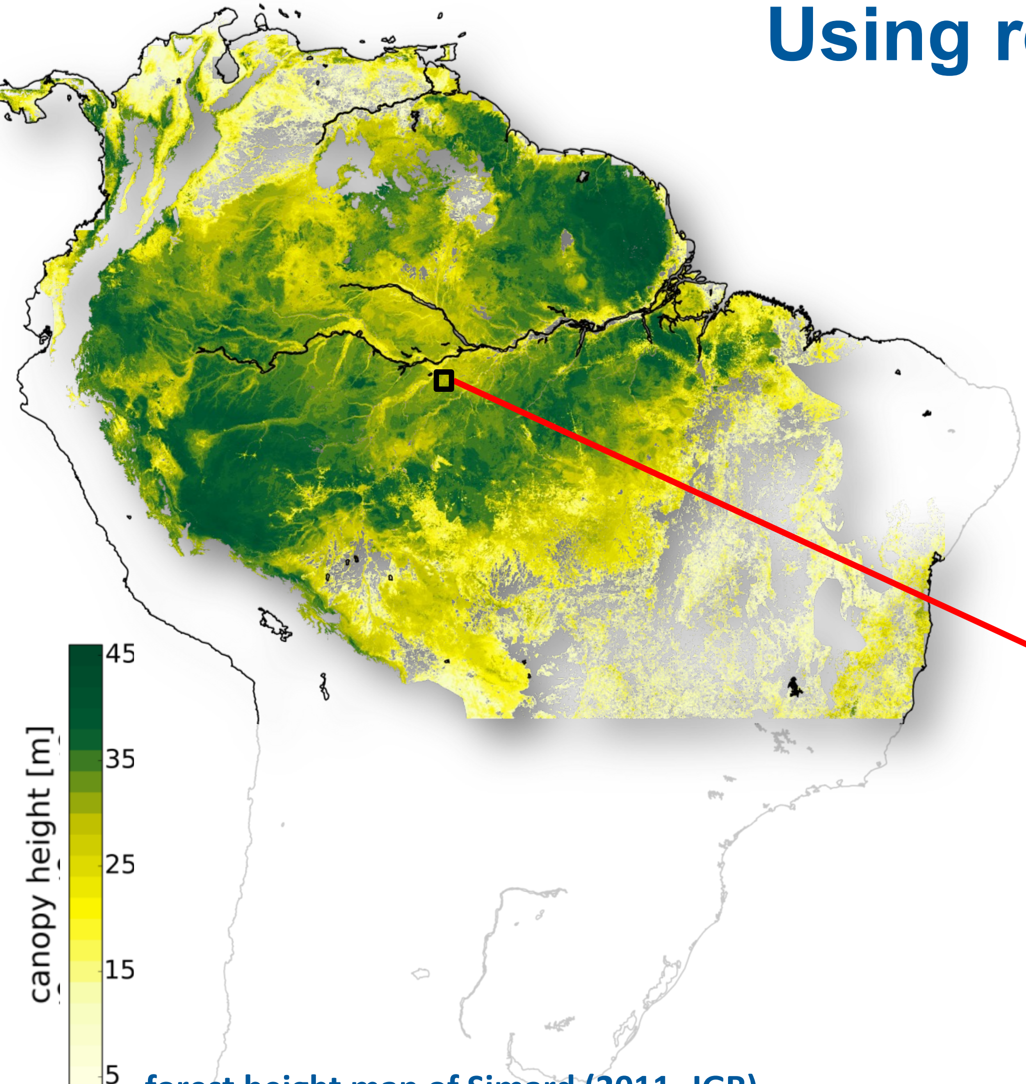


Remote sensing product

Vegetation modelling

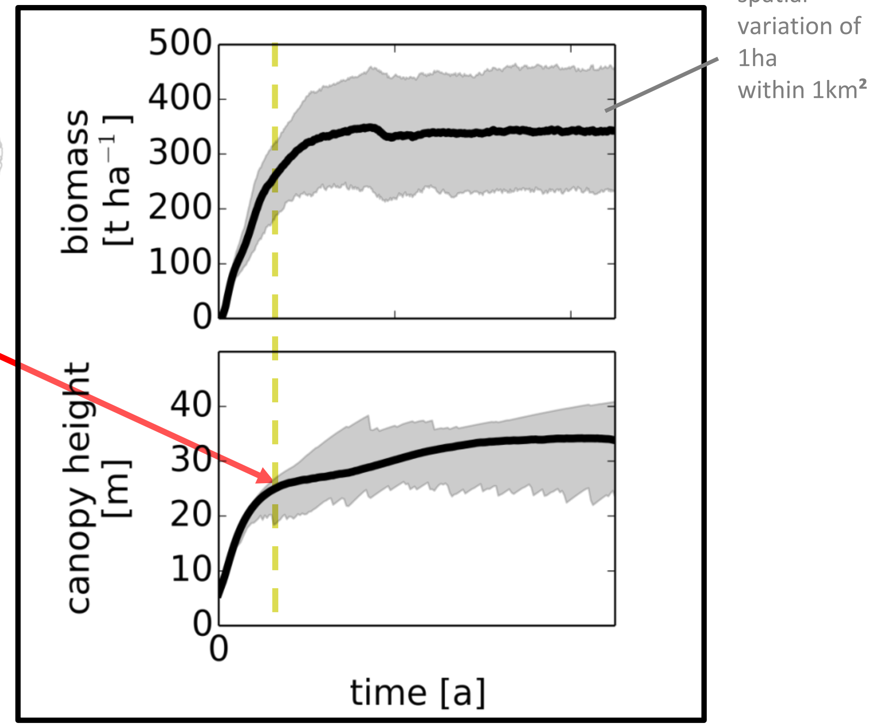
Rödig et al. 2018, Env Research Let
Rödig et al. 2017, Global Ecol Biogeogr

Using remote sensing as filter for forest simulations



forest height map of Simard (2011, JGR) based on ICESAT

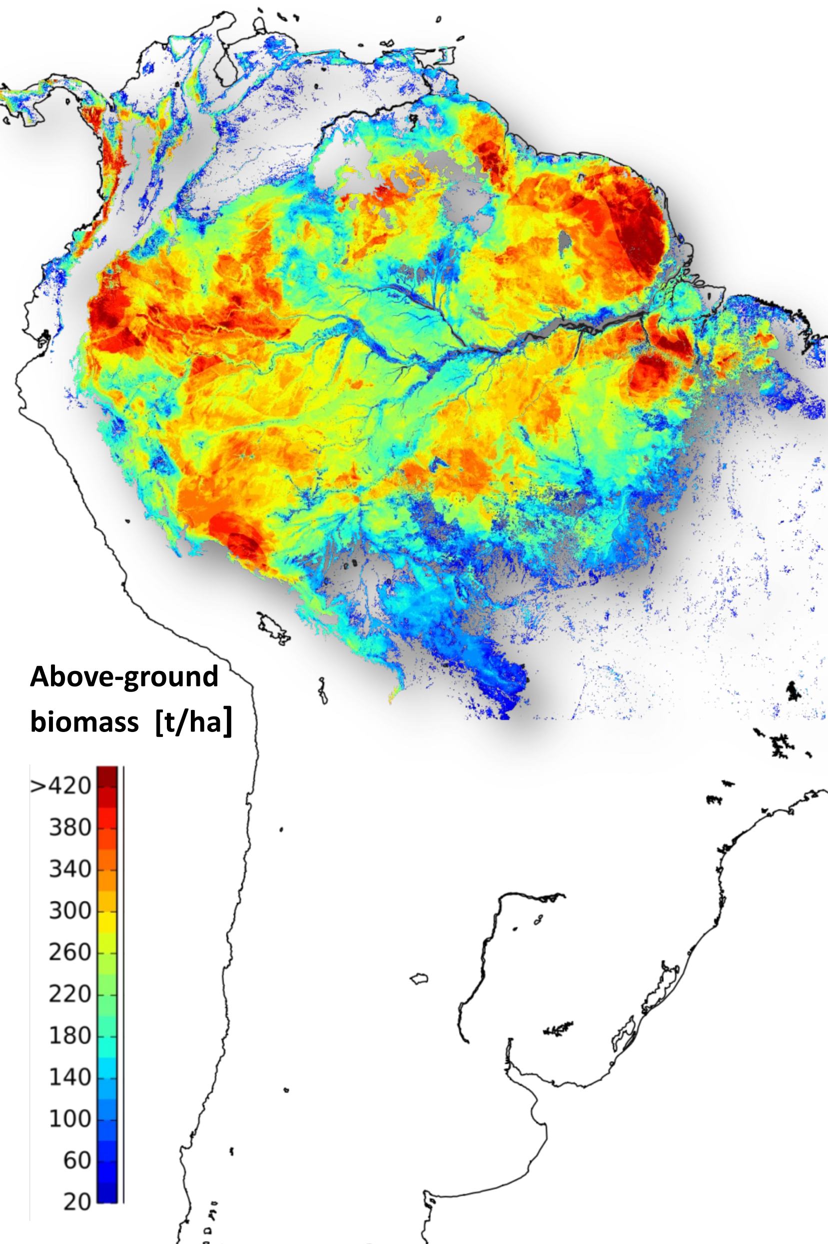
simulated local forest dynamics
(scale 1 ha, including local climate and soil cond.)



using canopy height to identify successional state of forest

Remote sensing product ⟷ **Vegetation modelling**

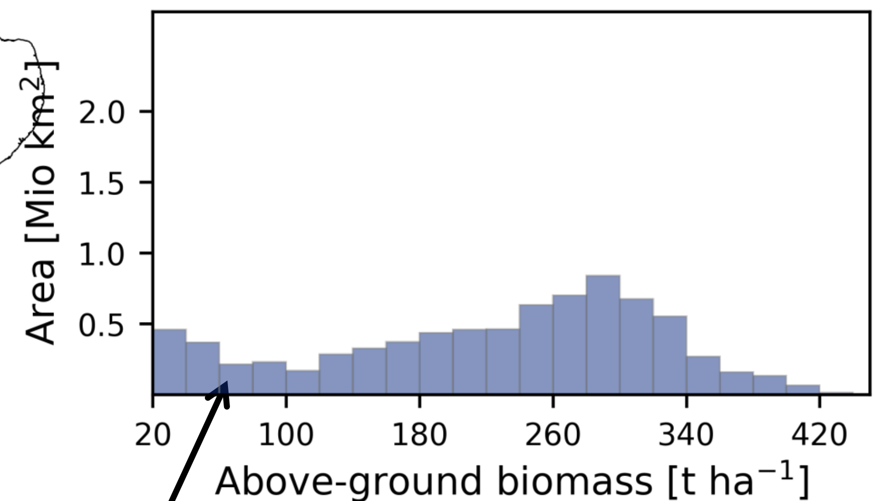
Biomass in the Amazon rainforest



forest biomass map of current Amazon rainforest

(based on linking remote sensing and forest modelling)

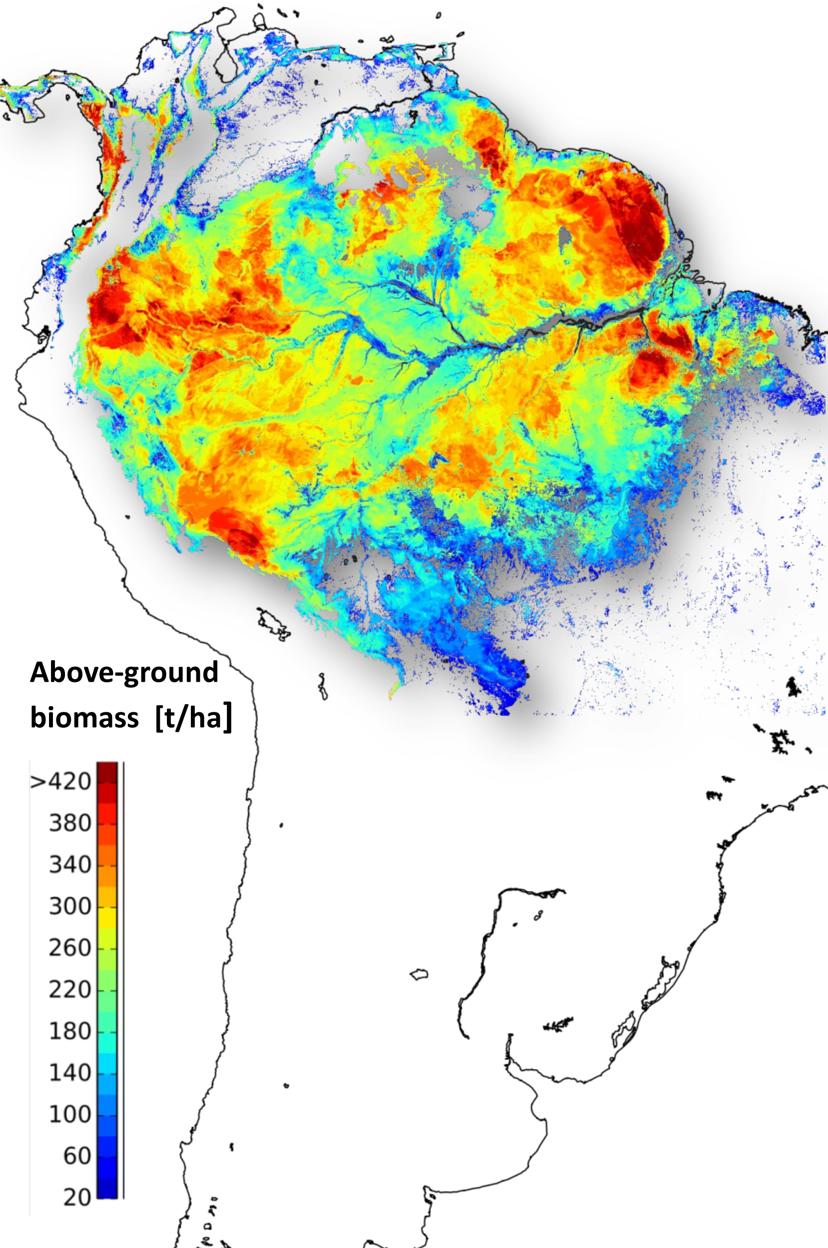
500 mill. ha, scale 1 km x 1km



including forest height information from remote sensing (incl. disturbed forests)

Rödig et al. 2018, Env Research Let
Rödig et al. 2017, Global Ecol Biogeogr

Biomass in the Amazon rainforest



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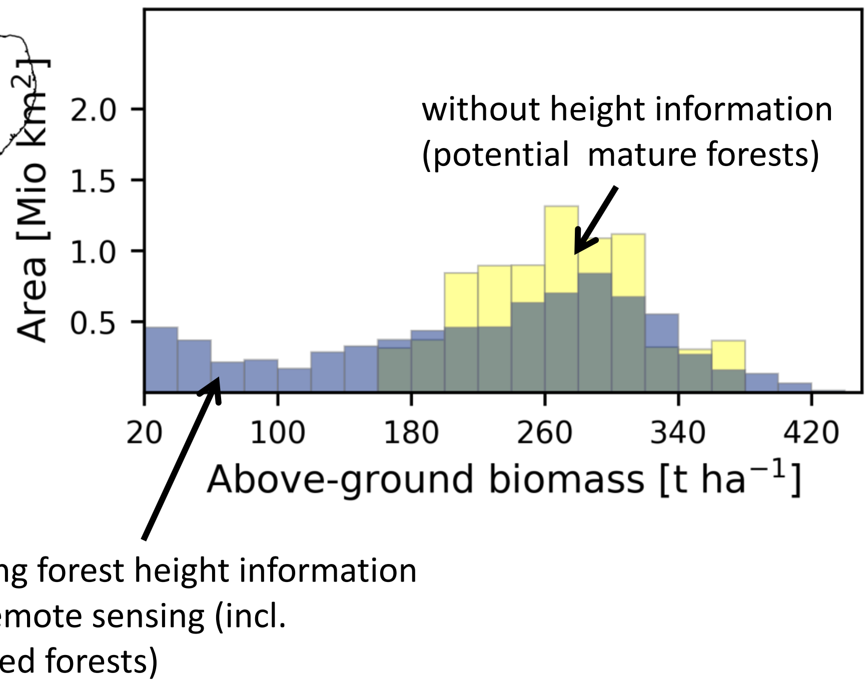


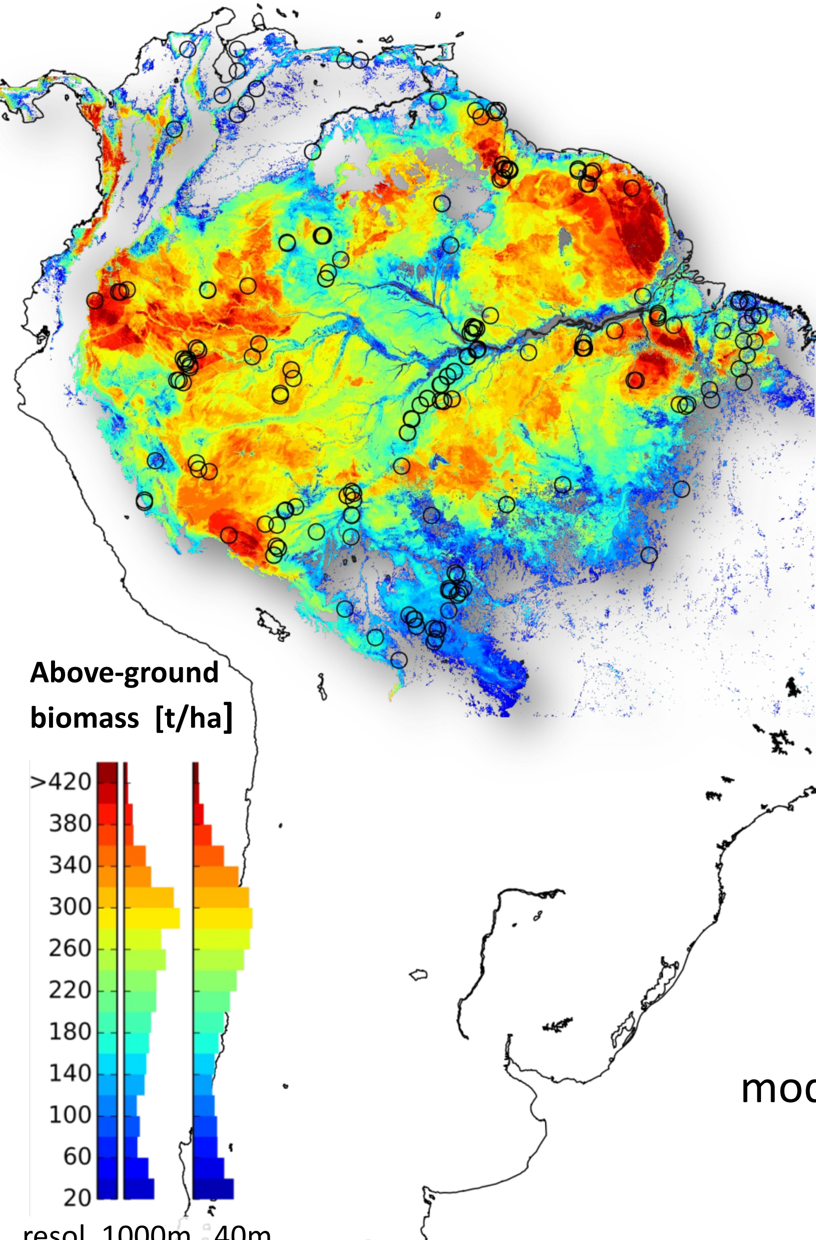
analysis can be done also for smaller scales (e.g. 1 ha, 50 m x 50 m)

Rödig et al. 2018, Env Research Let

Rödig et al. 2017, Global Ecol Biogeogr

Biomass in the Amazon rainforest

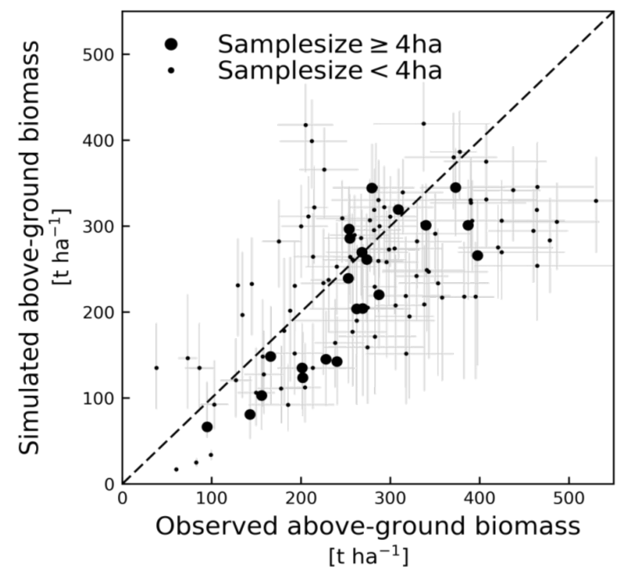
forest biomass map of current Amazon rainforest
(based on linking remote sensing and forest modelling)



multi-scale modelling approach

comparison with 114 field plots

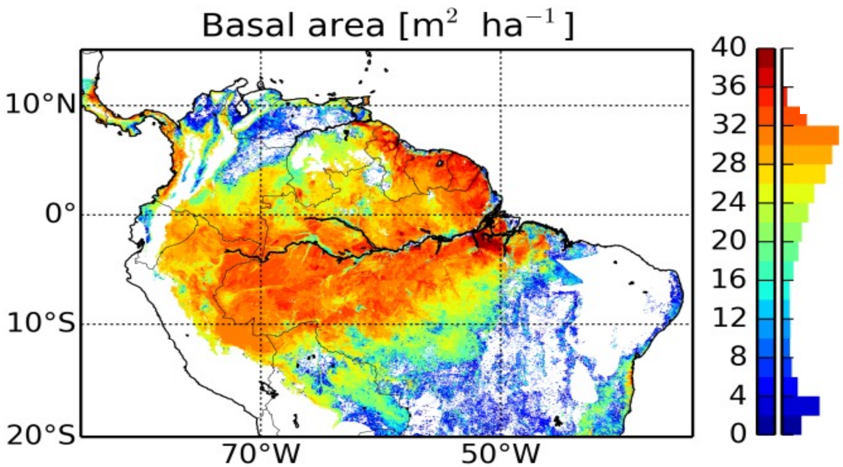
○ Mitchard *et al.*, 2014; Poorter *et al.*, 2015, Lopez-Gonzalez *et al.*, 2011;



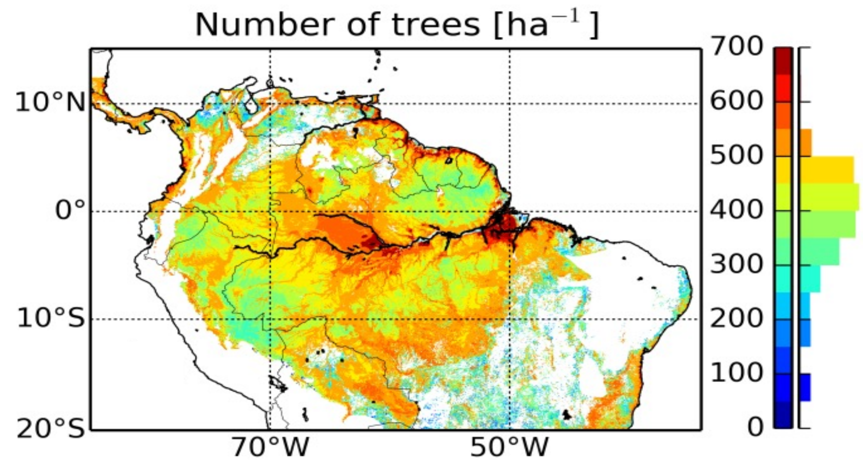
Rödig et al. 2018, Env Research Let
Rödig et al. 2017, Global Ecol Biogeogr

Structure of the Amazon rainforest

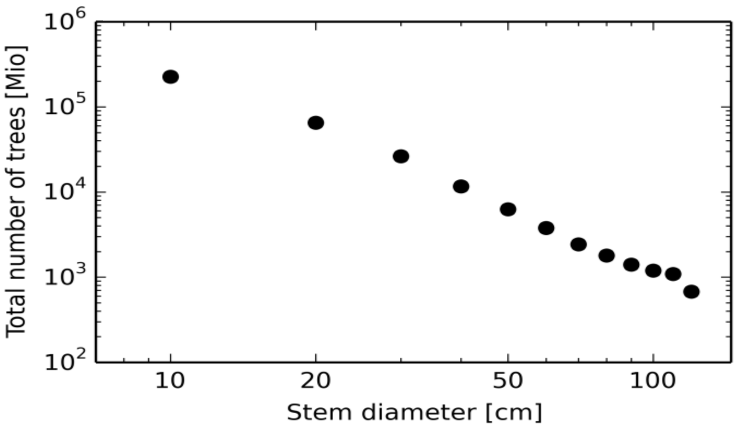
FORMIND simulations combined
with forest height from ICESAT Lidar



scale 1 km²



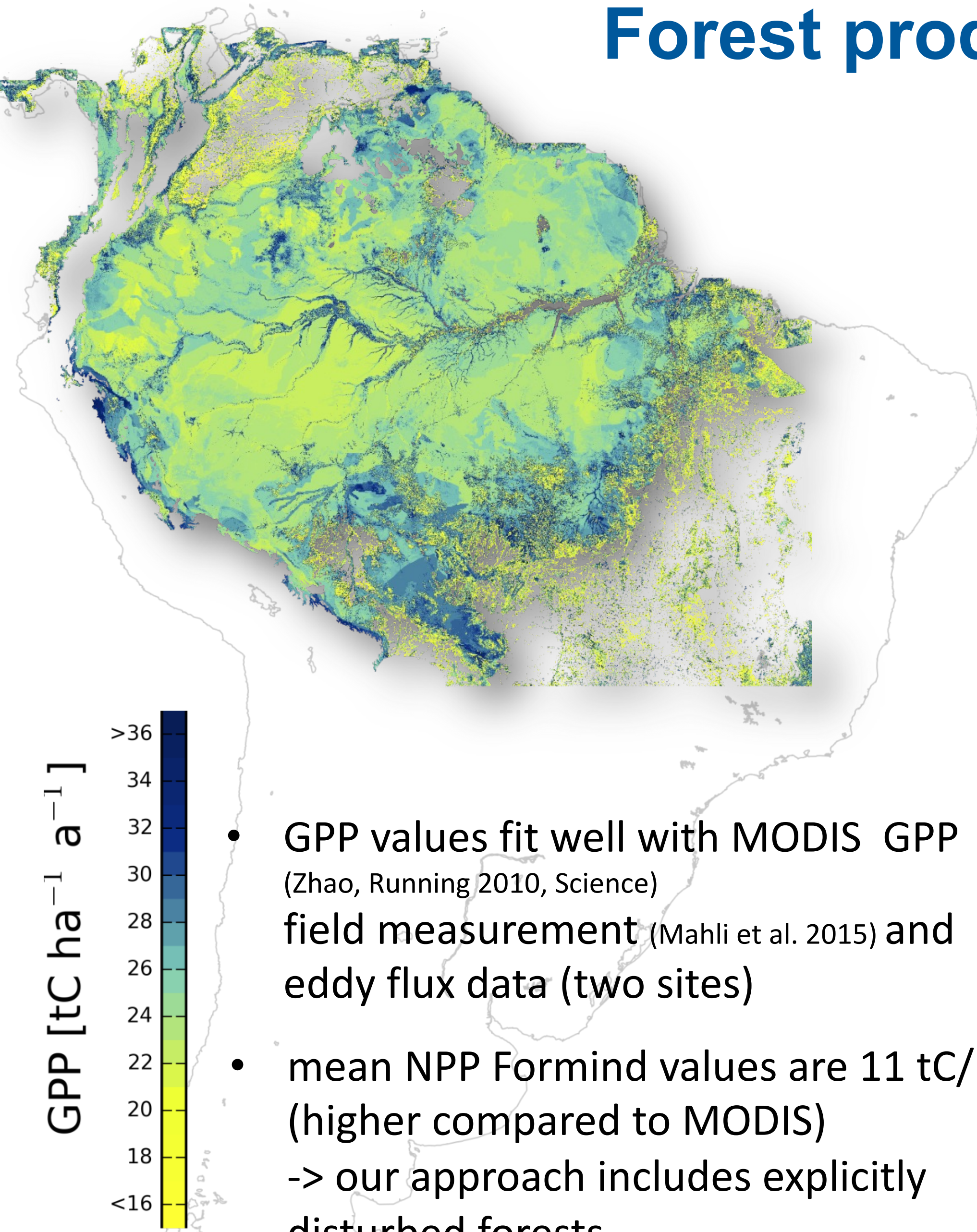
scale 1 km²
dbh > 10 cm

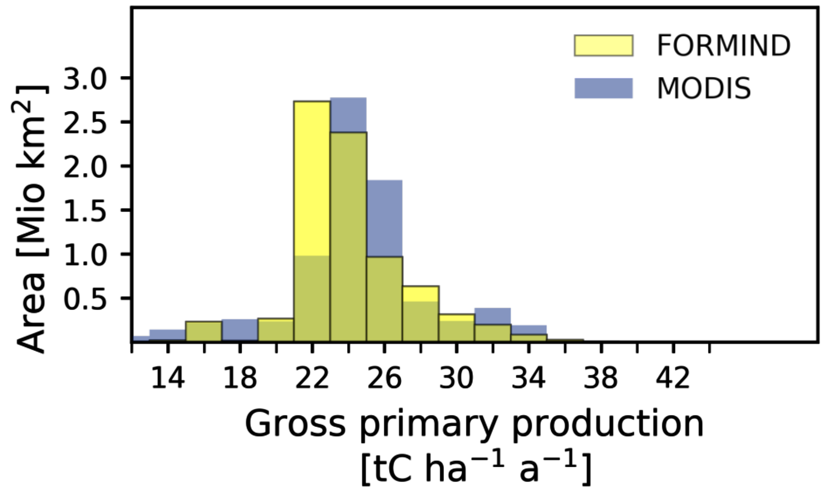


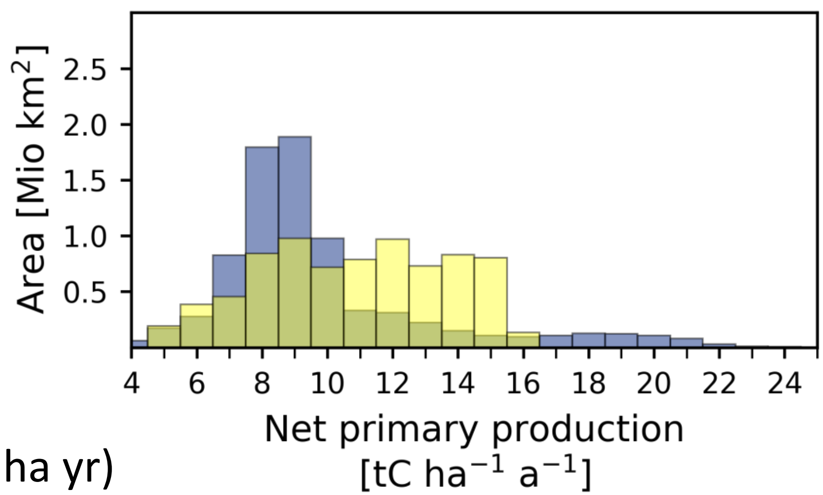
tree size distribution for the whole Amazon
total tree number:
410 bill. trees (dbh >10 cm)

Rödig et al. 2018, Env Research Let
Rödig et al. 2017, Global Ecol Biogeogr

Forest productivity in the Amazon



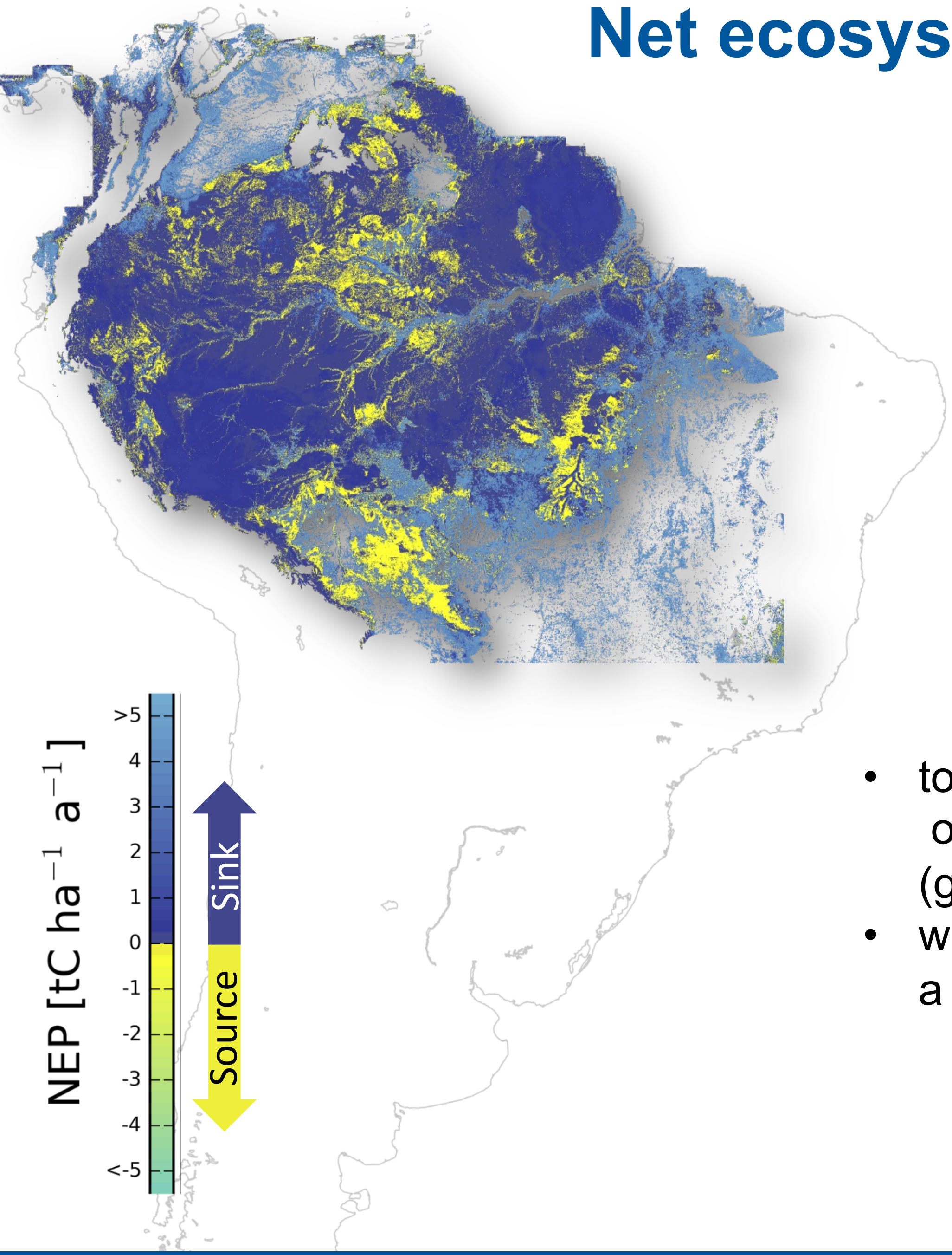




- GPP values fit well with MODIS GPP (Zhao, Running 2010, Science) field measurement (Mahli et al. 2015) and eddy flux data (two sites)
- mean NPP Formind values are 11 tC/(ha yr) (higher compared to MODIS)
  -> our approach includes explicitly disturbed forests

Rödig et al. 2018, Env Research Let
Rödig et al. 2017, Global Ecol Biogeogr

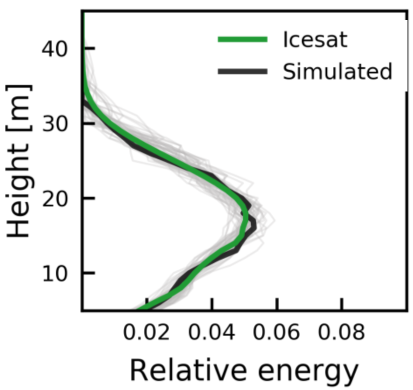
Net ecosystem productivity (NEP)

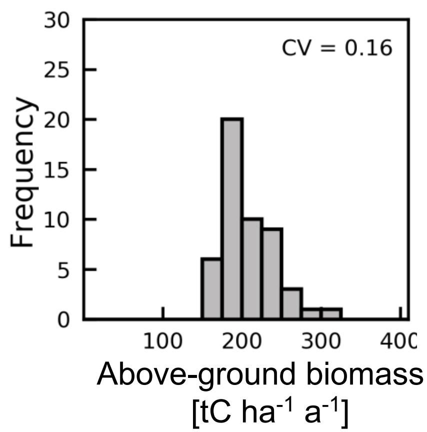


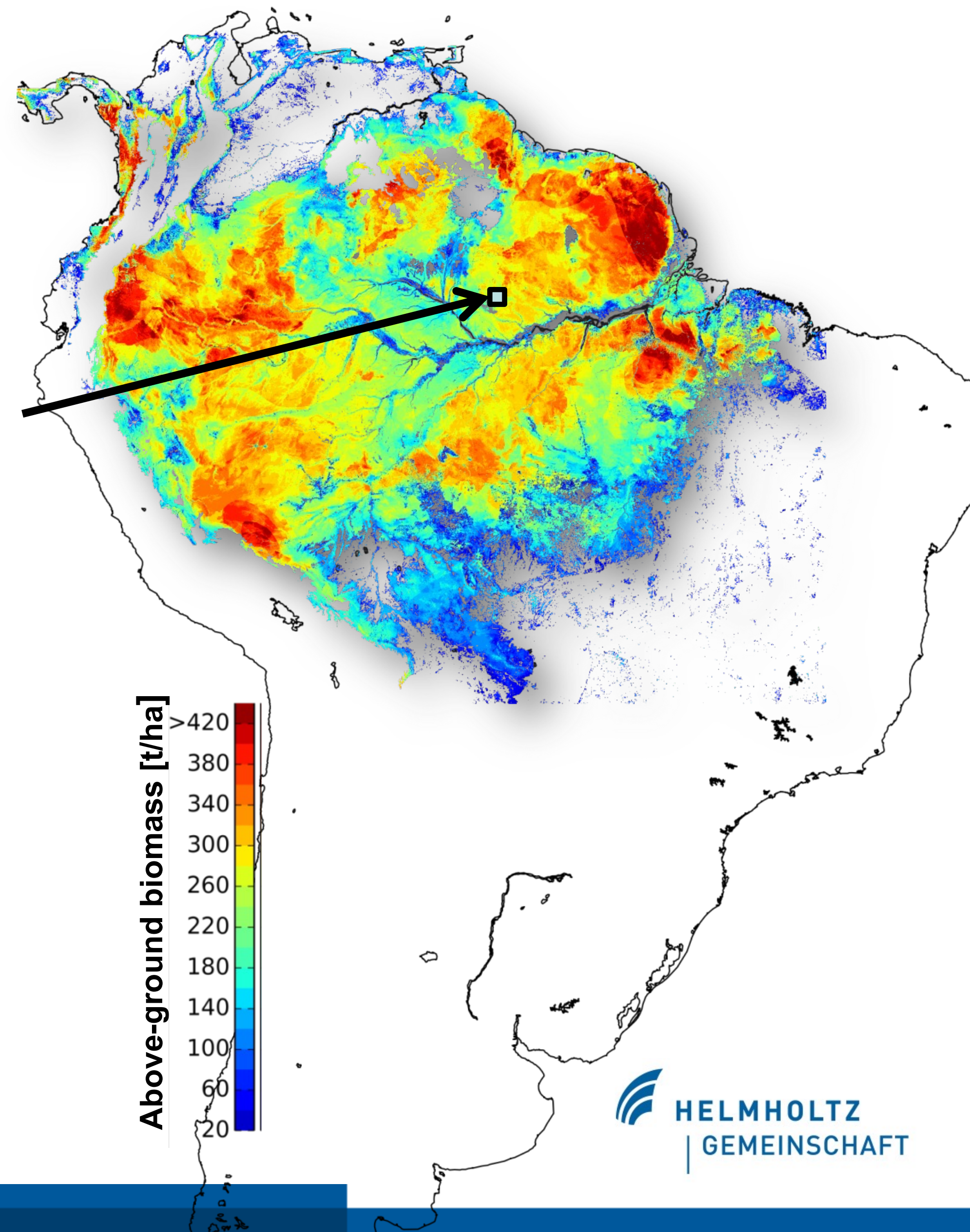
- total estimated carbon uptake of Amzaon forests: 0.6 Gt yr^{-1} (growth of forest)
- without land-use the Amazon forests is a relevant carbon sink

Integrating full Lidar profiles into the forest modeling framework

Example 1







- approach: for every profile we filter the forest states (from succession simulations) which fits with the profiles
- from this we derive probability distributions for forest biomass at every location

(thanks to Tang, Dubayah for Lidar profiles, Tang et al. 2017 PNAS)

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Integrating full Lidar profiles into the forest modeling framework for the Amazon

(Gedi 100 million profiles, IceSat 1 million profiles)

remote sensing MDPI

Article

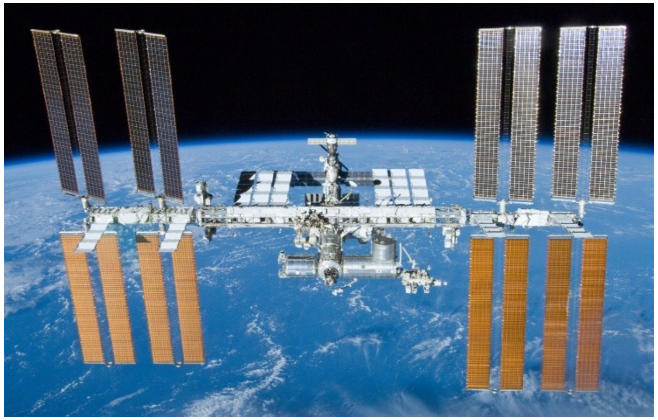
Mapping Amazon Forest Productivity by Fusing GEDI Lidar Waveforms with an Individual-Based Forest Model

Luise Bauer [1,*], Nikolai Knapp [1,2] and Rico Fischer [1]

nature COMMUNICATIONS

From small-scale forest structure to Amazon-wide carbon estimates

Edna Rödig [1,2*], Nikolai Knapp[1], Rico Fischer [1], Friedrich J. Bohn[1], Ralph Dubayah[3], Hao Tang [3] & Andreas Huth[1,4,5]



GEDI ECOSYSTEM LIDAR

NASA

University of Maryland 1856

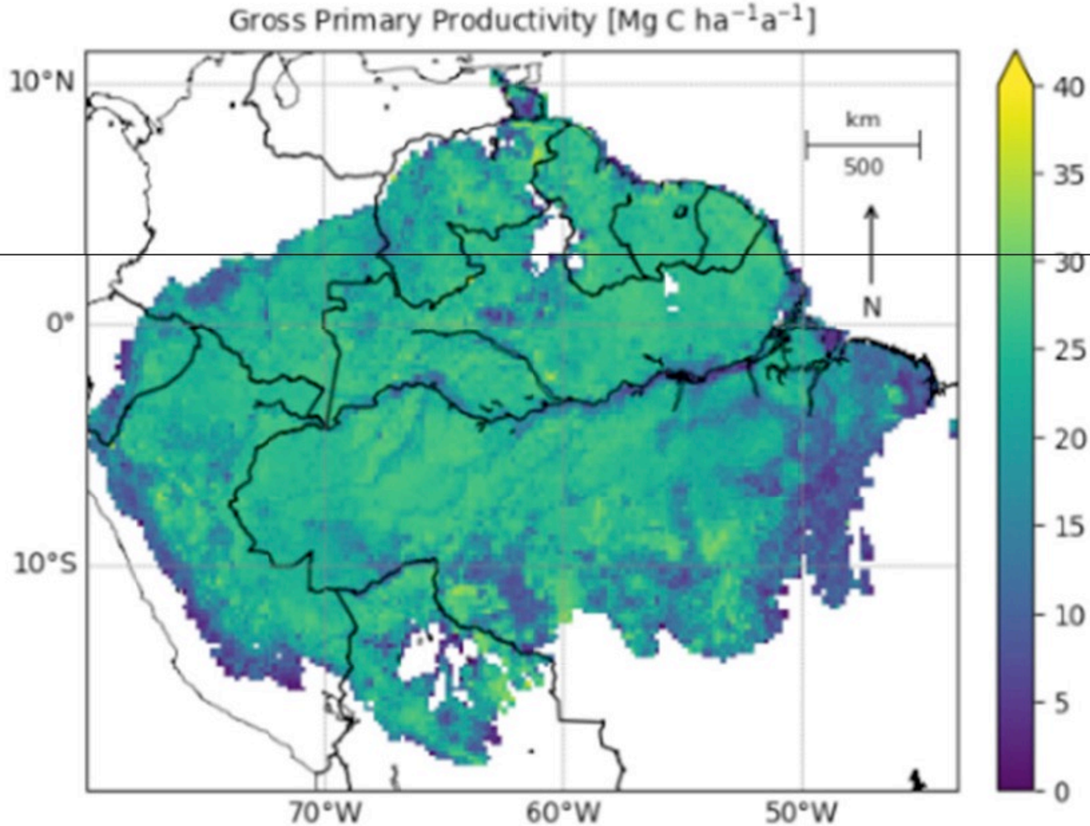
www.FORMIND.org

Rödig et al. 2019, Nature Com
Bauer et al. 2021, Remote Sensing

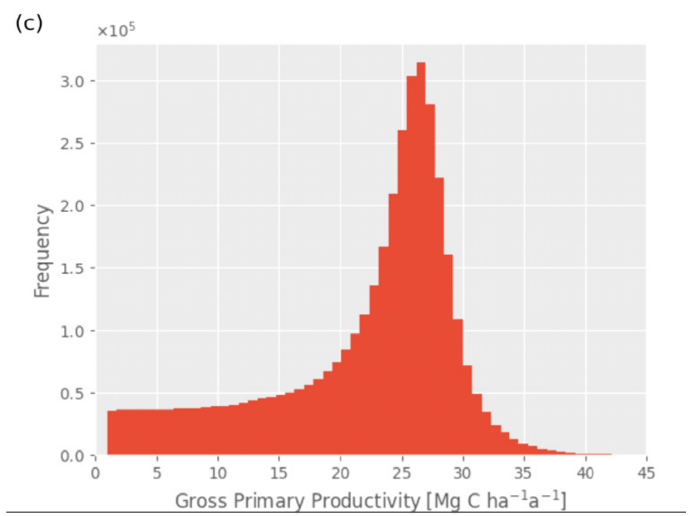
HELMHOLTZ GEMEINSCHAFT

Forest productivity maps for the Amazon 2021 using GEDI Lidar profiles and forest modelling

(110 million profiles)



derived GPP distribution for the Amazon (2021)



Estimated mean GPP for Amazon forests is 22 tC/(ha yr).
Similar analysis can be done also for other forest attributes: biomass, basal area, NPP, NEE...

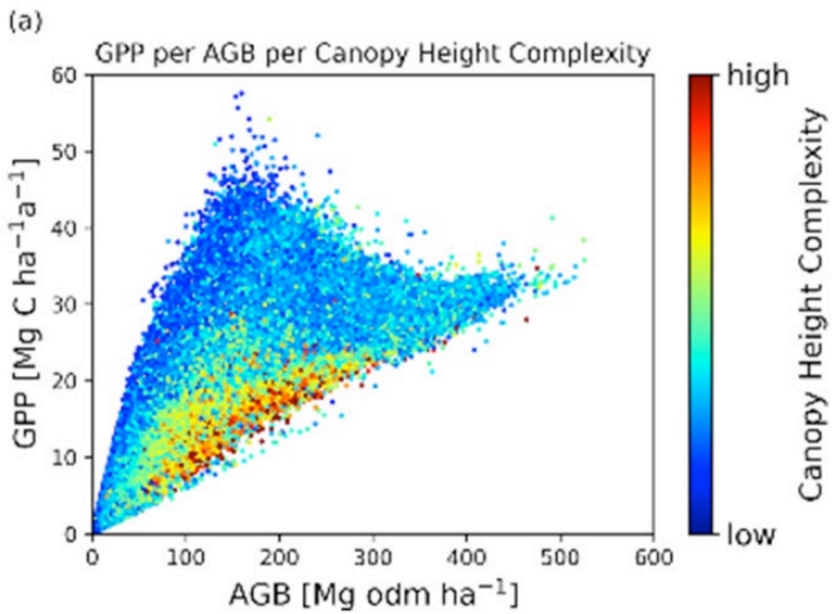
Bauer et al. 2021, Rem Sens
Roedig et al. 2019, Nat Com
Roedin et al. 2018, ERL

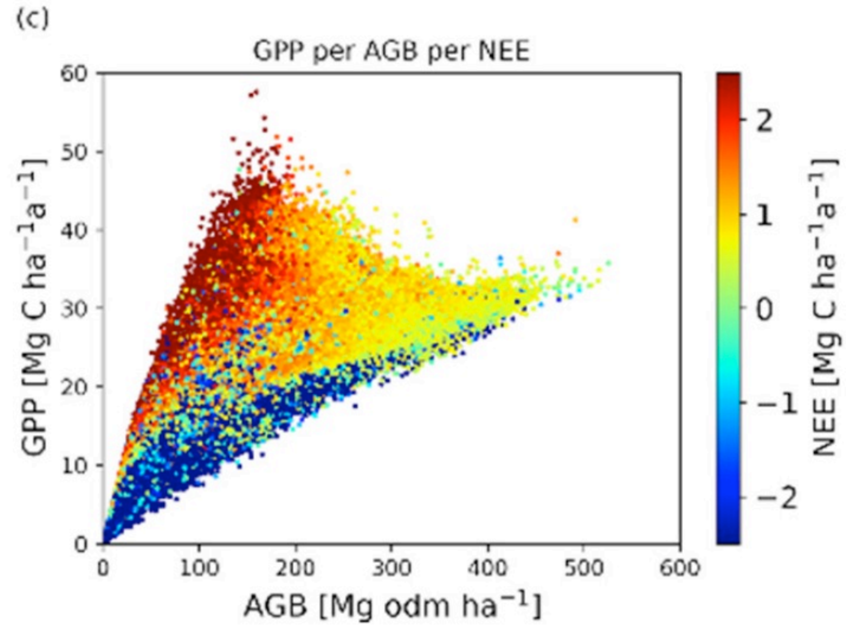
Forest productivity maps for the Amazon 2021 using GEDI Lidar profiles and forest modelling

(110 million profiles)

GEDI ECOSYSTEM LIDAR

FORMIND the forest model





Relations between forest biomass, productivity and structure can be explored (resolution 1 km²).
Forest with low height complexity show high productivity (GPP) and these forests are often a carbon sink (NNE >0).

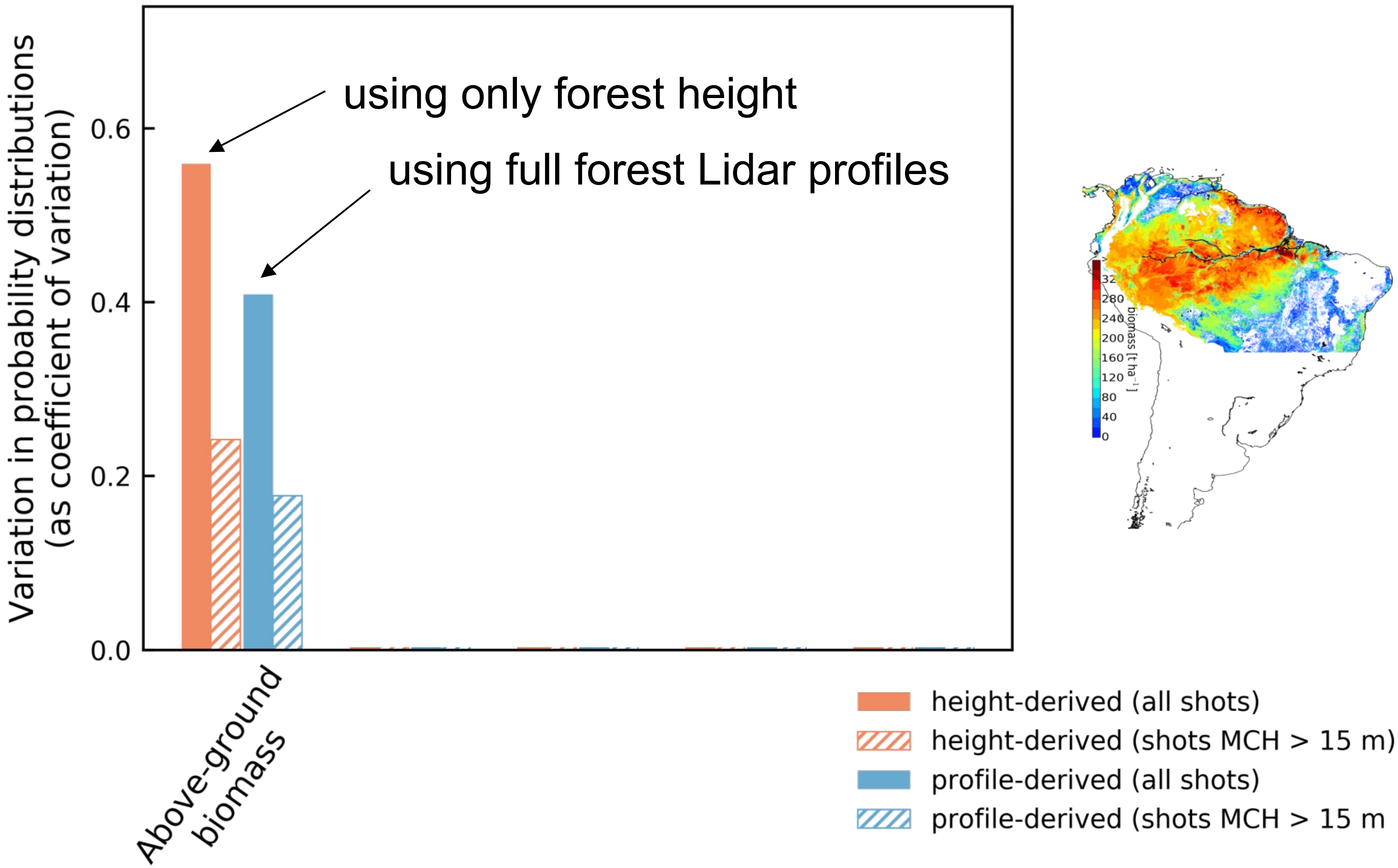
Bauer et al. 2021, Rem Sens
Roedig et al. 2018, ERL

Analyzing the information content of full Lidar profiles (one million Liadar profiles, Icesat, Amazon rain forest)

lower quality

quality of state detection (CV)
good quality = low values

good quality



States of forests with not to small heights could be detected quite well (CV ≈ 0.2)

Rödig et al. 2019, Nature Com

Analyzing the information content of full Lidar profiles (one million Liadar profiles, Icesat, Amazon rain forest)

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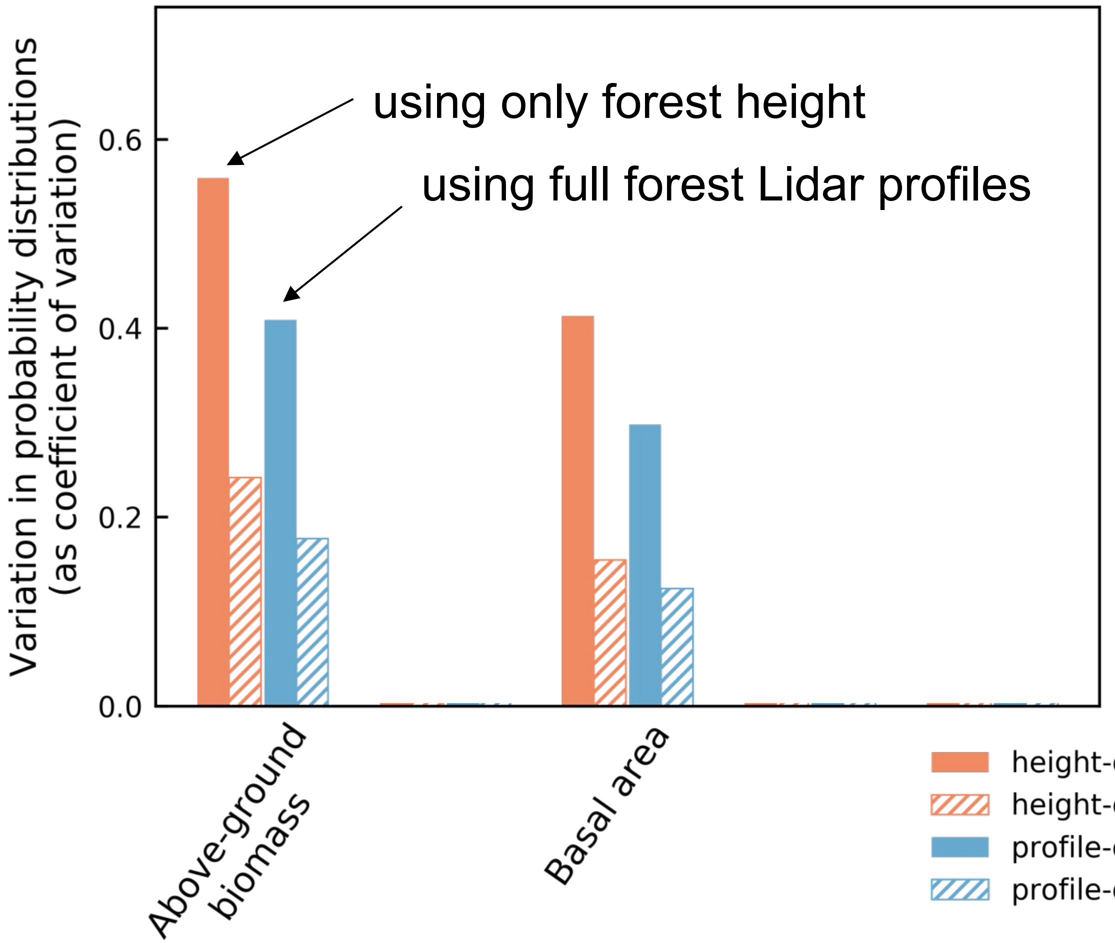

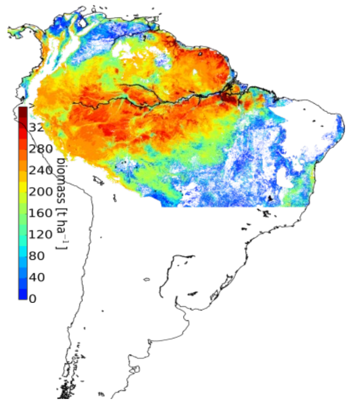

Basal area could be detected even better than biomass.

Rödig et al. 2019, Nature Com

Analyzing the information content of full Lidar profiles (one million Liadar profiles, Icesat, Amazon rain forest)

www.FORMIND.org

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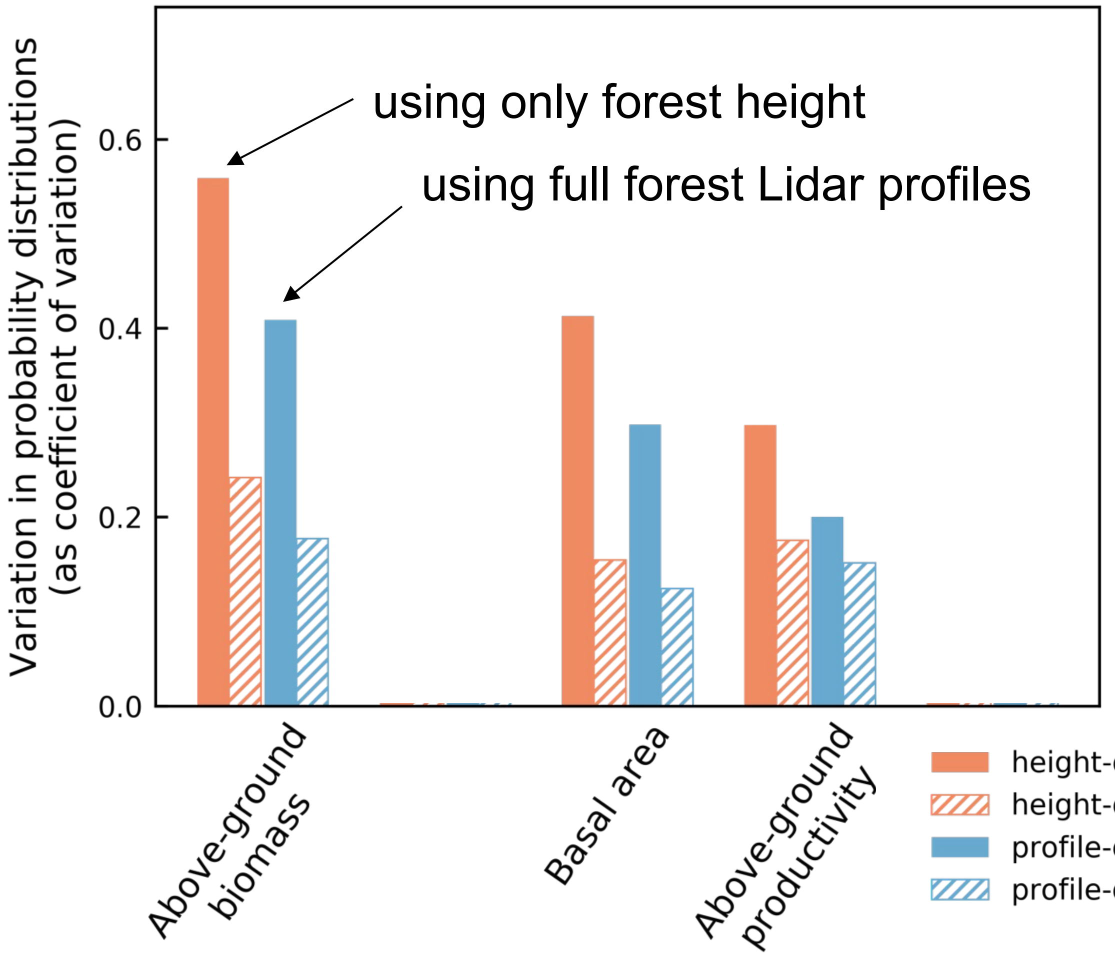
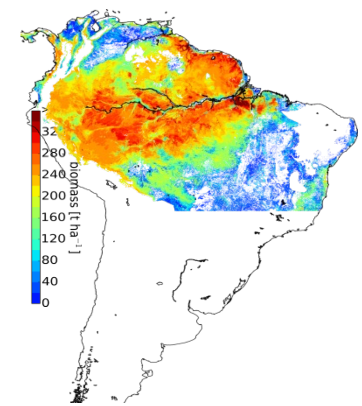


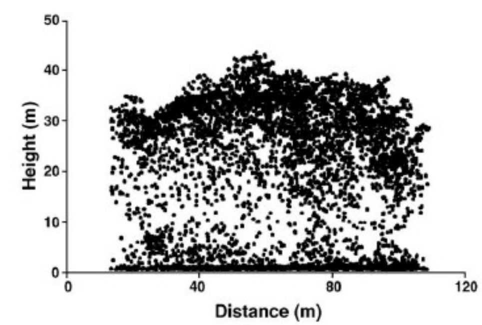


Forest productivity NPP could be detected quite well.

Rödig et al. 2019, Nature Com

Summary

- We applied a forest gap model (FORMIND) to the Amazon (every tree in the Amazon is simulated, in total 410 bill. trees) www.formind.org
- We developed a novel framework to integrate remote sensing products into forest modelling
  - remote sensing data (e.g. forest height) is used a filter (selection of states from forest succession simulations)
  - the filtered states can be used to derive important forest attributes (e.g. biomass, basal area, GPP, NEP) at high spatial resolution (e.g. 1 ha, 0.25 ha)
- this has several advantages:
  (a) remote sensing of forest structure allows us to consider also disturbed forest states (e.g. forests with low height)
  (b) validation experiments are possible without 'mixing' spatial scales
  (c) integration of different remote sensing products is possible (Lidar, Radar, optical, Henninger/Huth 2023, RS)
  (e.g. Radar: Tandem-X, Biomass, Tandem-L….)



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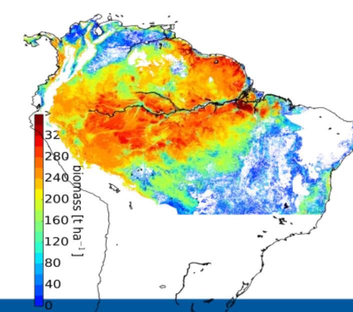
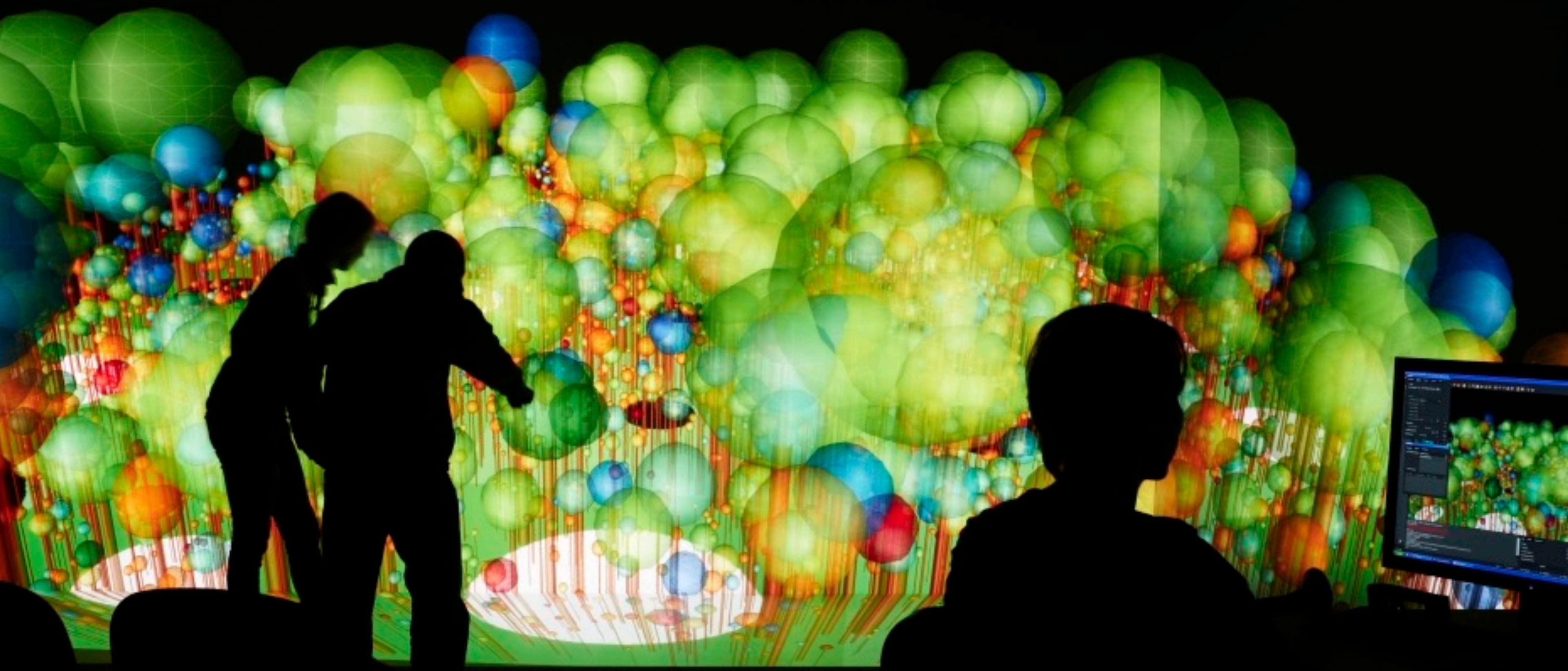
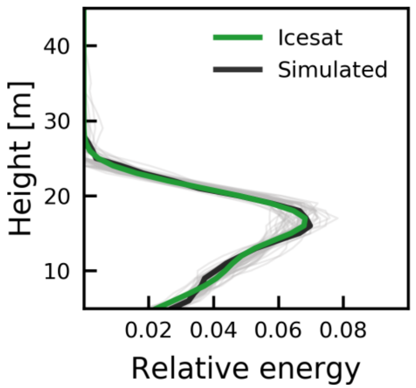


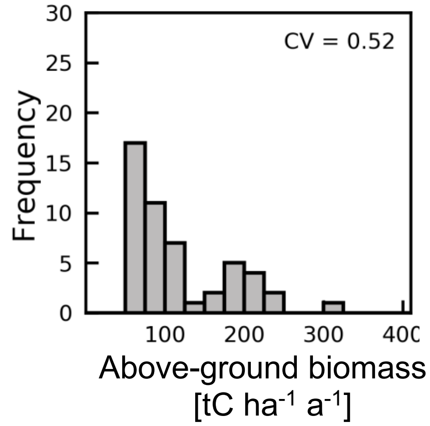


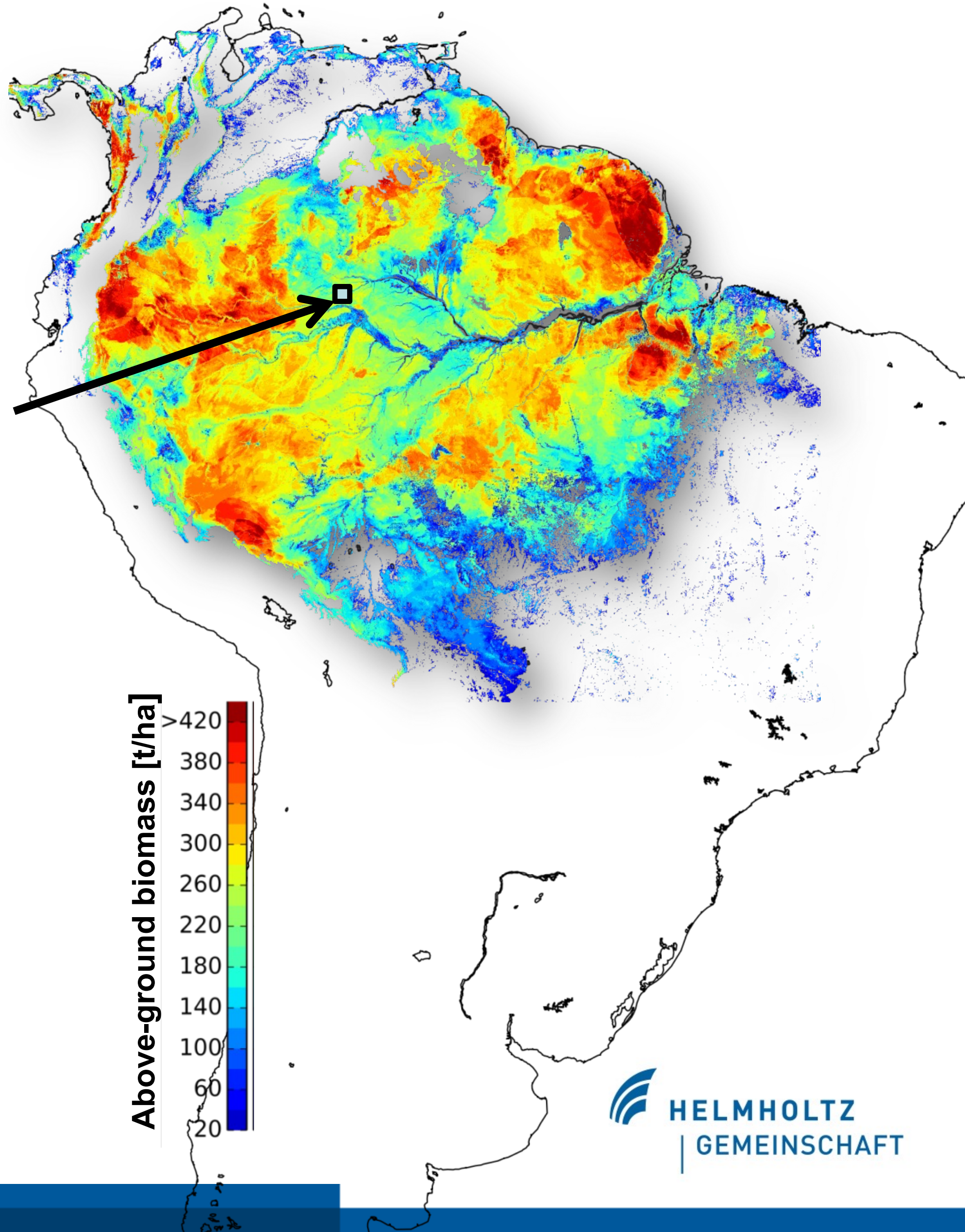
Many thanks!

Integrating full Lidar profiles into the forest modeling framework

Example 2







some profiles can be related to forest states which have quite different biomass values

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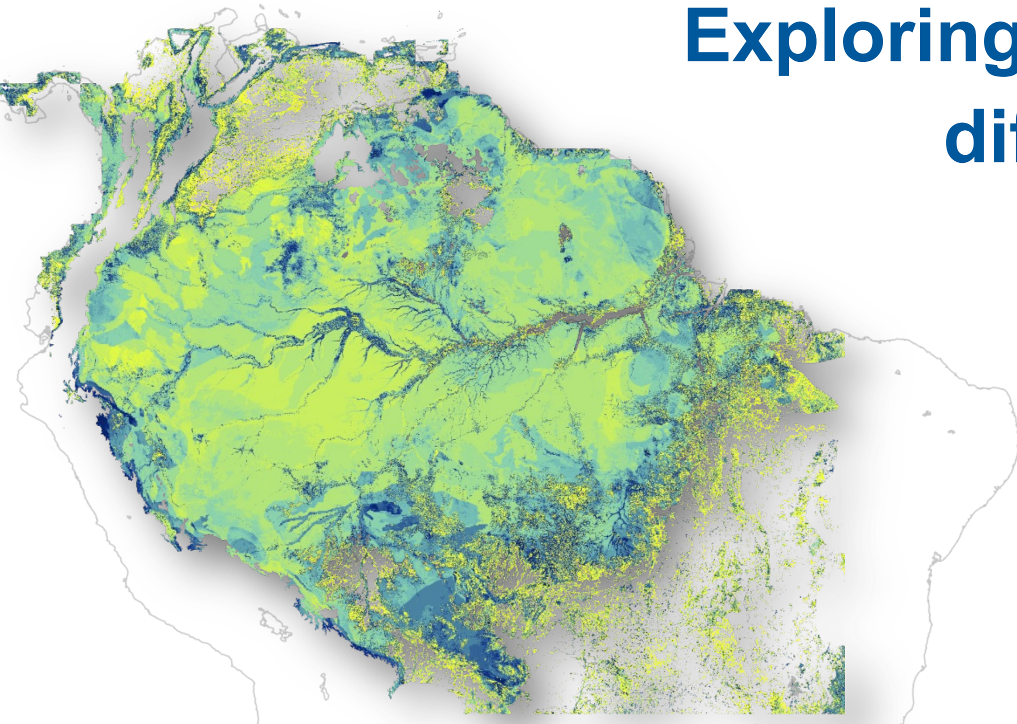
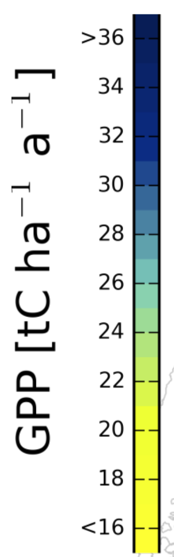
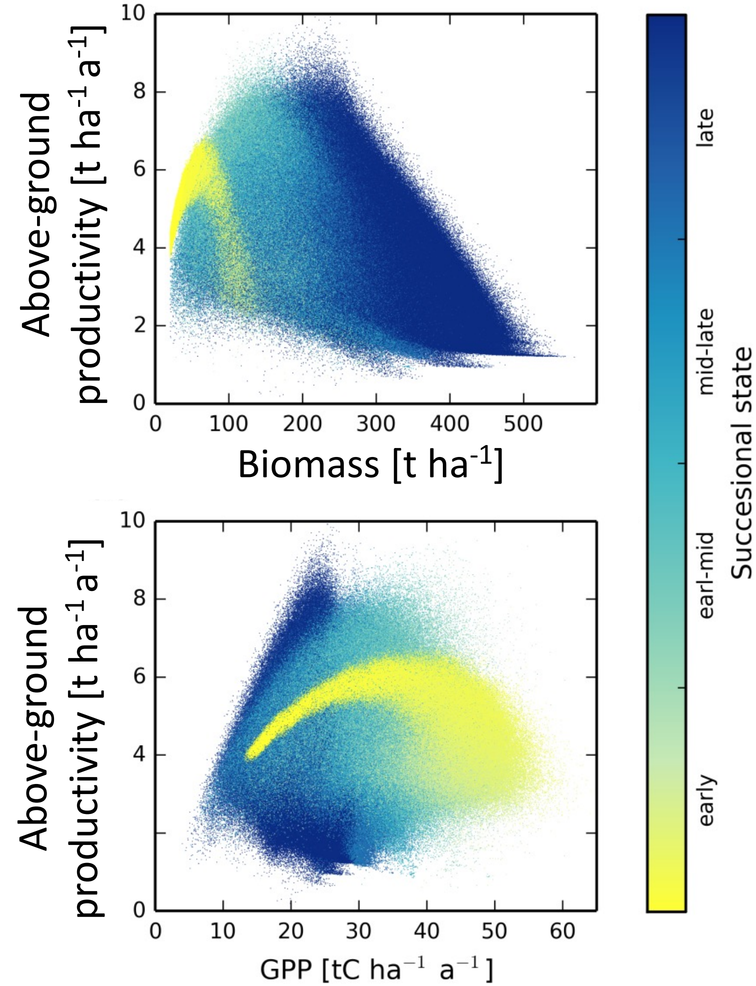
Exploring relationships between different forest attributes







- Results can be also used to explore relationships between different forest attributes

Rödig et al. (2018), Env Research Let
Dolmann (2018)), Env Research Let