Effect of tree demography and flexible root water uptake for modeling the carbon and water cycles of Amazonia

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The Amazon rainforest

- Essential importance for the global carbon and water cycles
  [*Eltahir and Bras*, 1994; *Werth and Avissar*, 2002]

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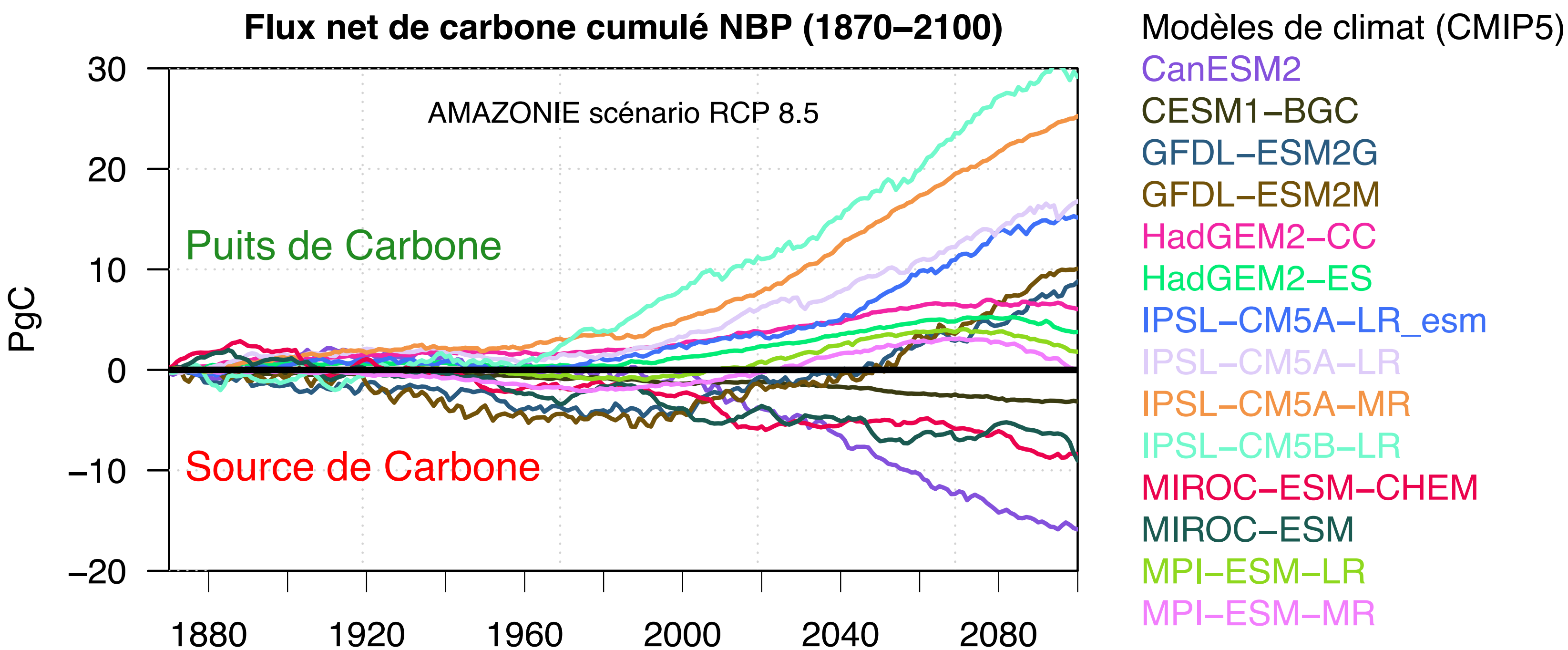
Global Climate Models projections (RCP8.5)



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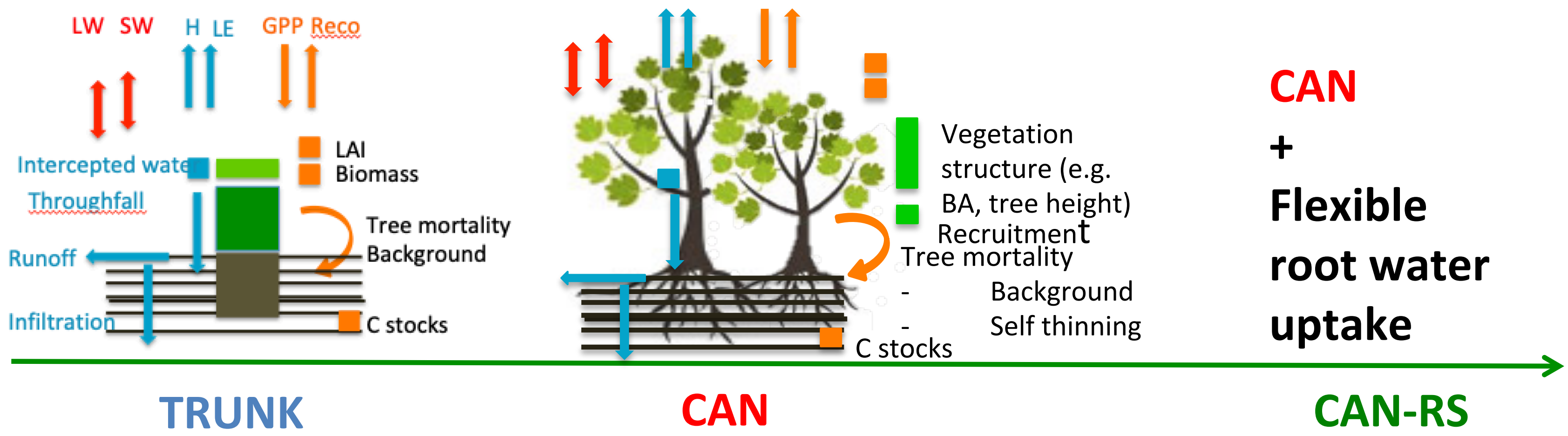
=> **Land carbon cycle processes** [*Booth et al.*, 2012; *Sitch et al.*, 2015]

→ Vegetation response to drought
[Joetzjer et al., 2014 *Restrepo-Coupe et al.*, 2016]

→ Tree demographic processes
[*Fisher et al.*, 2010; *Rödig et al.*, 2018]

Investigate the effects of **tree demography** and **flexible root water uptake** for modeling the carbon and water cycles of Amazonia

ORCHIDEE (land surface model) the 3 versions used



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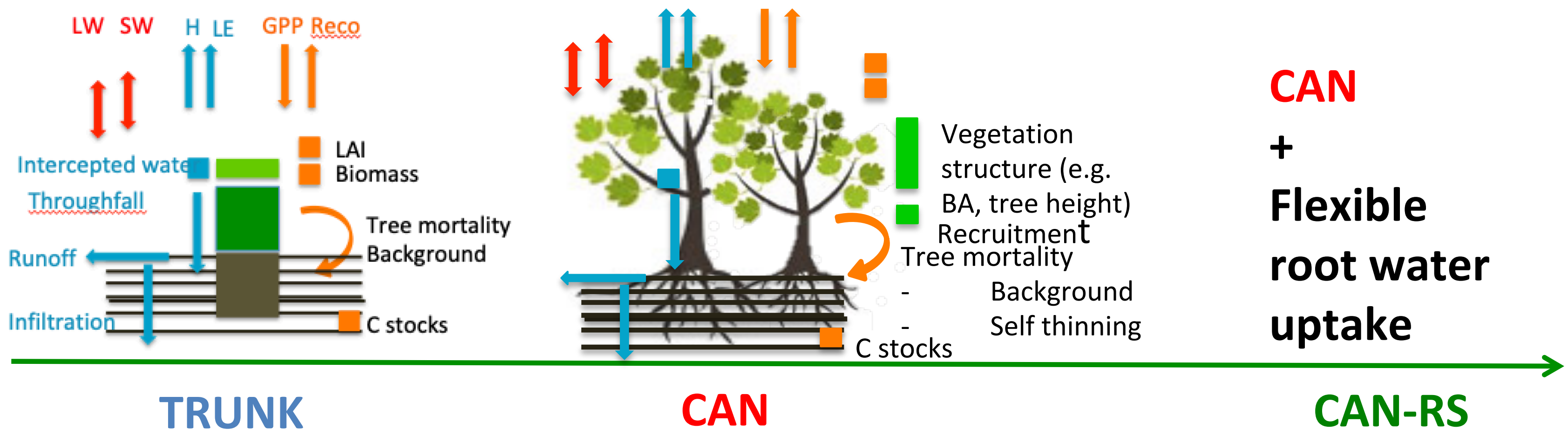

Big-leaf approach *(Krinner et al., 2005)*

Explicit demography represented by downscaling stand level NPP to mean individual (cohort) following the allocation rules of *Deleuze et al. (2004)*

Recruitment scheme and self-thinning

(Belassen et al., 2010, 2011; Naudts et al., 2015, Joetzjer et al., submitted)

“TROPICAL” VERSION

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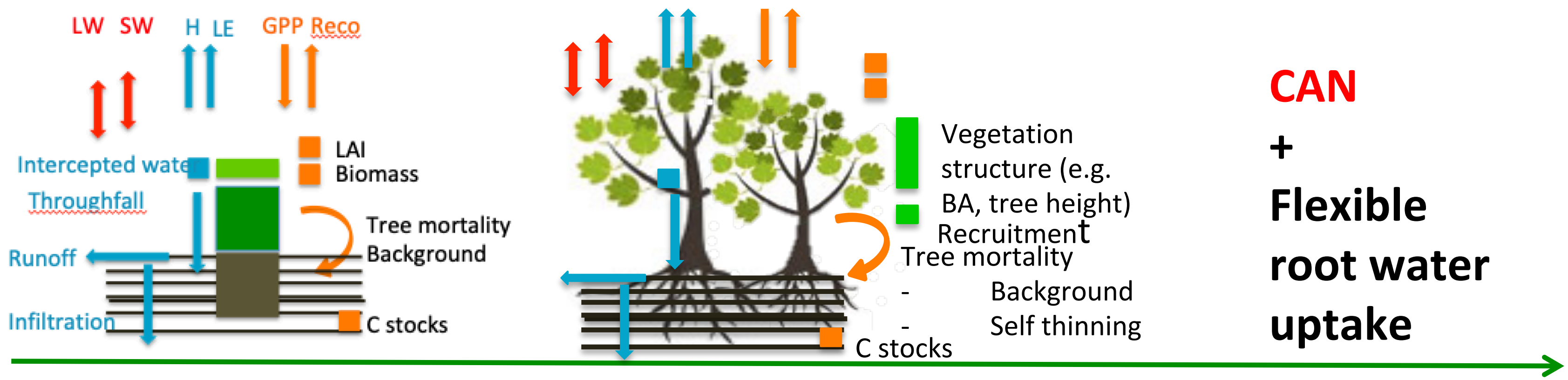

TRUNK | CAN | CAN-RS

Simple water stress function to limit photosynthesis when drought

Root water uptake (Psi_rz): Soil water potential weighted by the **root density profile**

Root water uptake takes in account soil-to-root water flow and roots hydraulic properties. **Driven by the water availability**

Hydraulic architecture to calculate water supply for plants (based on Hickler et al., 2007)

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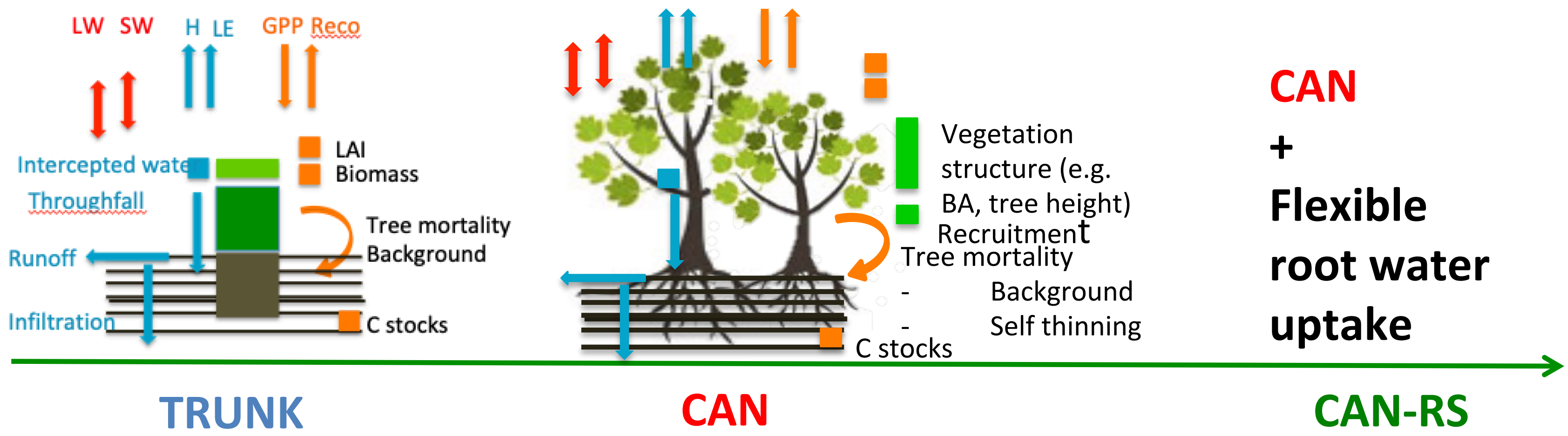


CAN vs CAN-RS : Water uptake scheme

CAN & CAN-RS vs. TRUNK : tree demography scheme

Flexible Roots effect on GPP Sites

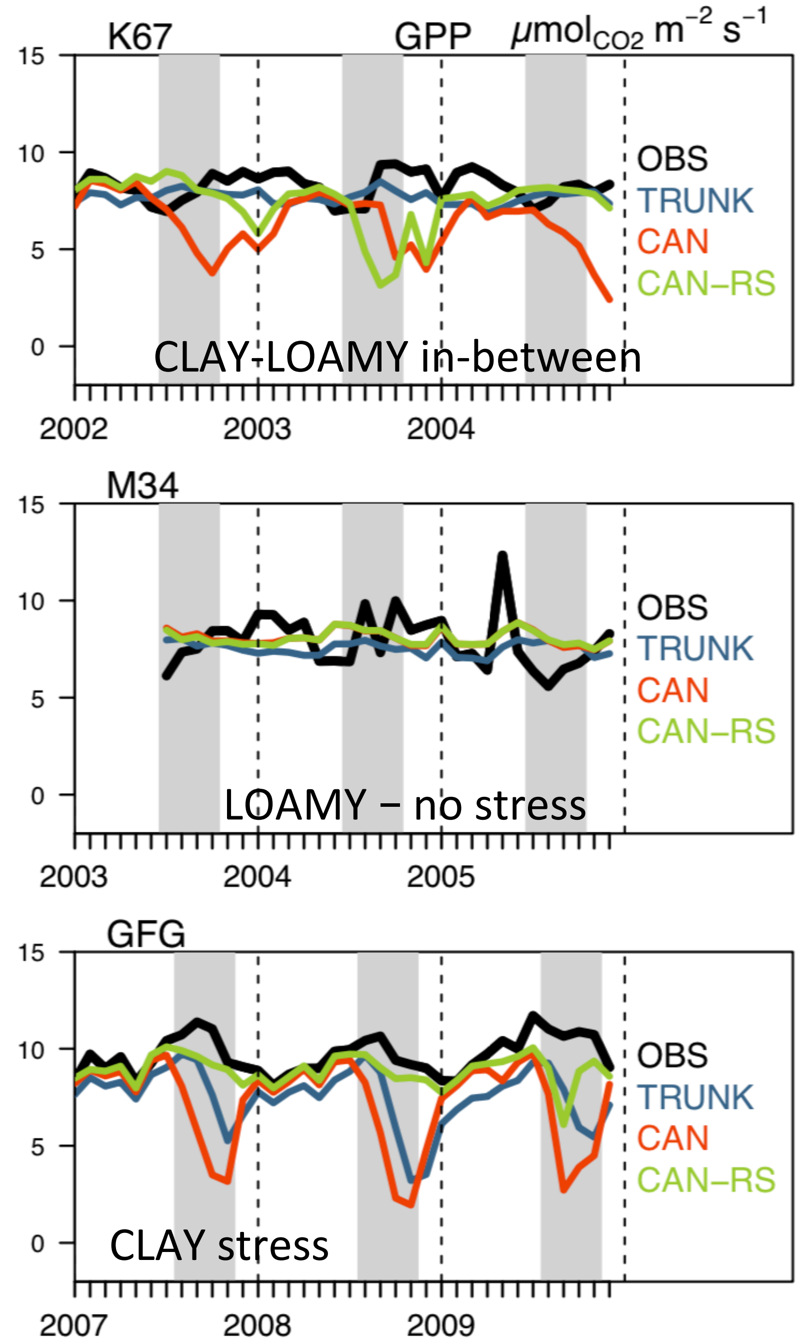
Monthly simulated GPP compared to observed GPP(FLUXTOWER) data at 3 sites.

Grey shaded area : dry seasons

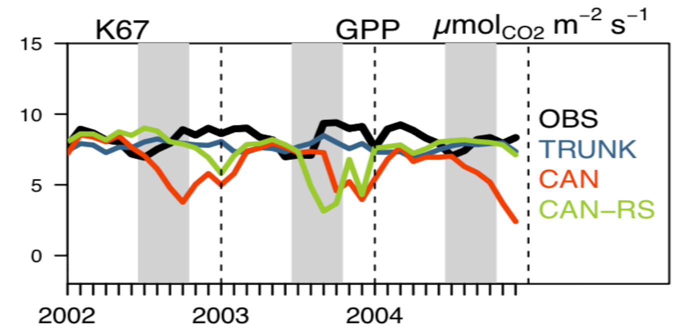
CAN vs CAN-RS : Water uptake scheme

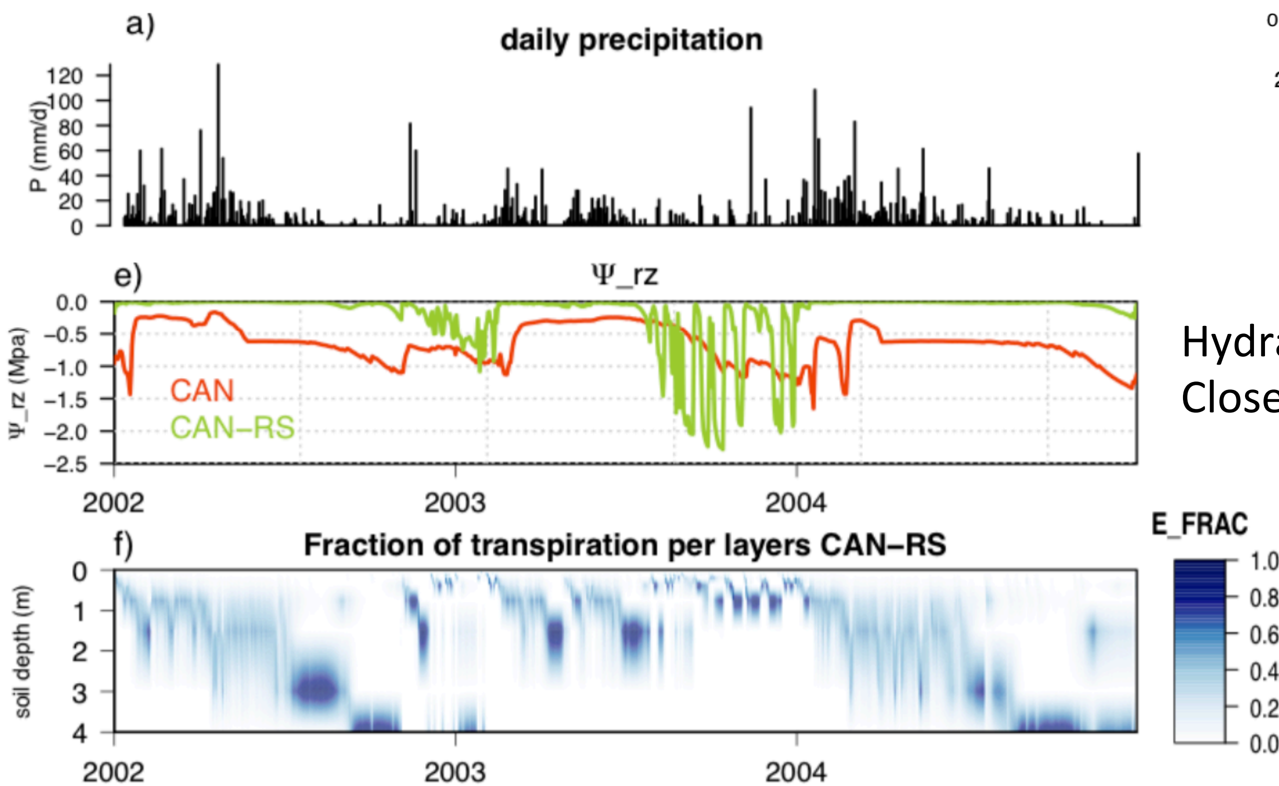
=> No effect on LOAMY soils

⇒ CAN-RS improve seasonality on CLAY & CLAY-LOAMY soils (2 years /3)



Flexible Roots effect on GPP
K67

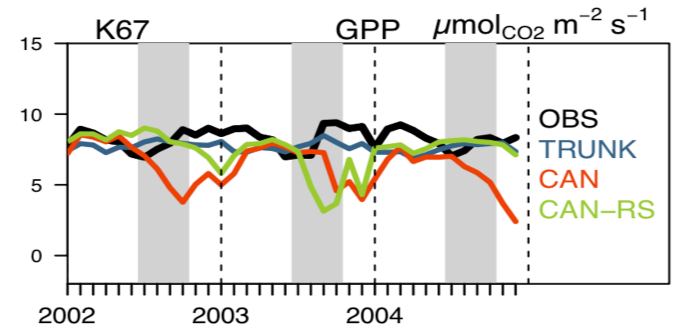


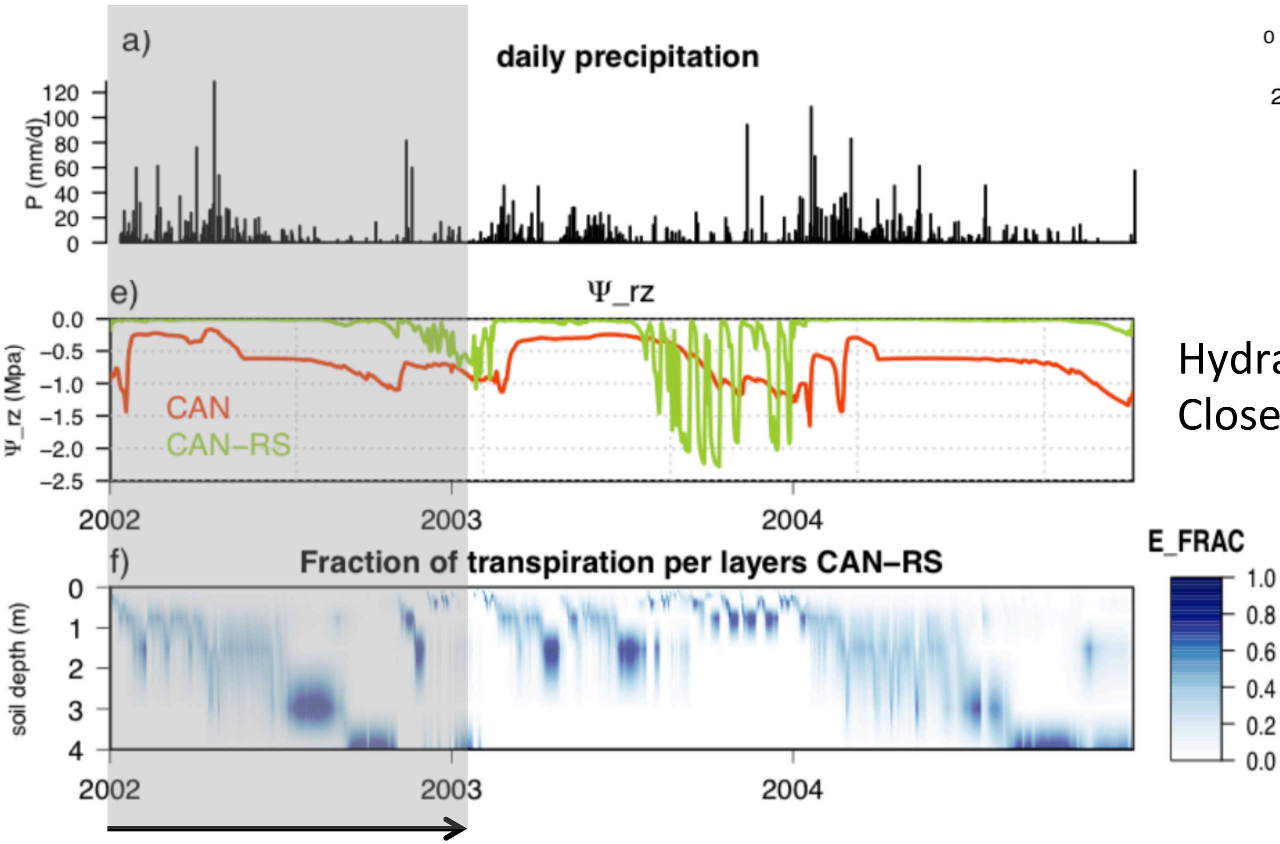


Hydraulic potential in the root zone
Close to zero => easy available water

Where does the water extracted by the roots come from ?

Flexible Roots effect on GPP K67





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2002 CAN-RS alleviate water stress (Psi-RZ) close to zero water extracted from the deepest layers

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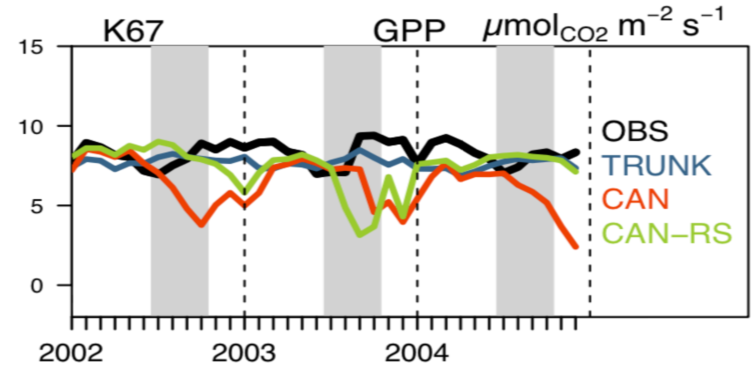

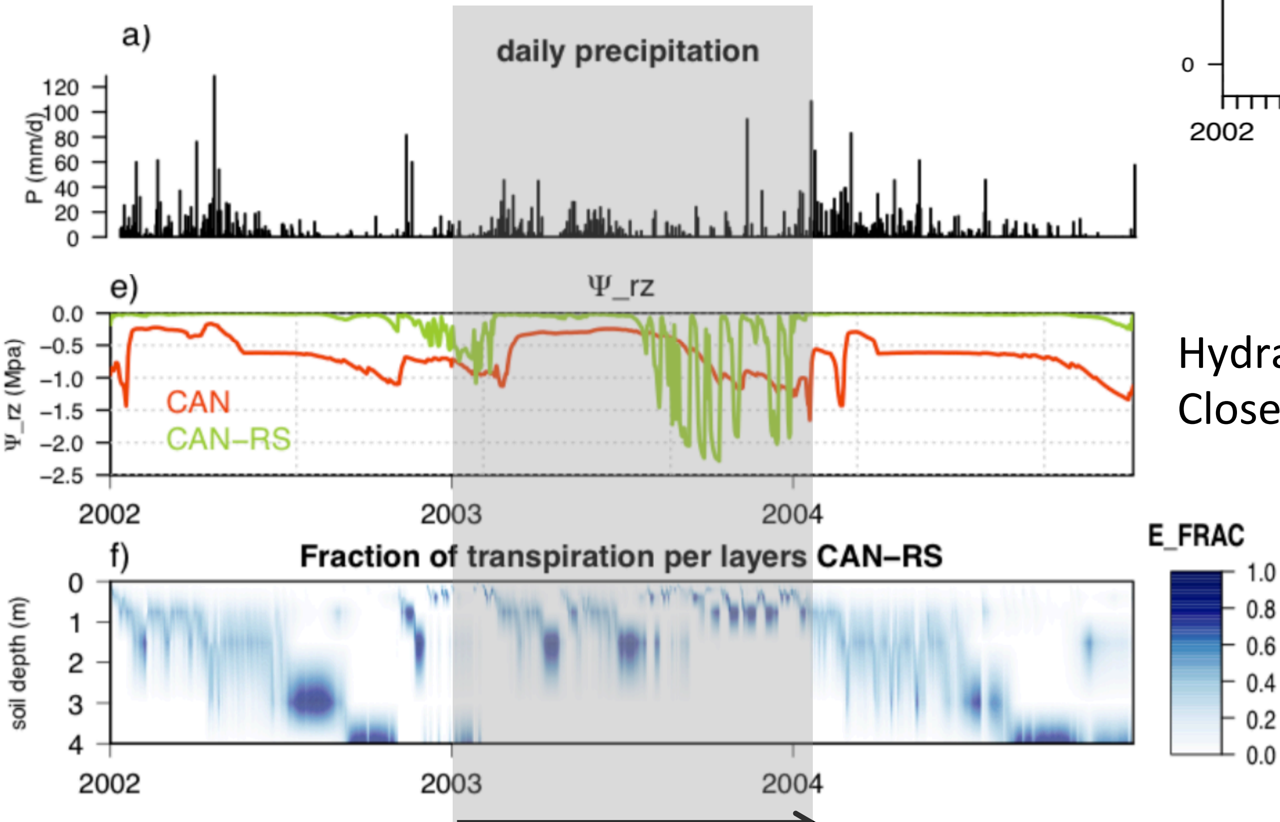

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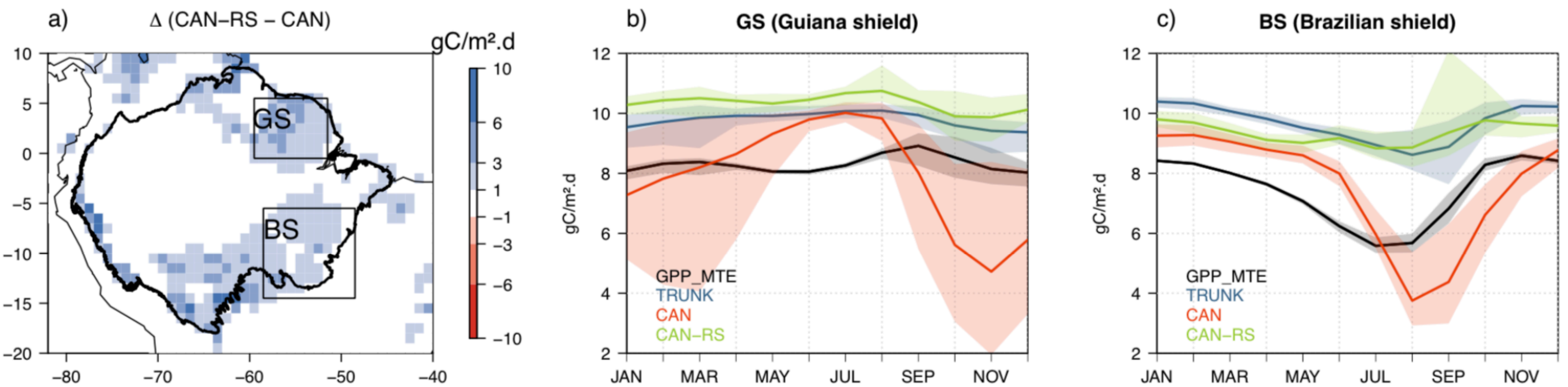
2003 wet season was too dry – not enough soil water recharge

Flexible Roots effect on GPP REGIONAL

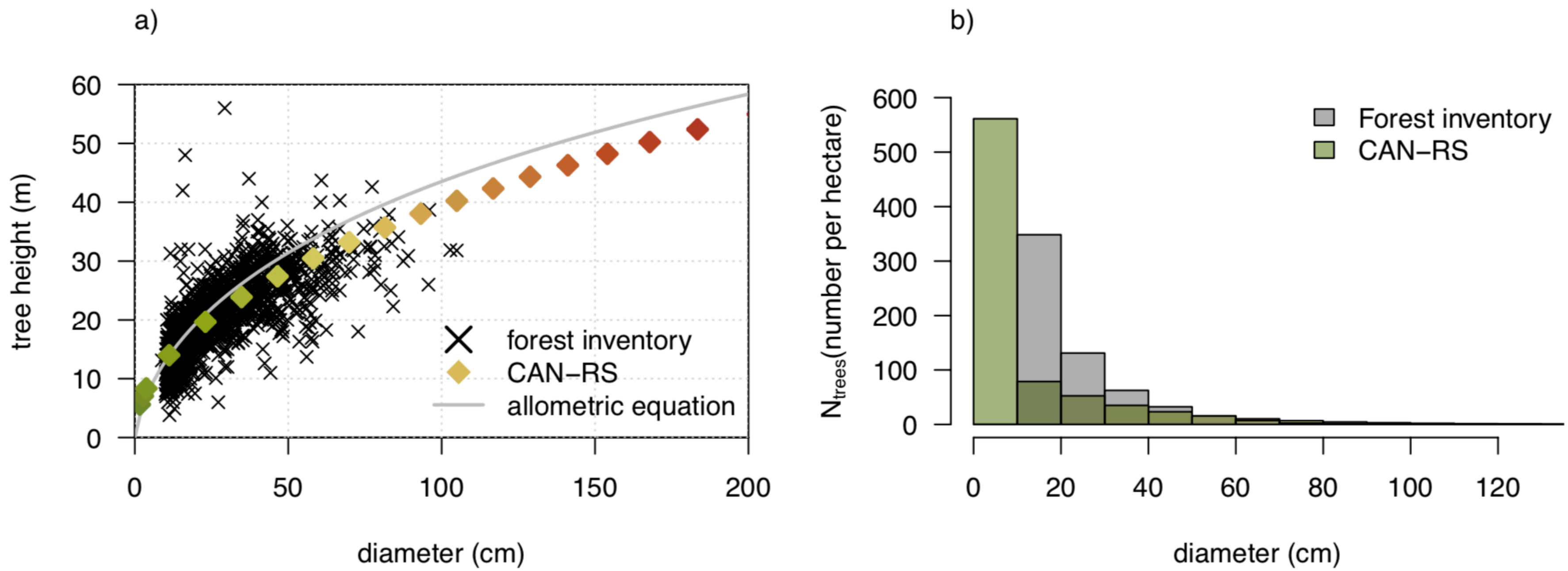


(a) Difference in annual GPP between the simulations of CAN-RS and CAN from 1982 to 2016. (b) Comparison of the three model versions with GPP - FLUXCOM (MTE) over the Guiana Shield (GS) region, and (c) same for the Brazilian Shield (BS) region. The shaded areas represent monthly minimum and maximum values over the entire period of simulation.

Forest structure evaluation

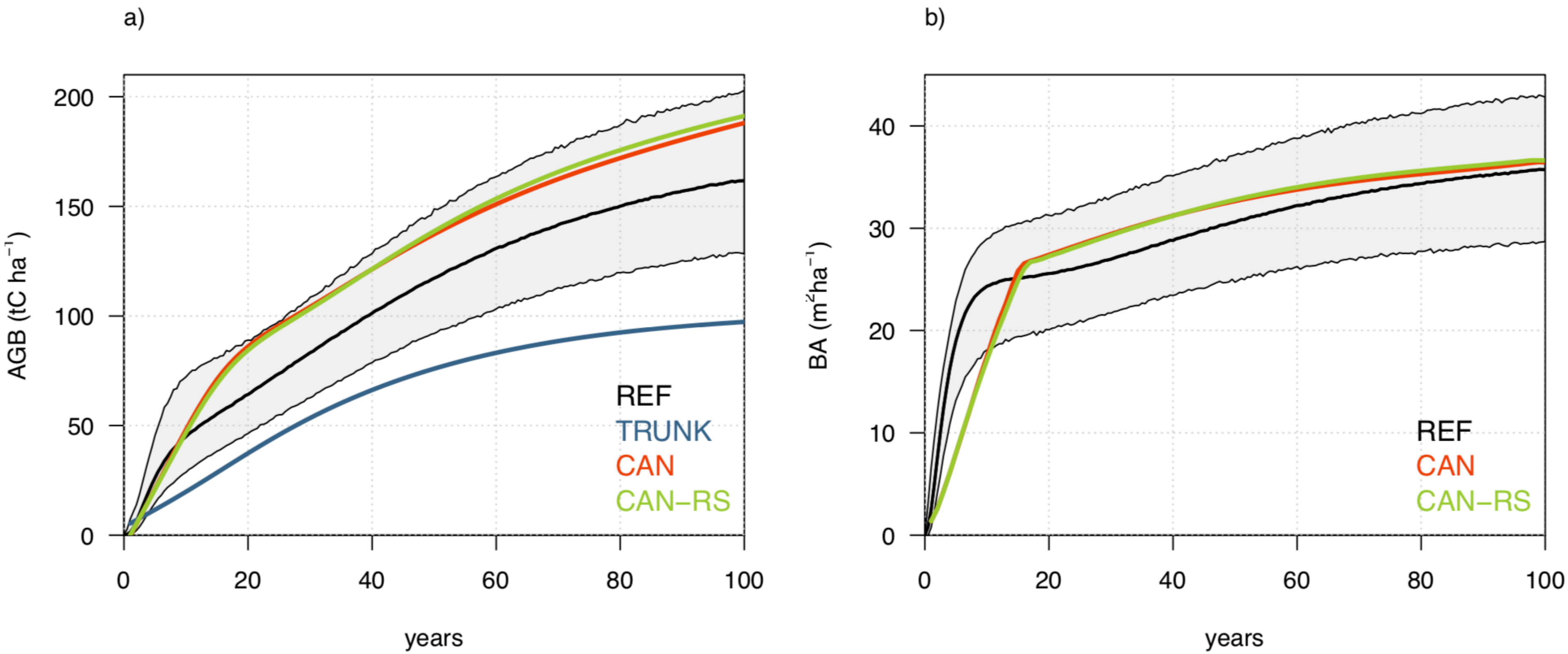
-> recruitment scheme implementation

-> model calibration



Forest structure modelled in CAN-RS compared to forest inventory data at Paracou, with (a) allometric relationship between tree diameter and tree height for the 20 simulated diameter classes in CAN-RS plotted in colours compared to 1592 measurements (b) mean diameter distribution per hectare for CAN-RS compared to data from a forest inventory of 6.25 ha plot in Paracou, French Guiana

Forest establishment



Dynamics of (a) the aboveground biomass (AGB) and (b) basal area simulated by the different versions of ORCHIDEE during the first hundred years after clear-cut, compared to pseudo-data for a forest site (ARBOCEL) that was clear-cut and left regenerating in French Guiana (Chave et al., submitted).

CAN & CAN-RS

⇒ Reasonable forest structure

⇒ Useful for applications (e.g. canopy height data assimilation, Joetzjer et al., 2017) & A.S Lonzo's talk

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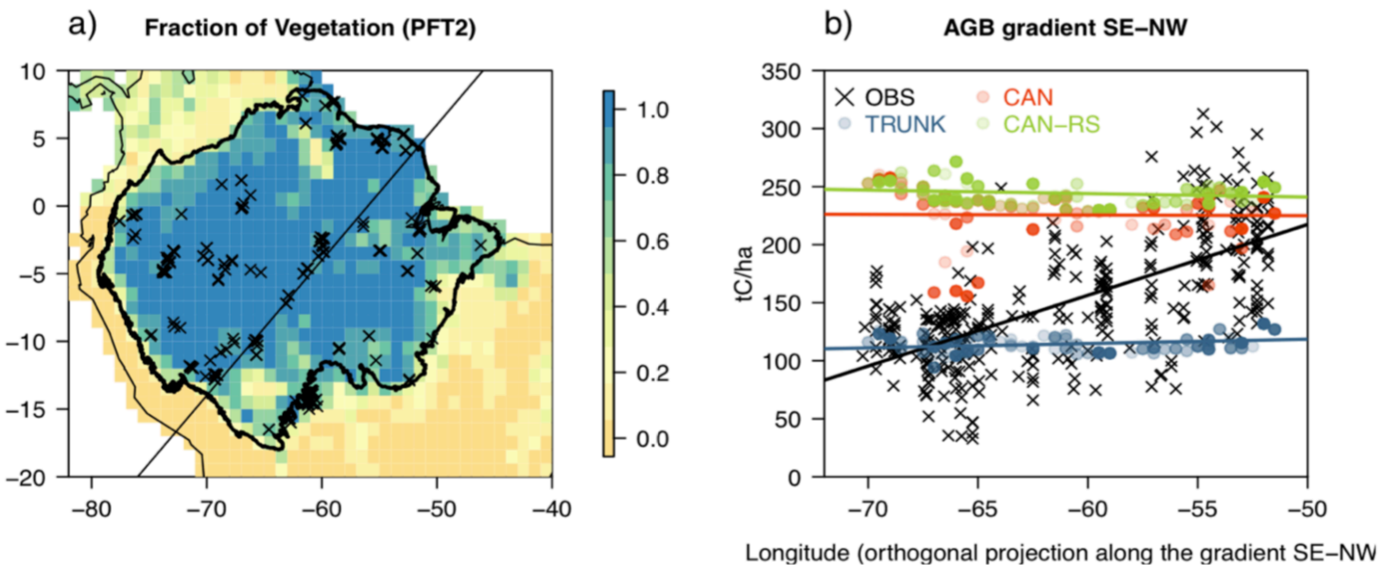

a) Fraction of evergreen tropical forests (PFT2) (b) comparison of simulated and observed aboveground biomass (AGB) (Mitchard 2014)

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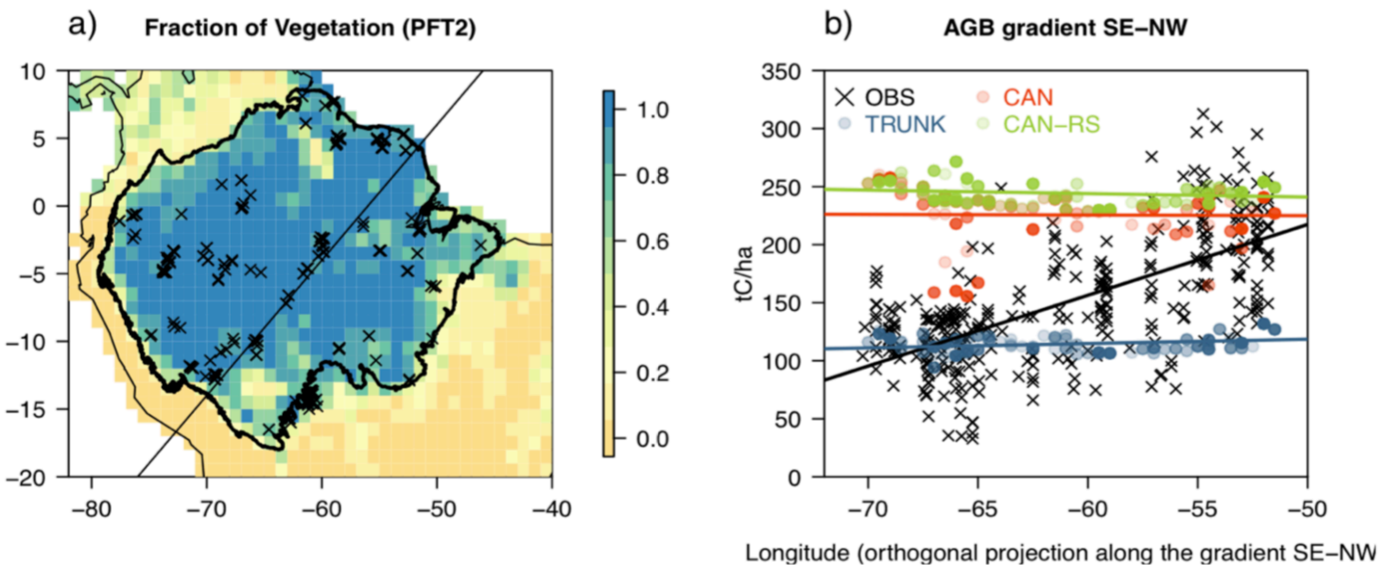

a) Fraction of evergreen tropical forests (PFT2) (b) comparison of simulated and observed aboveground biomass (AGB) (Mitchard 2014)

Demography parameters are set constant for a single PFT describing all evergreen tropical forests

⇒ spatial variability of AGB, mortality and basal area across the Amazon remains rather uniform compared to observations, and are very comparable to the "big-leaf" version (TRUNK).

CAN vs CAN-RS : Water uptake scheme

Water uptake by trees is driven more by water availability rather than biomass density, and this process should be included in DGVMs to correctly capture flux seasonality across the Amazon.

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CAN & CAN-RS vs. TRUNK : tree demography scheme

Demography representation is not sufficient by itself to capture the spatial gradient of AGB within the Amazon (forest dynamic).
Additional processes such as climate driven mortality and nutrient (phosphorus) limitation on growth leading to the prevalence of species with different functional traits across the Amazon need to be included in the future development of CAN-RS.

$$\Psi_{rz} = \sum_{l=1}^{L}\left[\Psi_s(l)\, d_{root}(l)\right] + m_{\psi} \qquad (3)$$

$$\Psi_{rz} = \frac{\sum_1^L \Psi_s(l)\, E_{\max}(l)}{\sum_1^L E_{\max}(l)} \text{ with } E_{max}(l) = [\Psi_s(l) - \Psi_{root,m}] / R_{sr}(l) \qquad (5)$$

$\Psi_{root,m}$ is a parameter set at -3 MPa (Duursma and Medlyn, 2012). The soil-to-root resistance R_{sr} estimates the effective pathlength for water transport from the soil matrix to the root surface (Gardner, 1960), and is computed as follows:

$$R_{sr}(l) = \frac{\ln\left(\frac{r_s(l)}{r_r}\right)}{2\,\pi\, l_r(l)\, G_{soil}(l) \Delta_D(l)} \qquad (6)$$

Here, l_r (m^{-2}) is the root length per unit of soil volume, and is a function of the specific root length (SRL), with SRL set at 10 m g^{-1} (Metcalfe et al., 2008), and of the fine root biomass density per layer ($Biomass_{froots}(l)$, in g m^{-3}): $l_r(l) = Biomass_{froots}(l)\ SRL$; r_s (m) is one-half of the mean distance between roots, computed following (Newman, 1969):

$$r_s = \left(\frac{1}{\pi\, l_r(l)}\right)^{0.5} \qquad (7)$$

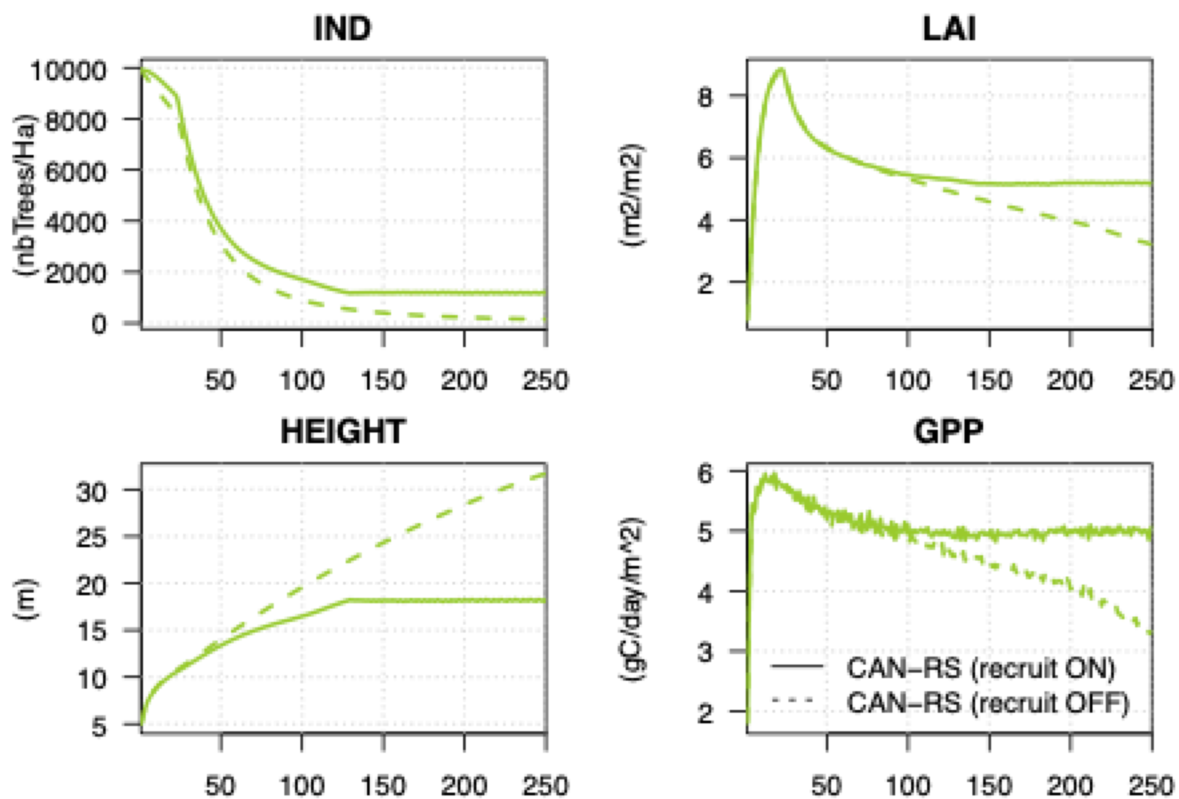

Fig. S1 Annual time series of the number of trees, LAI, quadratic mean height and GPP simulated by CAN-RS with the recruitment scheme activated (solid lines) and deactivated (dashed lines).