Reparameterizing the Richard's equation in CLM 3.0: are deep roots really necessary?

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Brad Christoffersen (presenting)

Standard CLM3.0

Model	Hydrology	Deficiencies
CLM3.0	- *theta-based* (volumetric water content) as opposed to *psi-based* (pressure head) solution to Richard's equation	- Steady state solution NOT maintained for a saturated bottom soil boundary

$$\frac{\partial\theta}{\partial t} = \frac{\partial}{\partial z}\left[K \times \frac{\partial(\psi + z)}{\partial z}\right] + S$$

Net result:
Vertical profile of soil moisture too dry in CLM3.0

Recent Modifications to CLM3.0

Model	Components Modified	Improvements
CLM3.5	-representation of canopy interception -subsurface drainage and groundwater scheme -parameter optimization	-seasonal cycles of runoff -partitioning to evapotranspiration
CLM3.5 modRch	-subsurface drainage scheme -explicit incorporation of steady-state solution into numerical scheme for Richard's equation	-same as above -***plus*** magnitude and vertical characteristics of soil moisture *variability*

Model runs

- CLM3.0 ctrl – standard CLM3.0
- → CLM3.0 DGVM – CLM3.0 with dynamic vegetation
- CLM3.0 modRch – CLM3.0 with reparameterized Richard's equation
- CLM3.5 ctrl – standard CLM3.5
- → CLM3.5 DGVM – CLM3.5 with dynamic vegetation

Model runs

Effects of soil moisture

- CLM3.0 ctrl:
- CLM3.0 modRch:

Effects of dynamic vegetation

- CLM3.5 ctrl: improved representation of canopy interception and ground water storage
- CLM3.5 DGVM:

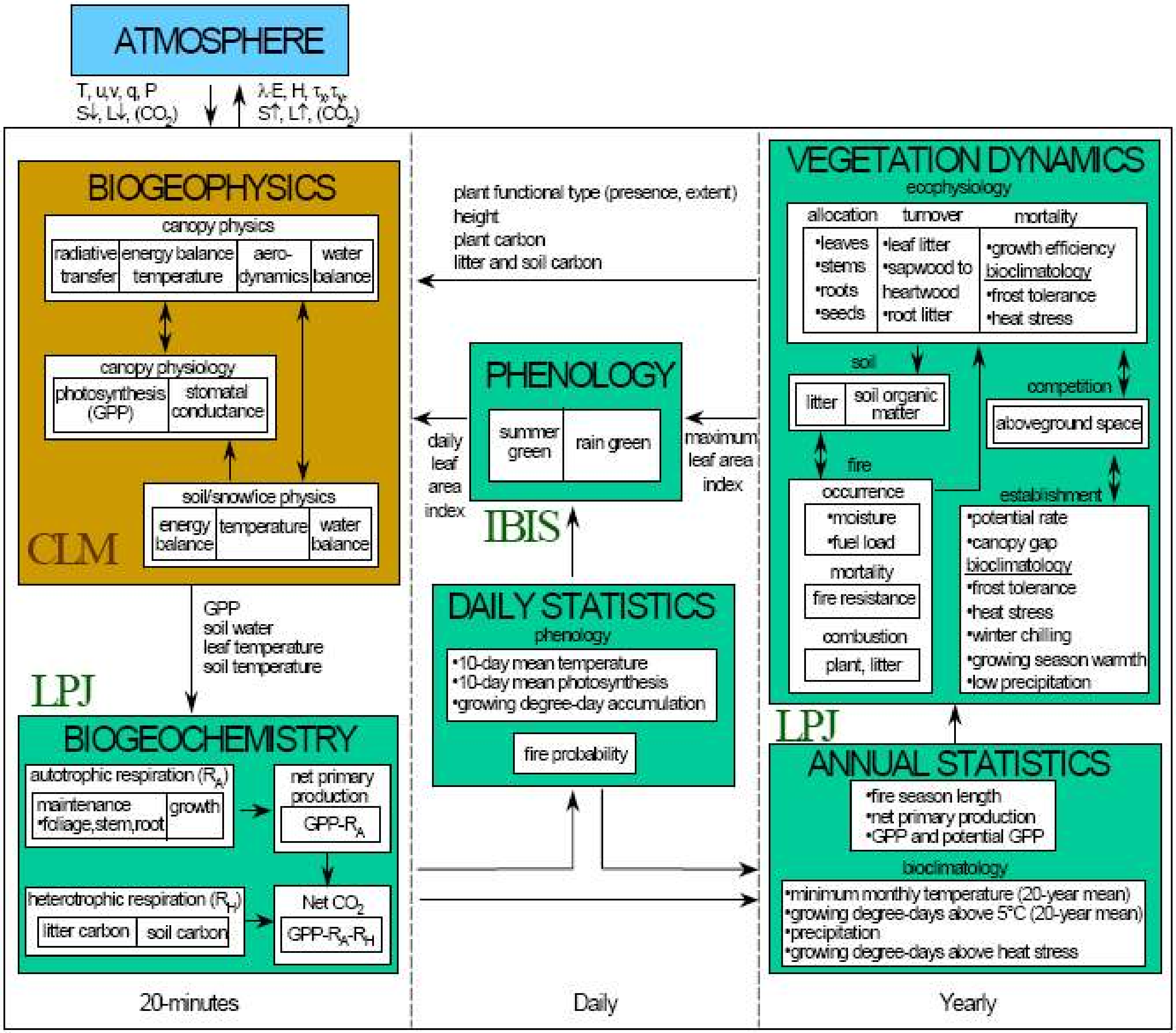
Modified numerical scheme: Richard's equation

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left[K \times \frac{\partial(\psi + z)}{\partial z} \right] + S$$

Revised Richard’s Equation

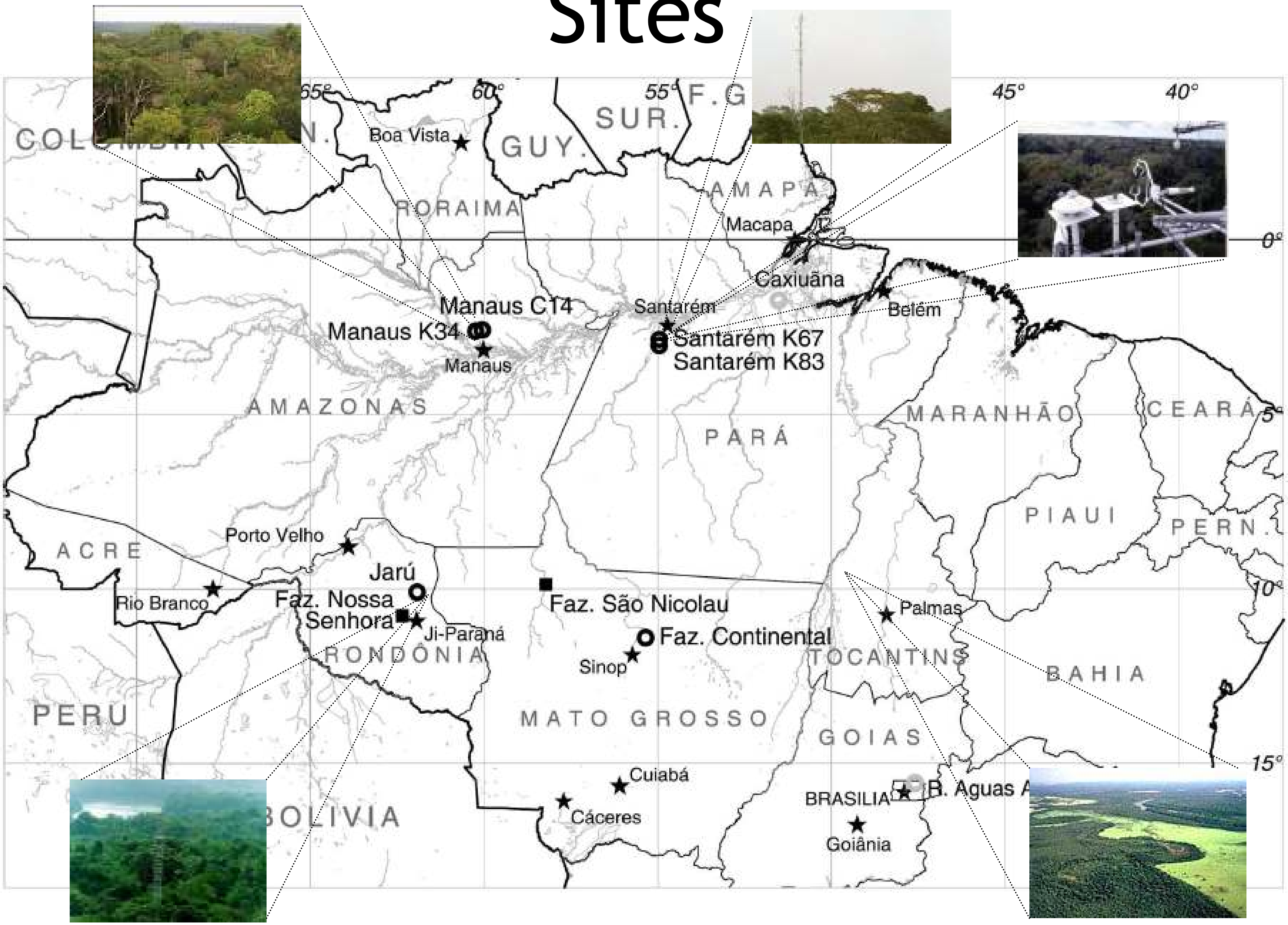
- In CLM3.0: primary cause of overly dry soil conditions
- By introducing a simple modification in the numerical scheme solution of the Richard's theta-based equation for soil moisture, many of the improvements effected by CLM3.5 are reproduced.
- Here I will show some examples of the changes induced by a new Richard's equation numerical scheme and show how these results are highly similar to CLM3.5.

DGVM



Levis et al. 2004

Sites



65°
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F.G.
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Macapa
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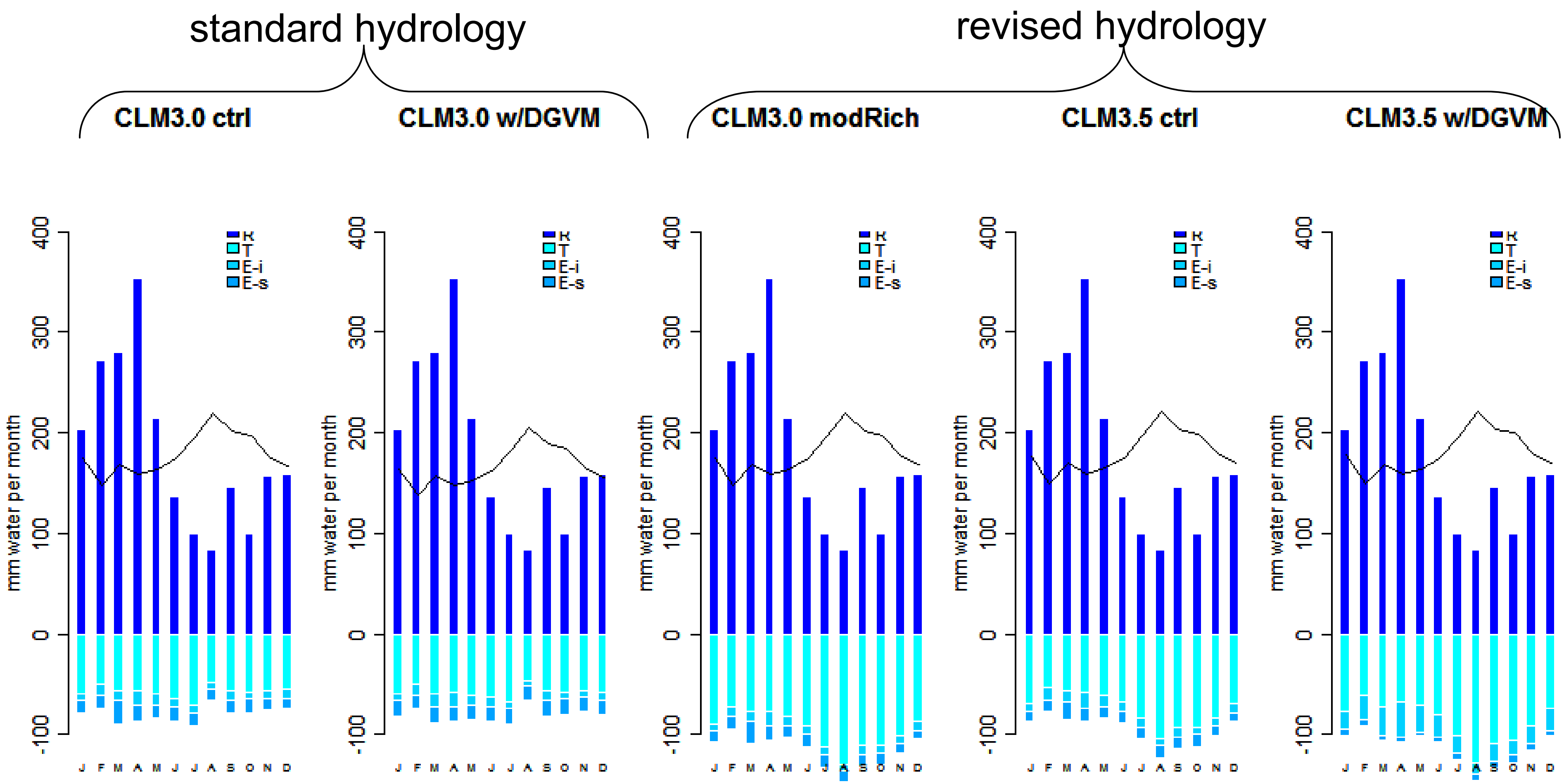
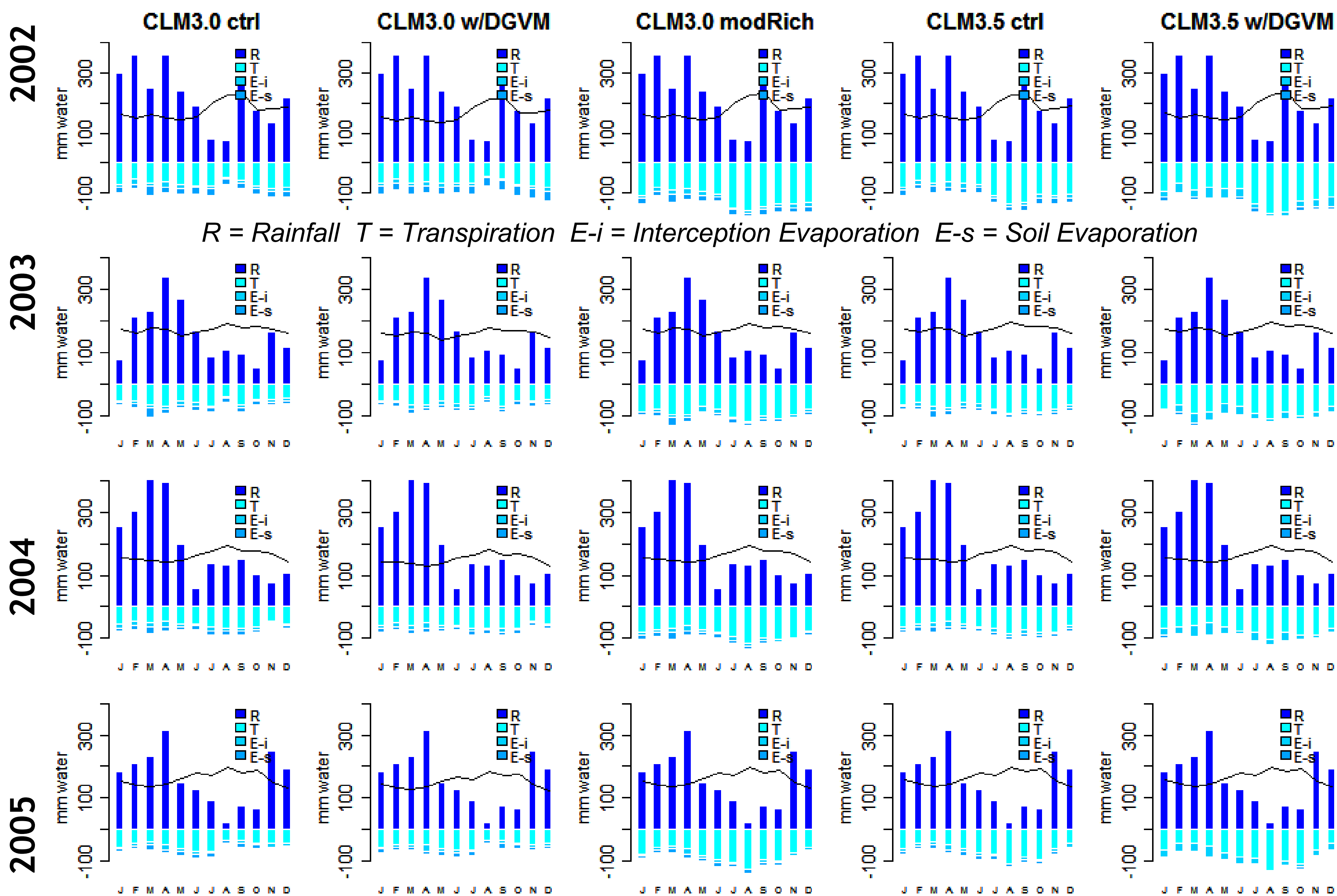
Belém
Santarém
Manaus C14
Manaus K34
Manaus
Santarém K67
Santarém K83
AMAZONAS
PARÁ
MARANHÃO
CEARÁ
PIAUI
PERN.
ACRE
Porto Velho
Rio Branco
Jarú
Faz. Nossa Senhora
Ji-Paraná
RONDÔNIA
Faz. São Nicolau
Faz. Continental
Sinop
Palmas
TOCANTINS
BAHIA
PERU
MATO GROSSO
GOIAS
BOLIVIA
Cuiabá
Cáceres
BRASILIA
B. Aguas A
Goiânia

CLM Simulated Water Balance – Manaus K34

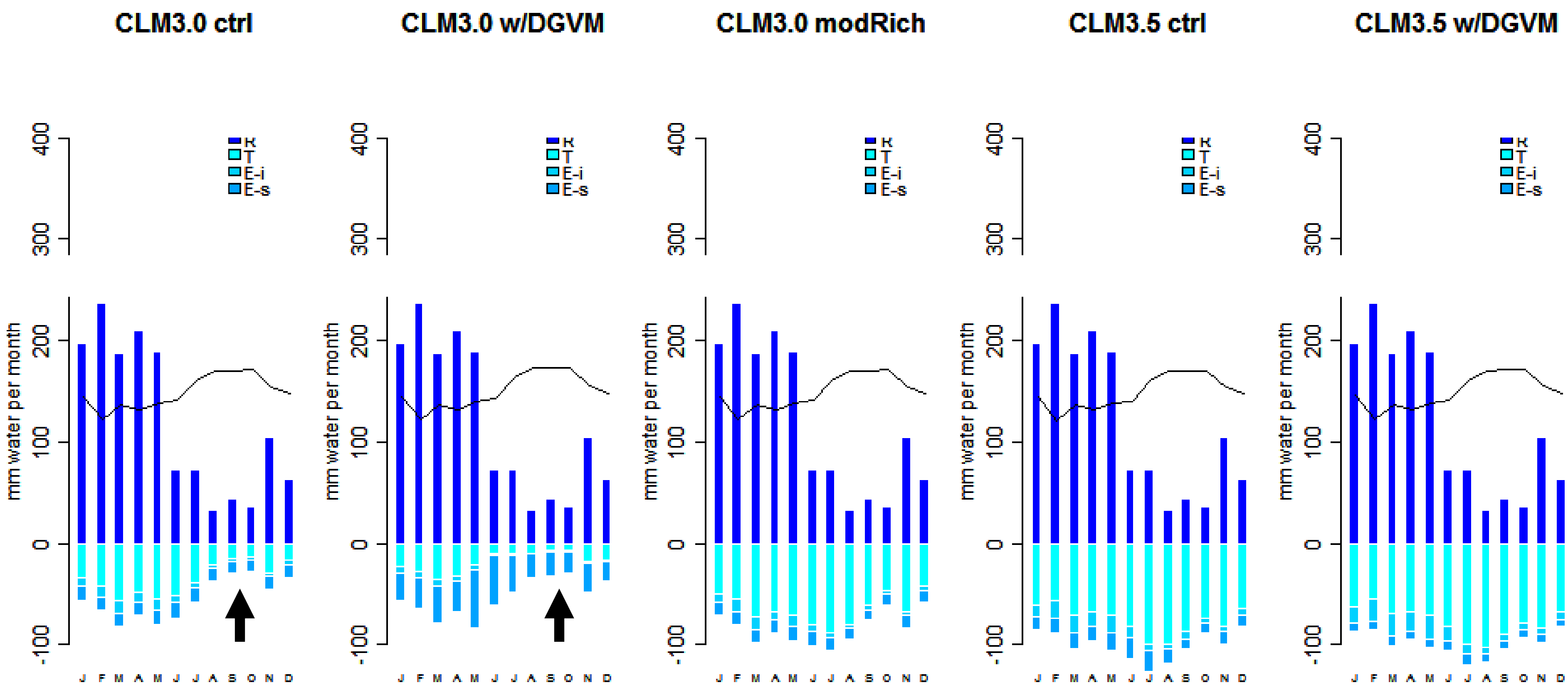


R = Rainfall T = Transpiration E-i = Interception Evaporation E-s = Soil Evaporation

CLM Simulated Water Balance – Manaus K34



CLM Simulated Water Balance – Tapajós K67



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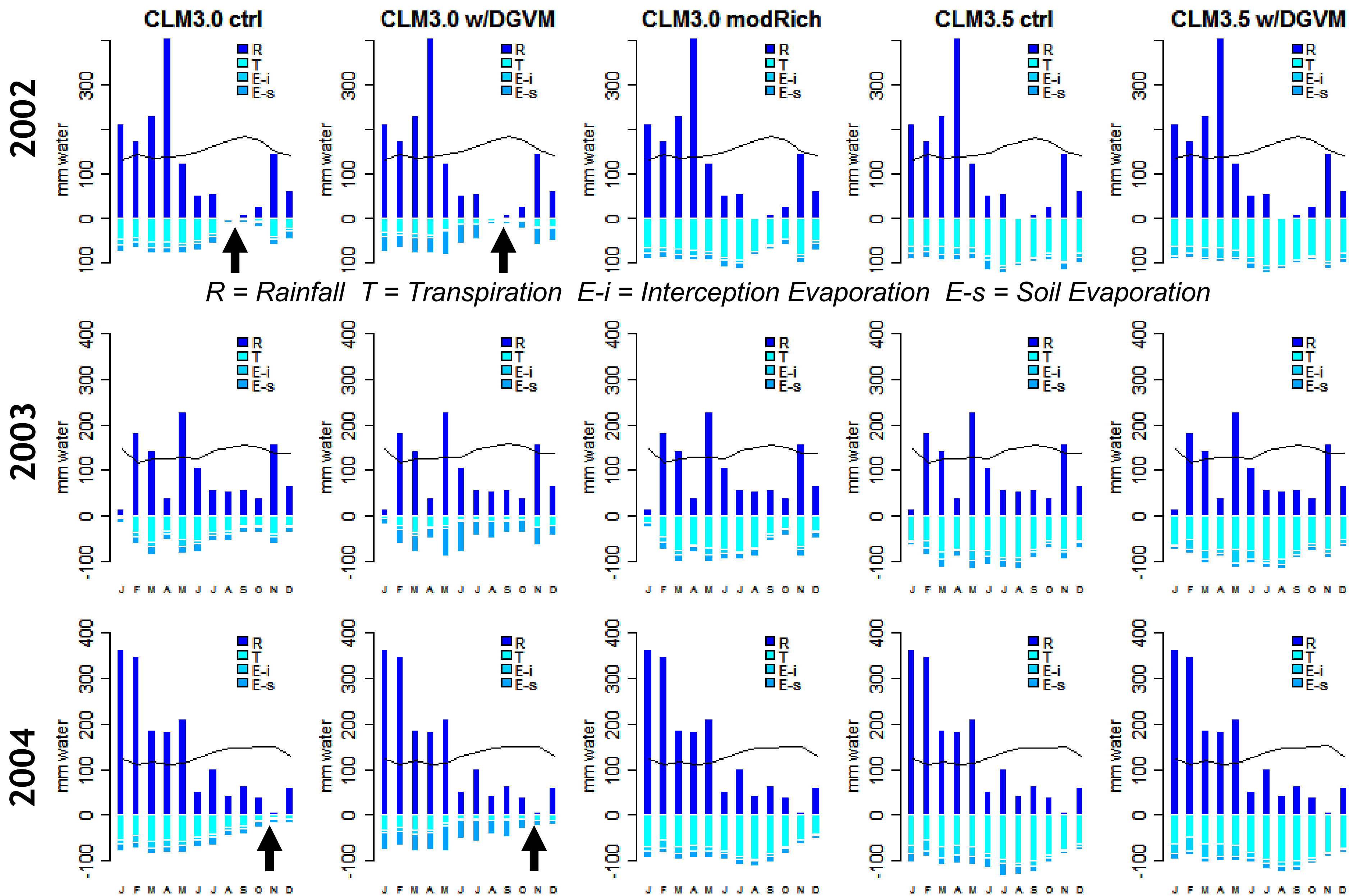

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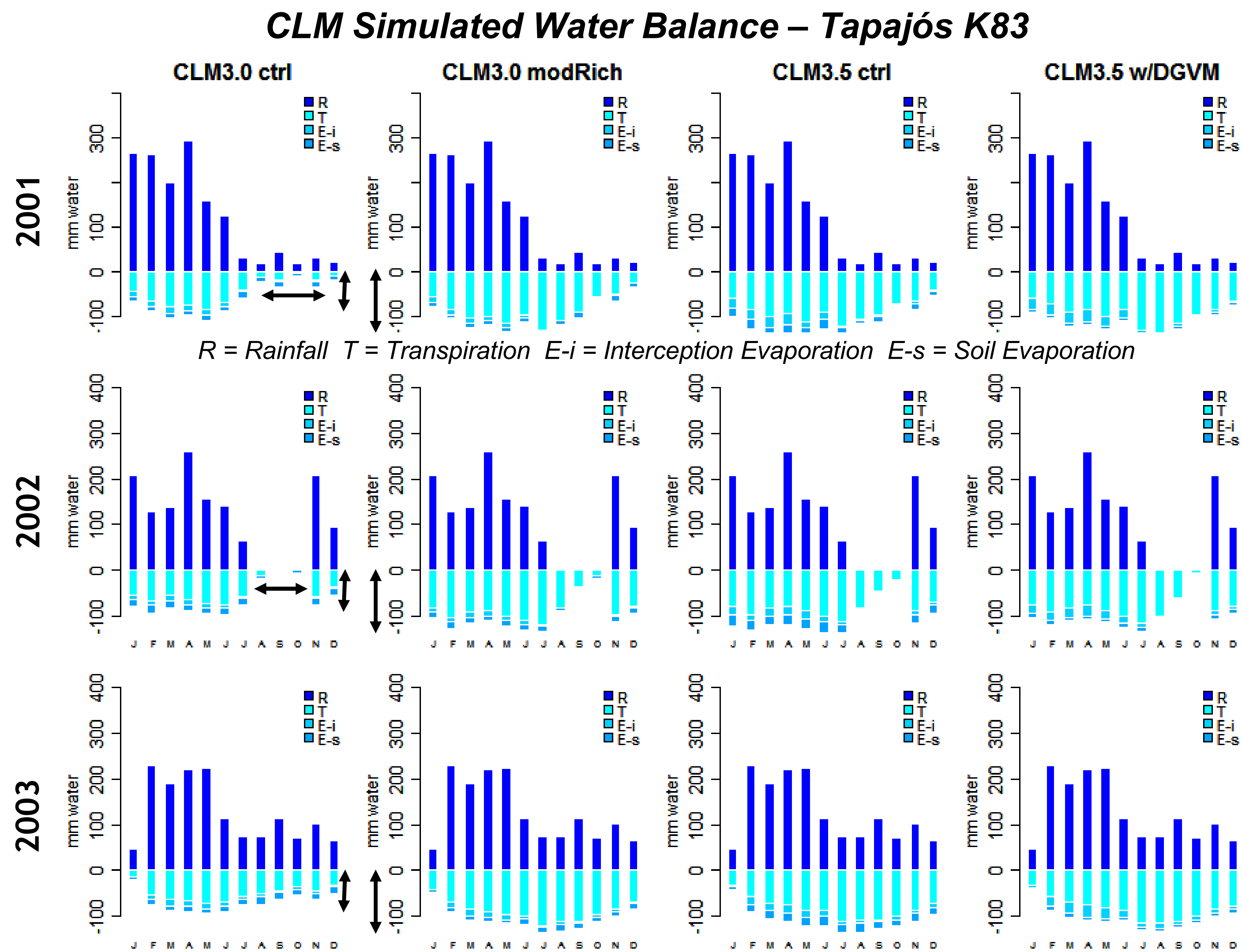
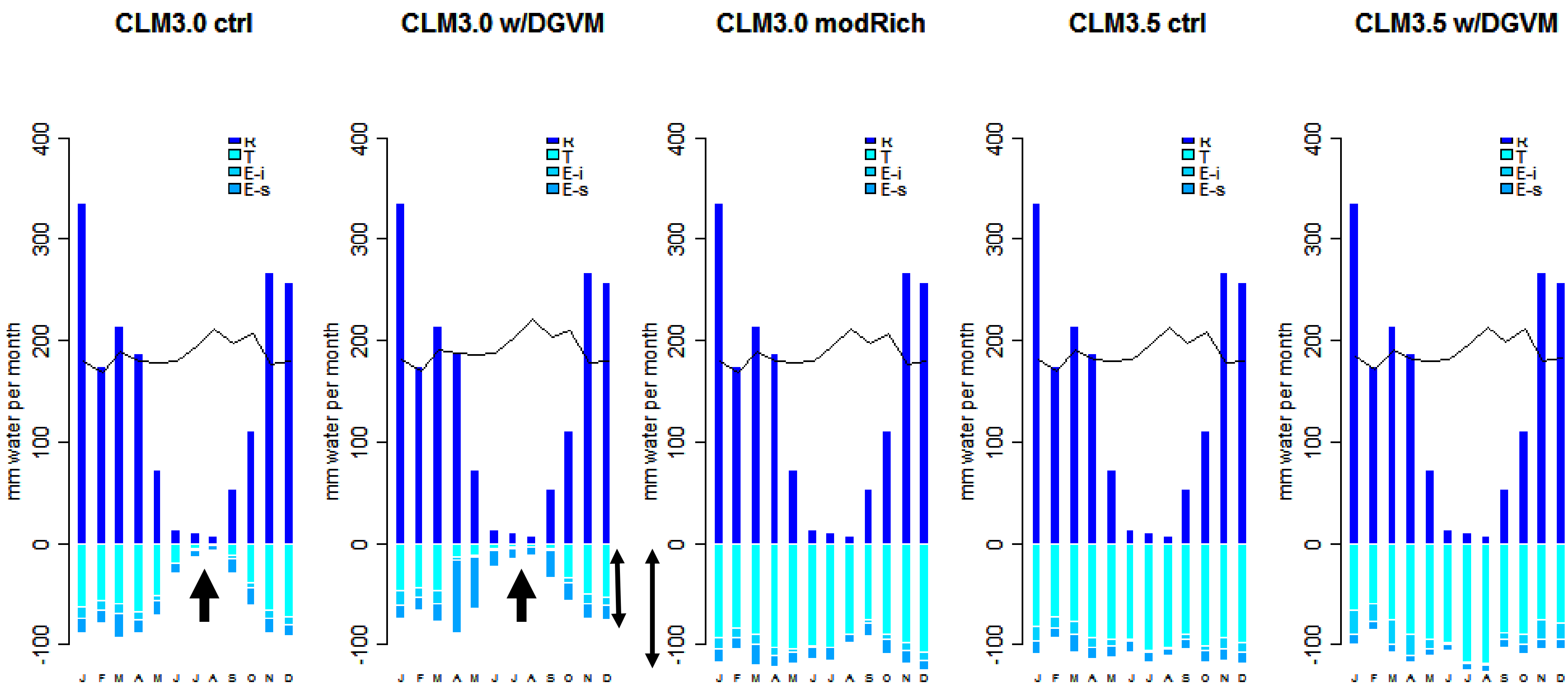

CLM Simulated Water Balance – Tapajós K83
CLM3.0 ctrl
CLM3.0 modRich
CLM3.5 ctrl
CLM3.5 w/DGVM
2001
2002
2003
mm water
R
T
E-i
E-s
R = Rainfall T = Transpiration E-i = Interception Evaporation E-s = Soil Evaporation
J F M A M J J A S O N D

CLM Simulated Water Balance – Reserva Jarú



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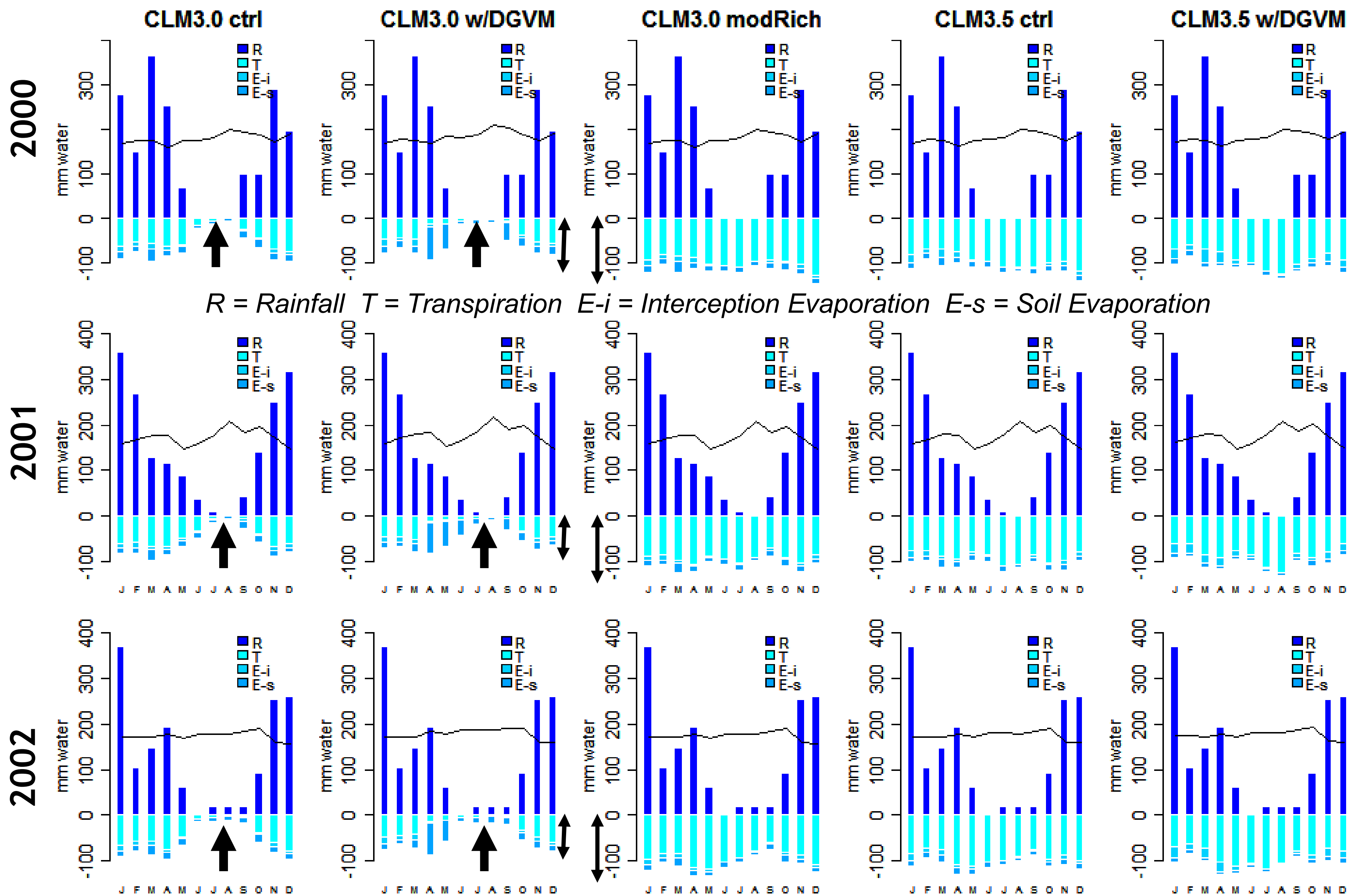
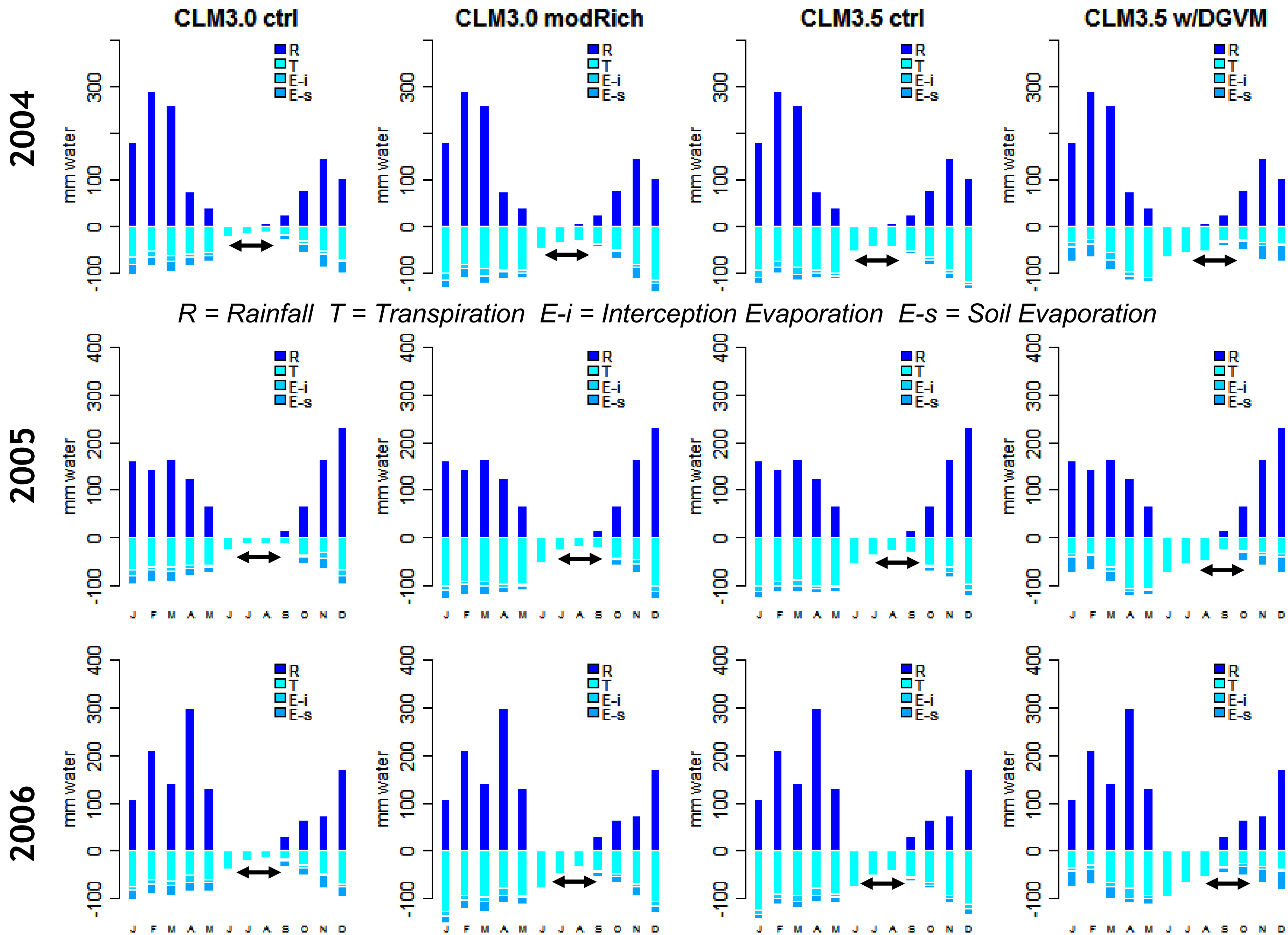
CLM Simulated Water Balance – Reserva Jarú



CLM Simulated Water Balance – Bananal



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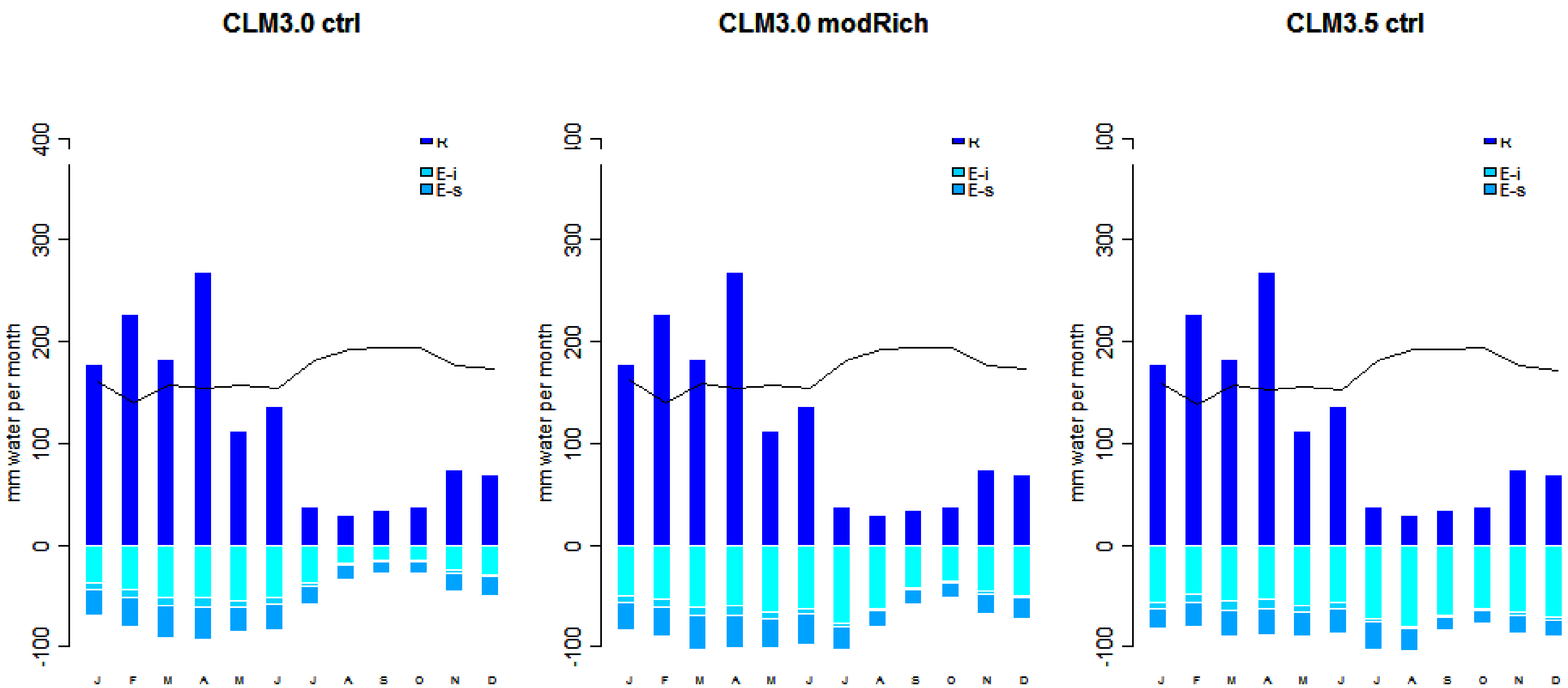
CLM Simulated Water Balance – Tapajos K77



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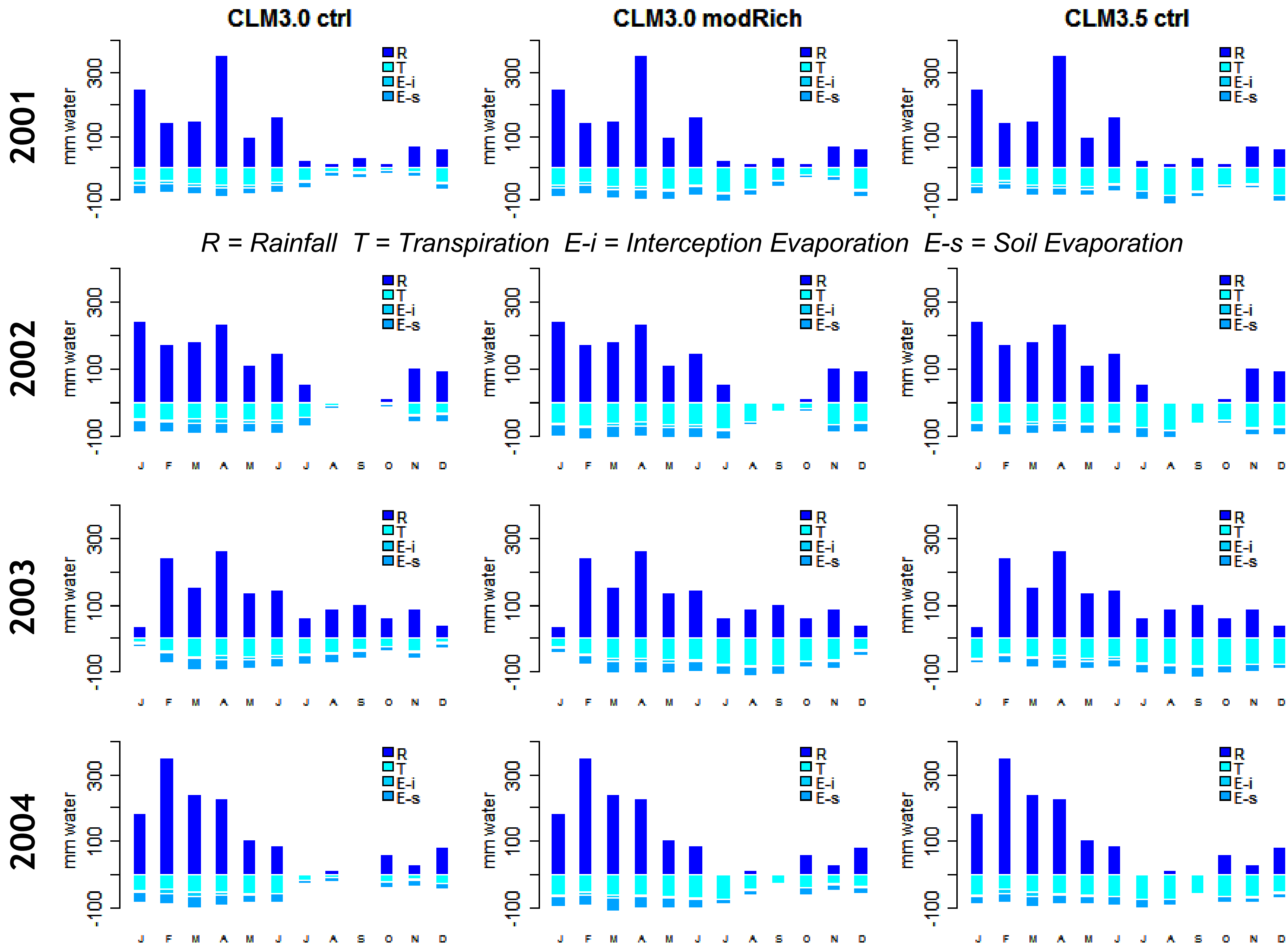
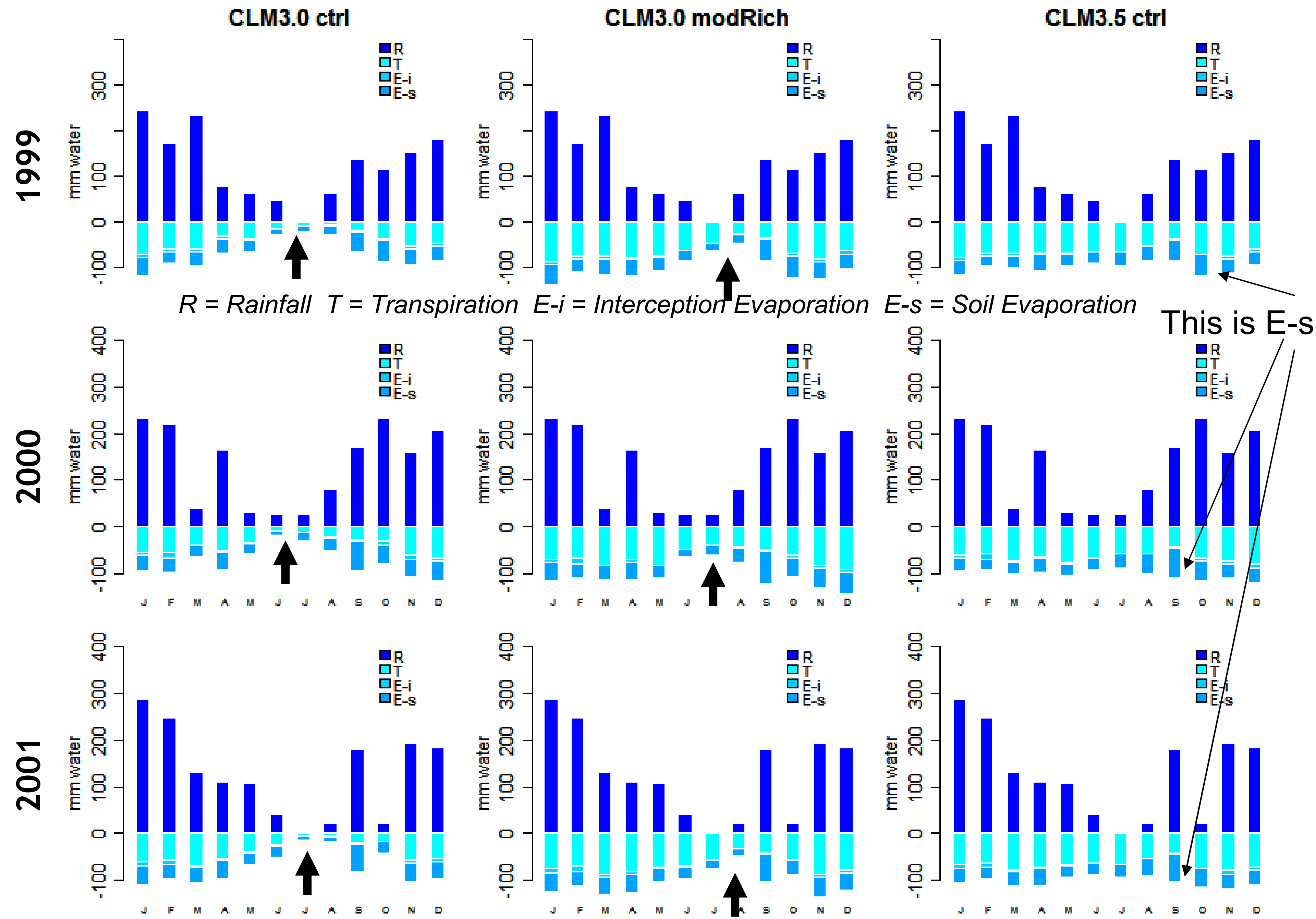
CLM Simulated Water Balance – Tapajos K77



CLM Simulated Water Balance – Fazenda Nossa Senhora

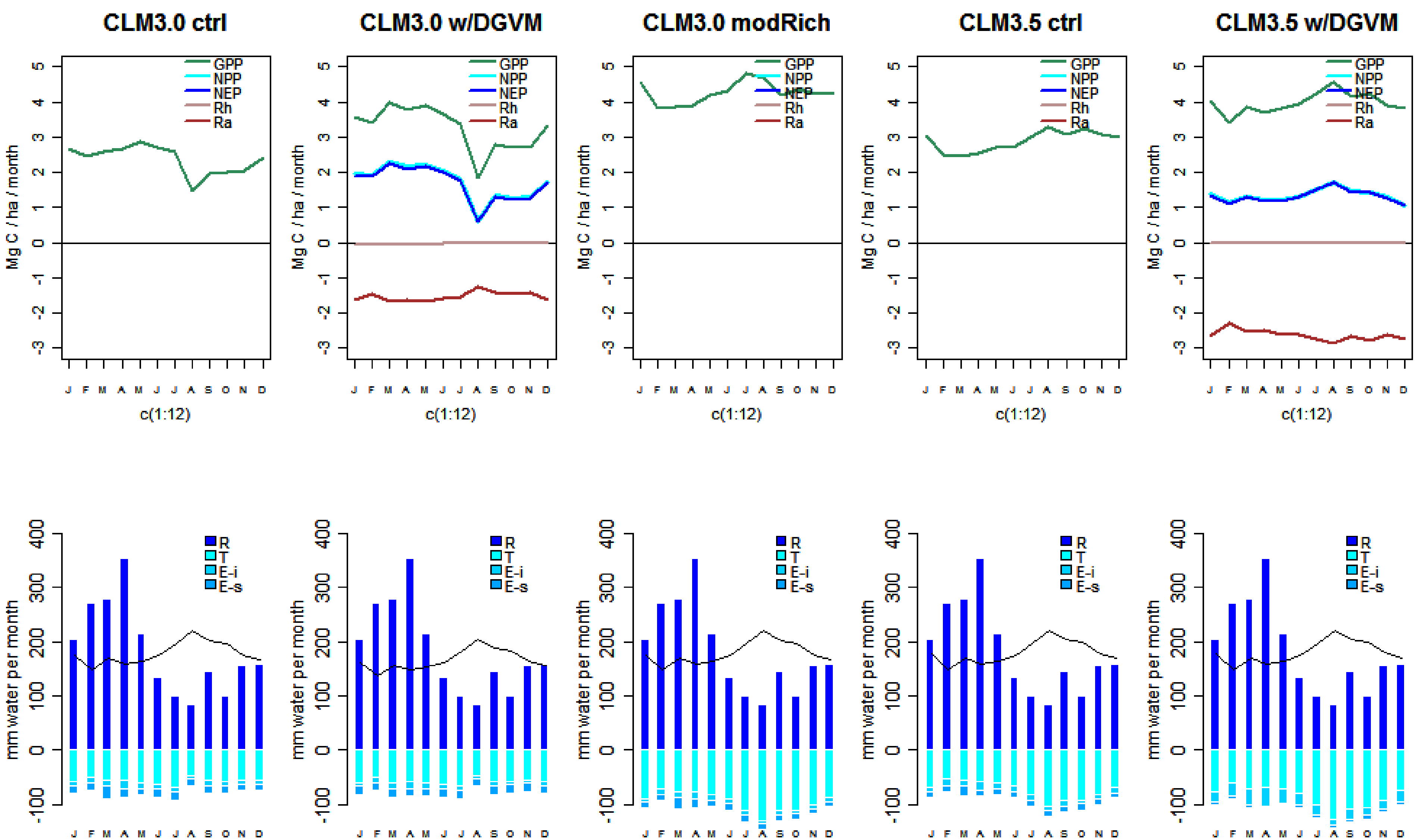


Water Balance given by CLM

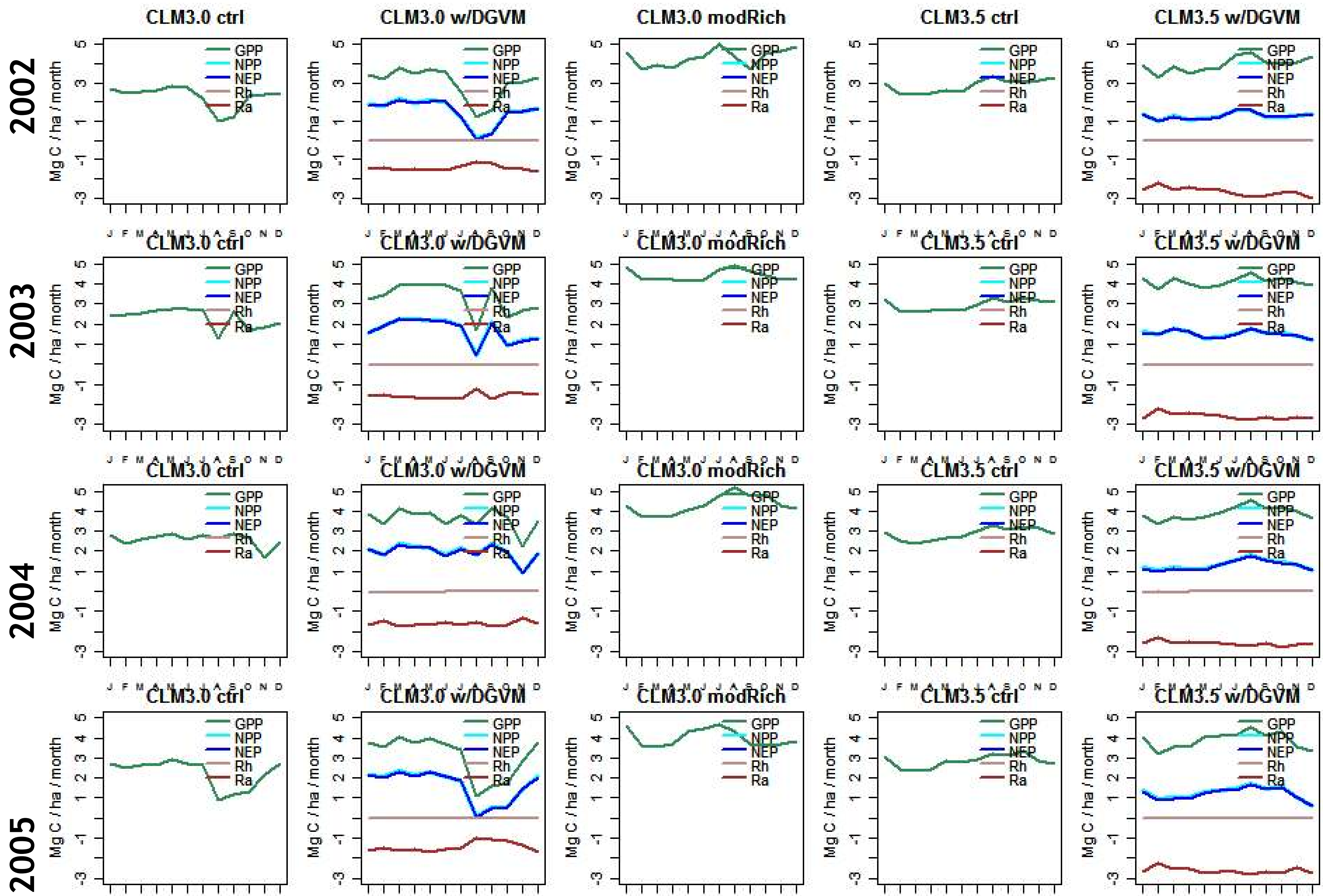
- Reparameterization of Richard's equation and complex tunings of CLM3.5 produce highly similar results

- Notable effects on ET by CLM3.5 revisions & Richards eqn. revised numerical scheme:
  - Transpiration increased via wetter soil
    - Reduction in amplitude of seasonal cycle
  - Elimination of dry season physiological shut-down (*see more w/ C fluxes*)
  - Peak is 2-4 months later for sites of moderate to intermediate seasonality (Manaus, Tapajós)
  - ET – Rnet correlation seems much stronger for sites w/ decreasing seasonality and increasing MAP (Manaus)

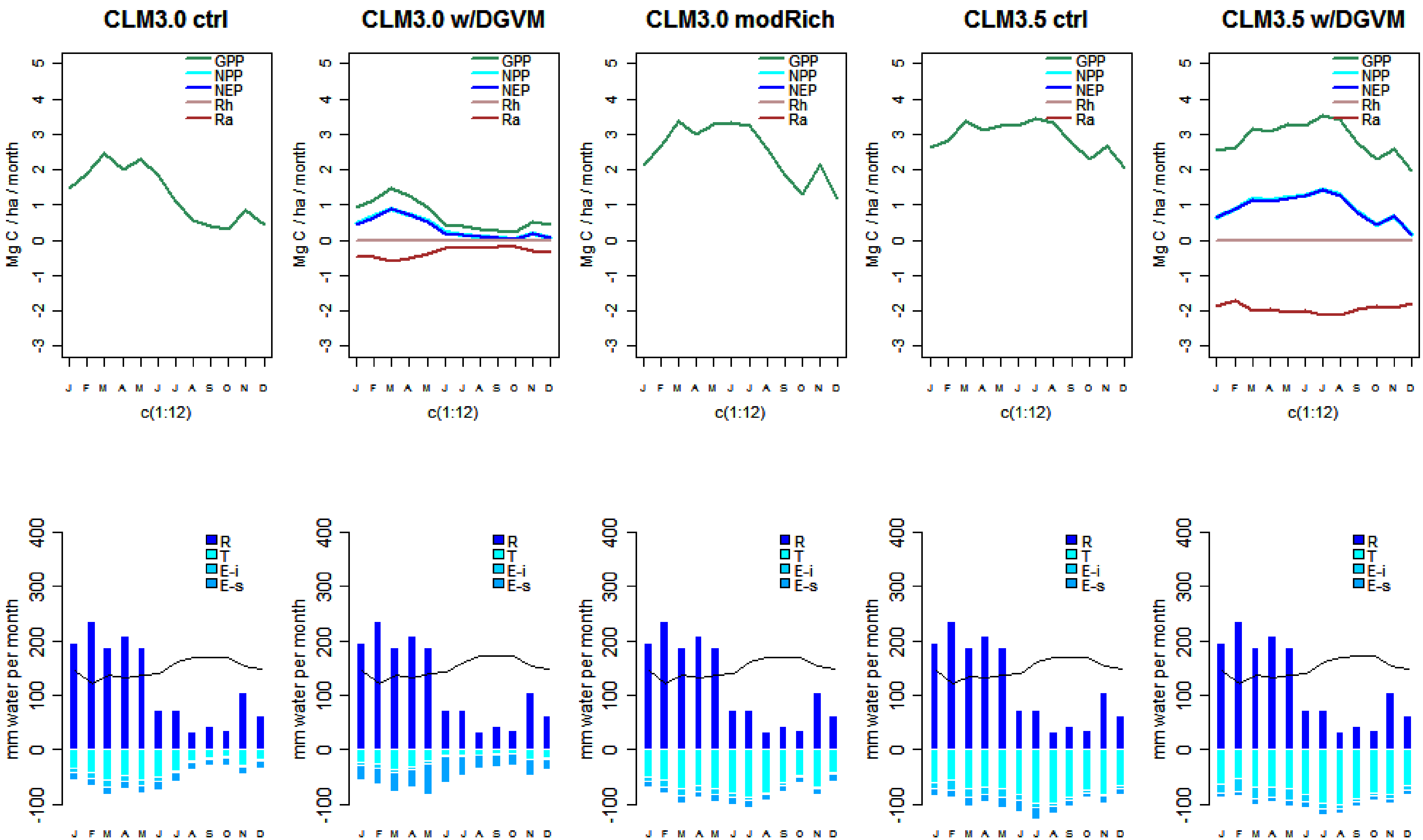
CLM Avg. Carbon Fluxes – Manaus K34



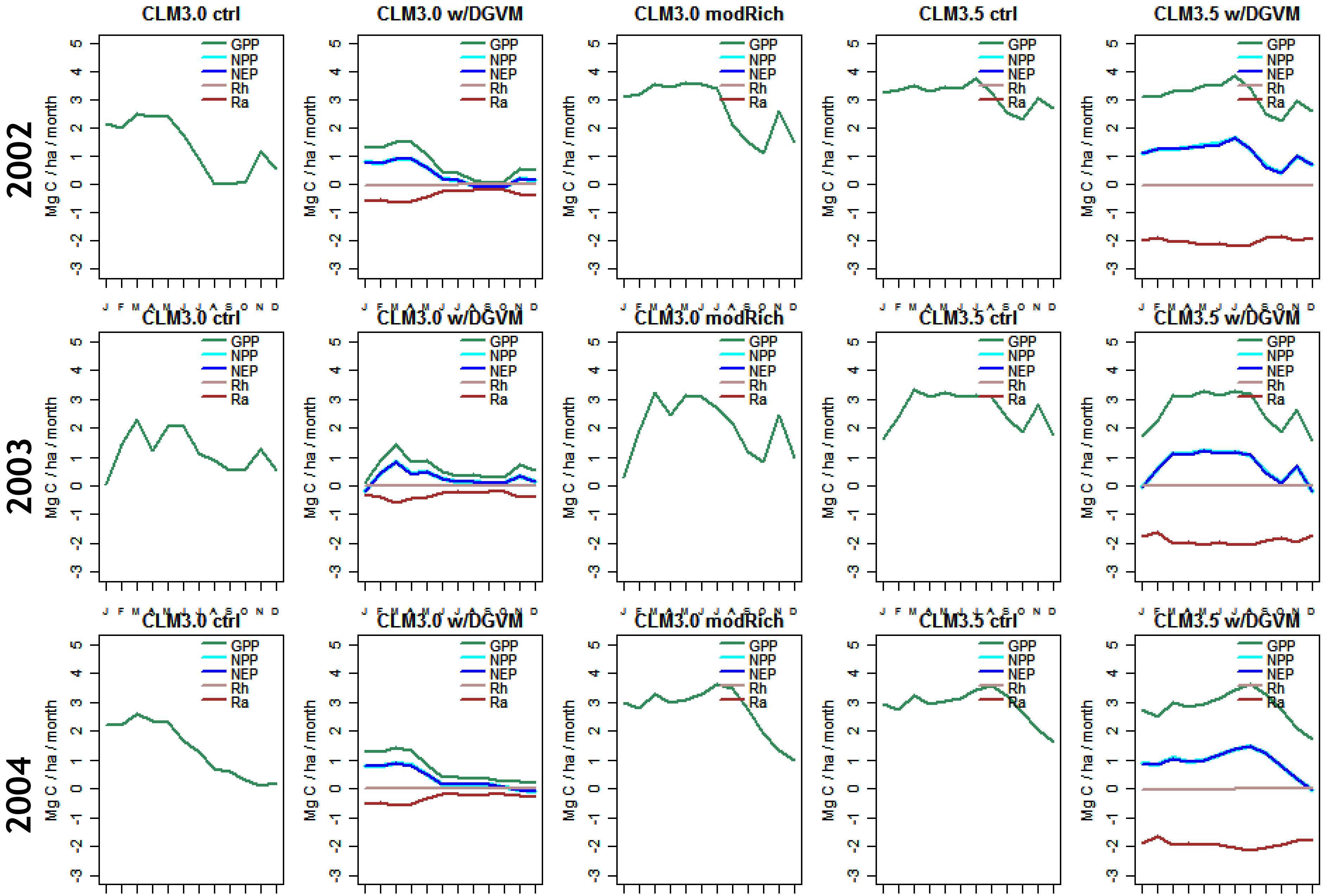
CLM Simulated Carbon Fluxes – Manaus K34



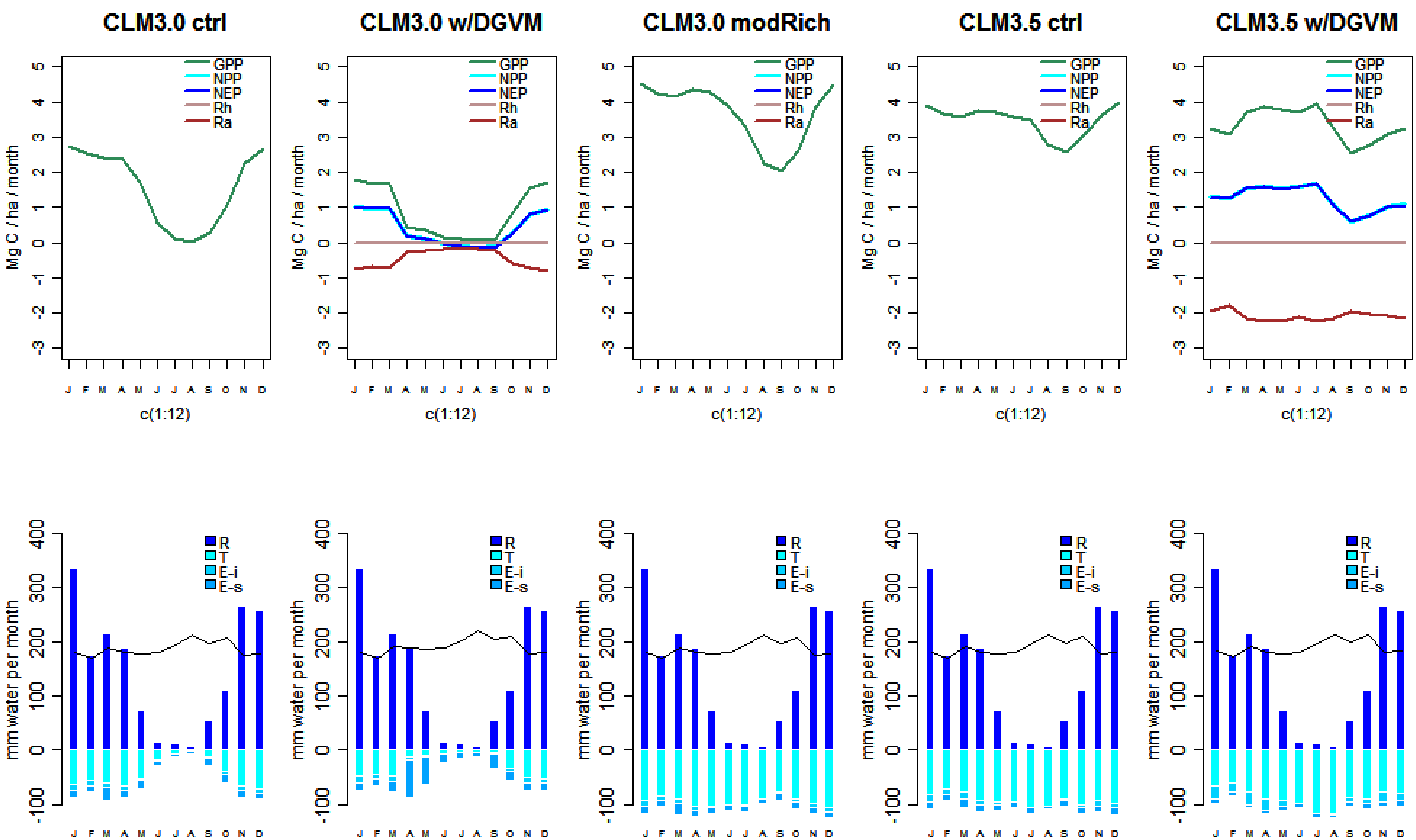
CLM Avg. Carbon Fluxes – Tapajós K67



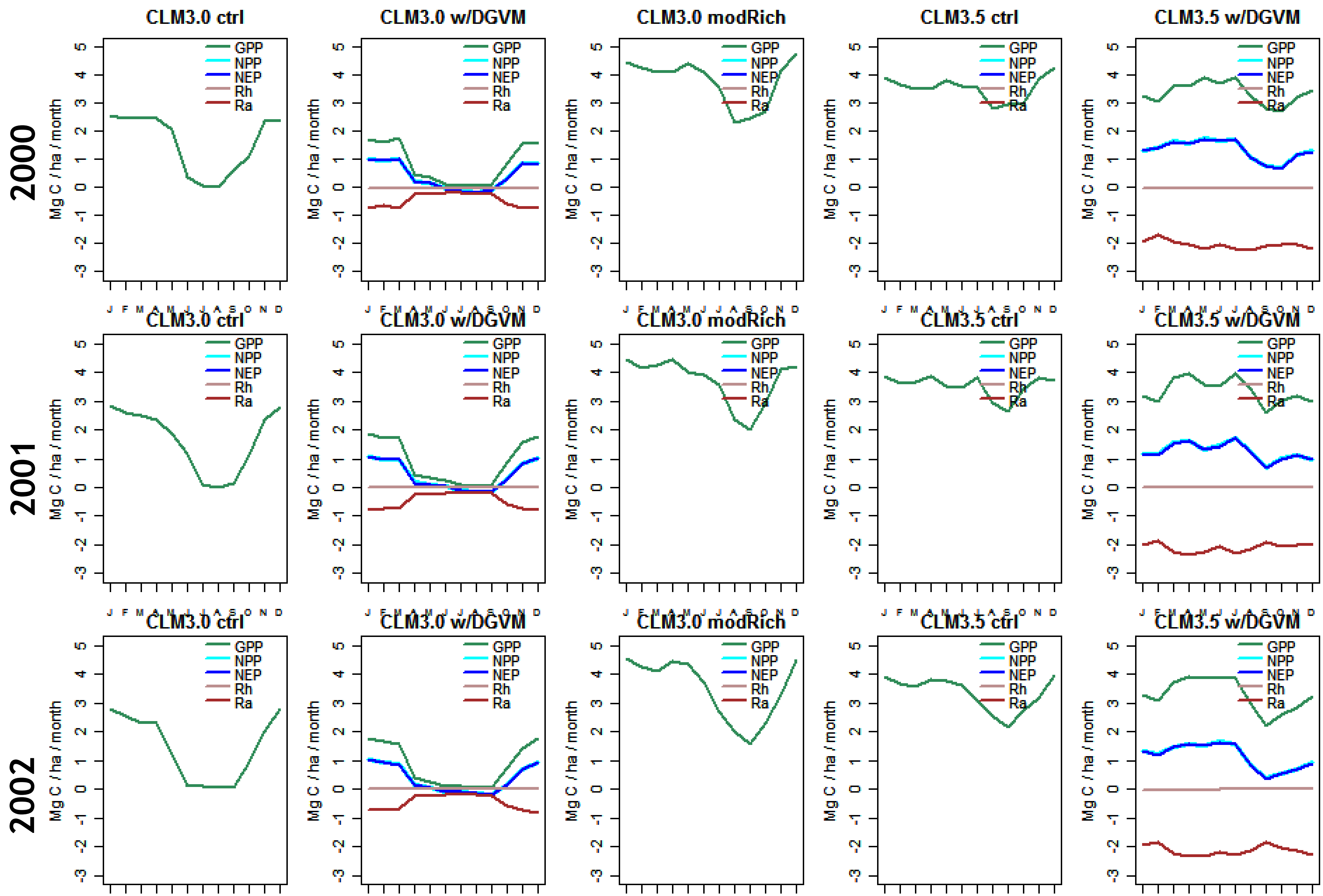
CLM Simulated Carbon Fluxes – Tapajós K67



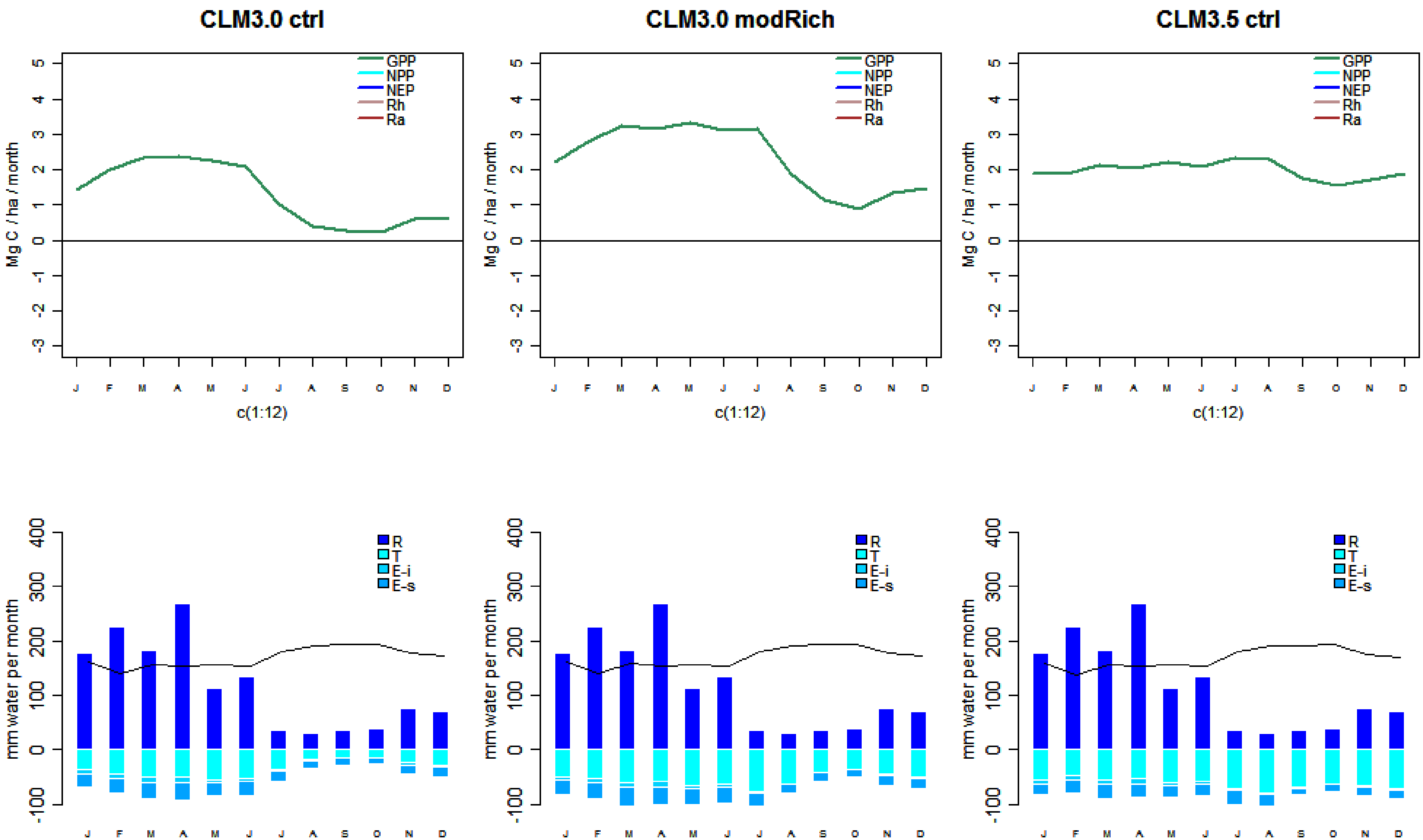
CLM Avg. Carbon Fluxes – Reserva Jarú



CLM Simulated Carbon Fluxes – Reserva Jarú

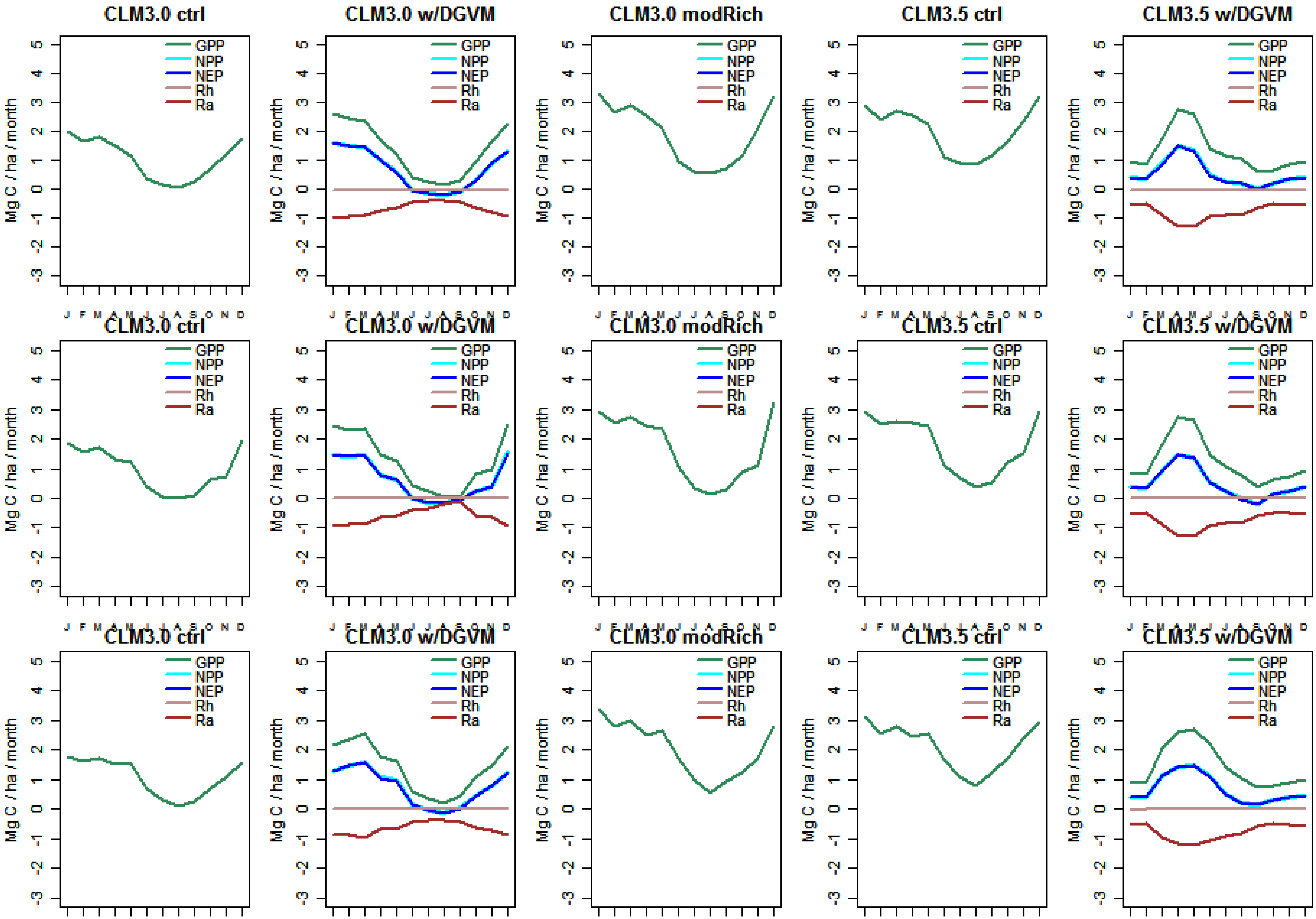


CLM Avg. Carbon Fluxes – K77

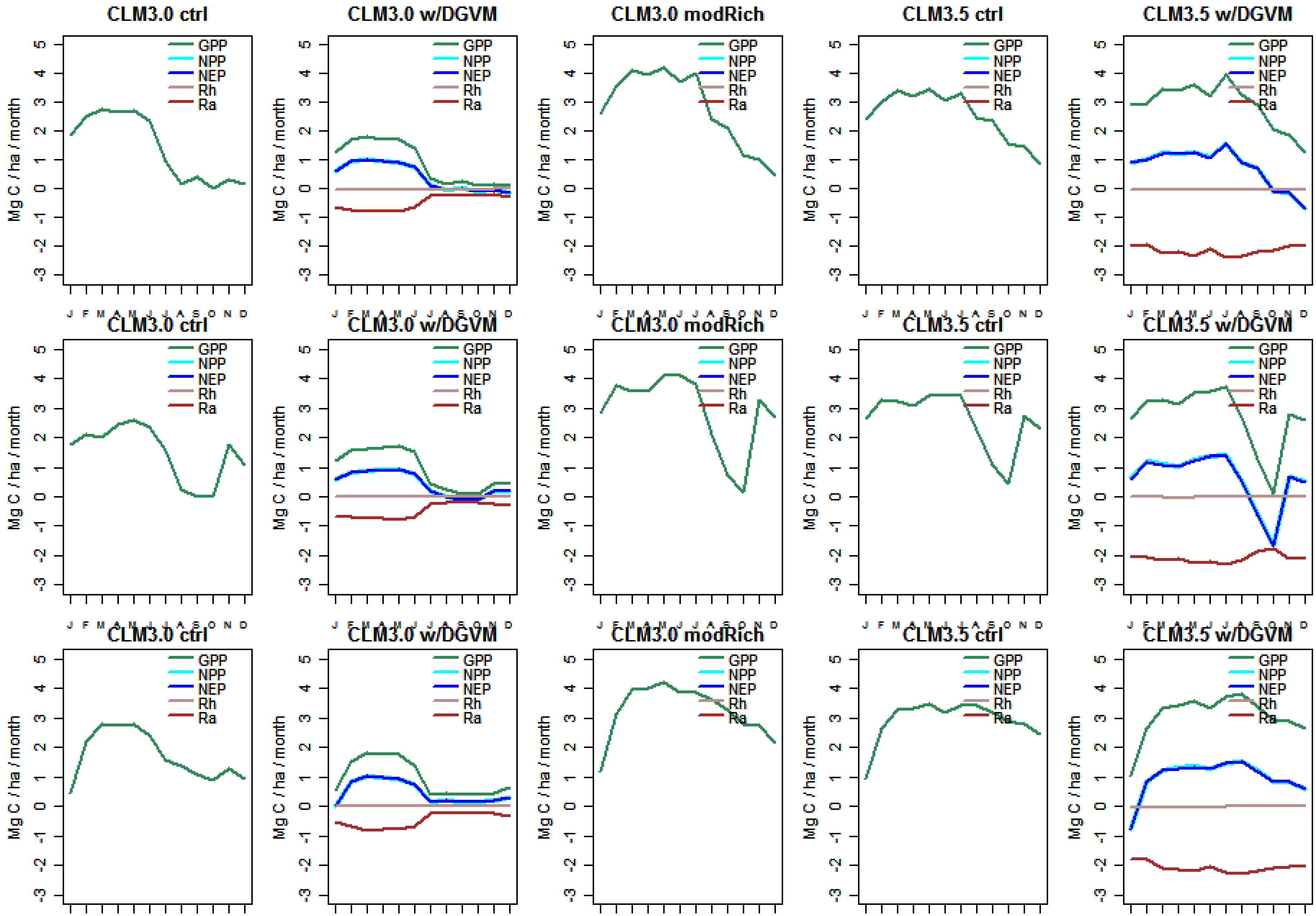


Conclusions: Carbon Fluxes given by CLM

- Reparameterization of Richard’s equation and complex tunings of CLM3.5 produce highly similar results
- Seasonality of NEE follows precipitation cycle and is driven by seasonality in GPP.
- Heterotrophic respiration still poorly represented.



CLM3.0 ctrl
CLM3.0 w/DGVM
CLM3.0 modRich
CLM3.5 ctrl
CLM3.5 w/DGVM
GPP
NPP
NEP
Rh
Ra
Mg C / ha / month
J F M A M J J A S O N D


CLM3.0 ctrl
CLM3.0 w/DGVM
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GPP
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