Data-Model Intercomparison of ET Fluxes Across Amazonia: Hydrological Mechanisms

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Specific Questions

• What are the **seasonal** drivers of evapotranspiration (ET)?

• Belowground mechanisms: How does **soil moisture storage capacity** and **representation of roots** influence model performance?
Drivers of ET Seasonality
ET Seasonality: K67 (Observations)

(seasonal moist tropical forest)

Observations

Net radiation (w/m²)

LE W/m²

R²: 0.86
ET Seasonality: K67 (Observations)

*(seasonal moist tropical forest)*

**Observations**

- Precipitation (mm/month)
- Net radiation (mm/month water equivalent)
- ET (mm/month)
- Soil moisture (normalized to maximum)

Red: Dry season ET
Blue: Wet season ET
ET Seasonality: K67 (Observations)
(seasonal moist tropical forest)

- ET peaks in the dry season
- Deep drying & root water uptake
- Available energy explains 86% of variation in ET
ET Seasonality: K67 (Intercomparison)

(seasonal moist tropical forest)

Observations

IBIS

CLM3.0

CLM3.5

Noah

Net Radiation (W/m²)

LE W/m²

R²

0.86

0.35

0.02

0.76

0.84
ET Seasonality: K67 (Intercomparison) (seasonal moist tropical forest)

Encouraging: Some models capture ET seasonal pattern
→ Release of moisture stress; available energy controls ET
→ Is aquifer in CLM3.5 justified?

Observations

IBIS
8m deep roots

CLM3.0
Deficient hydrology

CLM3.5
Improved hydrology

Noah
No vertical Root distribution

LE W/m²

Net Radiation (W/m²)
ET seasonality: RJA (observations)
(seasonal transitional tropical forest)

ET constant throughout dry season

Soil moisture (Hodnett & Gash; ABRACOS Experiment)
→ Shallow soil but seasonal water table influence

Available energy explains 87% of variation in ET
ET seasonality: RJA (intercomparison)

(seasonal transitional tropical forest)

 Observations

IBIS 8m deep roots
CLM3.0 Deficient hydrology
CLM3.5 Improved hydrology
Noah No vertical Root distribution

→ Aquifer in CLM3.5 is more justified
→ Release of moisture stress may “overfix” ET (overestimate)

LE W/m²

Net Radiation (W/m²)
ET seasonality: PDG (observations)

(cerrado / savanna)

ET trough in the dry season

Soil moisture observations N/A

Available energy explains only 34% of variation in ET
ET seasonality: PDG (intercomparison)  
(cerrado / savanna)

Observations

IBIS  
4m deep roots

CLM3.0  
Deficient hydrology

CLM3.5  
Improved hydrology

Noah  
No vertical Root distribution

→ ET seasonal pattern well captured by most models
→ Some models still overestimate (soil too wet?)

Net Radiation (W/m2)

LE W/m2

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<th>R²</th>
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Soil moisture storage capacity and net radiation control of ET

Seasonal Amplitude in Soil Moisture (mm)

R² of ET – Net radiation relationship

K67
- Noah Obs
- CLM3.5
- IBIS

K83
- Noah Obs
- CLM3.5
- IBIS

PDG
- CLM3.5
- IBIS
- Noah

RJA
- Noah CLM3.5
- IBIS

Obs
Ongoing & future work

Partitioning the biological from the physical: roles of root water uptake functions in explaining flux differences
Differences in soil moisture across models with standardized hydrology

**UPPER BOUNDARY CONDITION (INFILTRATION)**

- **JULES**
  - Darcy's Law

- **ED2**
  - Darcy's Law

- **IBIS**
  - Green-Ampt

- **CLM**
  - Darcy's Law

**BOTTOM BOUNDARY CONDITION**

- Free drainage
  - 0.33
  - 0.39
  - 0.45
Subsurface aquifer in CLM generates very wet soils and is unrealistic.

CLM-DGVM Default
Aboveground Biomass

Simulated: 210 MgC/ha
Observed: 148 MgC/ha

Obs ET moist forest site

Soil moisture (m3/m3)

depth (m)

water flux (mm/month)

Fluxes:
- Surface runoff
- Subsurface drainage
- Soil Evaporation
- Interception Evaporation
- Transpiration
- Sum of Fluxes + Change in storage (soil moisture, canopy interception, surface water)
Subsurface aquifer in CLM generates very wet soils and is unrealistic...as are shallow soils!

CLM-DGVM Default
Aboveground Biomass

Simulated: 210 MgC/ha
Observed: 148 MgC/ha

CLM-DGVM Free Drainage (no aquifer)
Aboveground Biomass

Simulated: 30 MgC/ha
Observed: 148 MgC/ha
Removal / modification of unrealistic model components

• **Observed** characteristics of clay-rich Amazonian soils:
  – Highly weathered & deep (FAO 2008)
  – High infiltration rates and low surface runoff (Nepstad et al., 2002) (high surface root densities?)
  – Deep water tables on remnant plateaus (Nepstad et al., 2002)

• **Modifications**
  – Model a deep soil column (increase from 3.5 to 8 m)
  – Create small (10mm max) prognostic surface water store to allow higher infiltration rates during pulse rainfall events
  – Reinstate free drainage bottom boundary condition:

\[ q_{bot} = k = f(ksat, \theta_{bot}) \quad (mm/s) \]
Proposed mechanism of drought tolerance

• Default case: Root density-dependent water uptake
  \[ r_{e,i} = \frac{\sum_{j=1}^{npft} (r_{e,i})_j (E_{v})_j (wt)_j}{\sum_{j=1}^{npft} (E'_{v})_j (wt)_j} \]
  Zeng et al., 2001, Jackson et al., 1996

• Alternative hypothesis: Relaxation of rooting density-dependent water uptake
  – Suggested by other models (Baker et al., 2008; Moorcroft et al., 2001)

• Neither hypothesis has been definitively rejected
Free Drainage
Deep soil (8m)

Aboveground biomass:
Simulated: 90 MgC/ha
Observed: 148 MgC/ha

Soil moisture (m3/m3)

Obs ET
moist forest site
Increased infiltration, rooting depth uptake

Aboveground biomass:
Simulated: 200 MgC/ha
Observed: 148 MgC/ha

Fluxes:
- Surface runoff
- Subsurface drainage
- Soil Evaporation
- Interception Evaporation
- Transpiration
- Sum of Fluxes + Change in storage (soil moisture, canopy interception, surface water)
Root water uptake estimates for model validation
(Markowitz et al., 2010)
Summary & Conclusions

• Here, I explored: mechanisms leading to deficiencies, mechanisms necessary for good performance
  – Deep roots: provides a fix in the right direction, but points to need to further develop uptake functions
  – Aquifers: provides a needed moisture reserve, but recharge fluxes are questionable
  – Seasonal soil moisture dynamics: capturing observed variability important for “atmospheric control” on ET