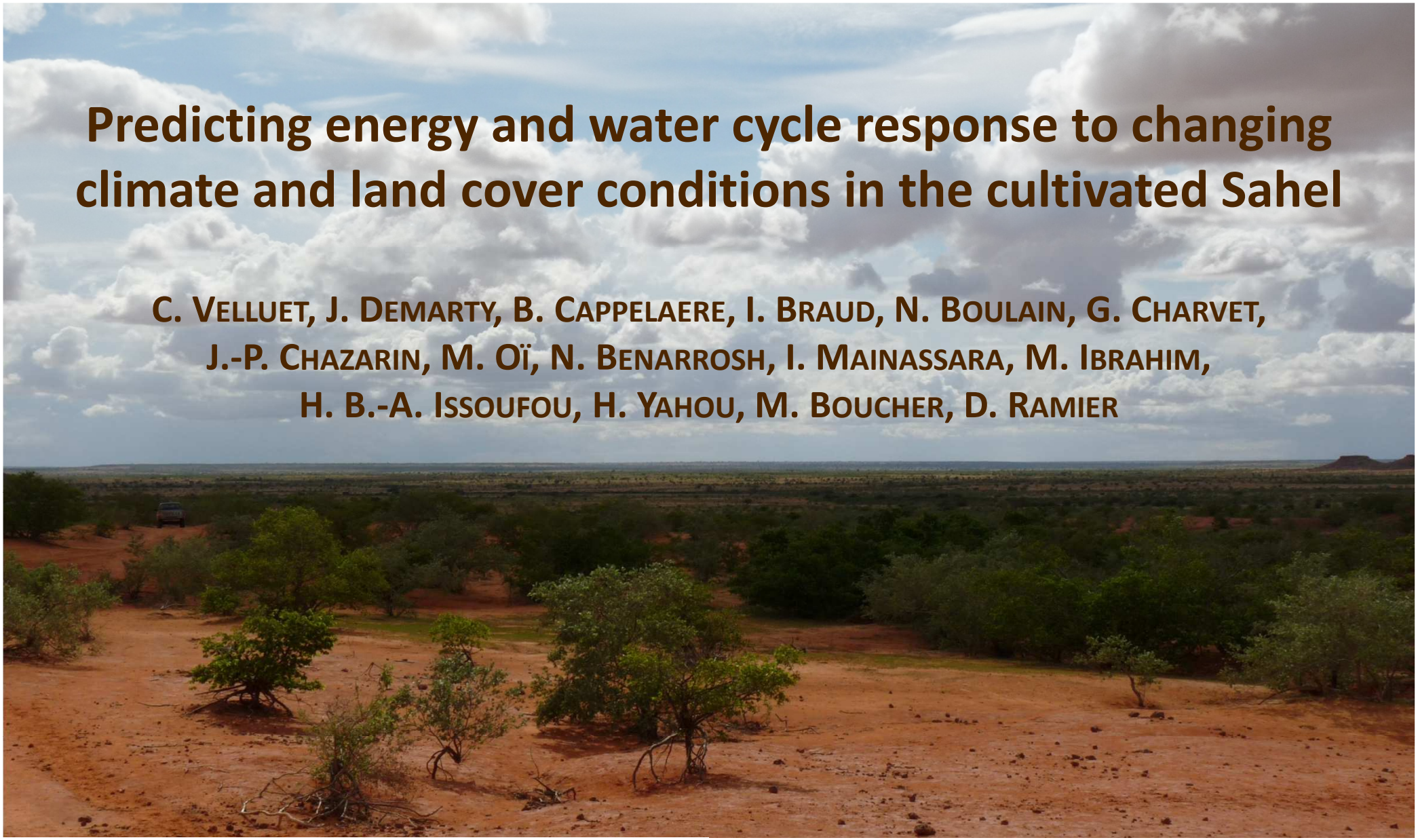
# Predicting energy and water cycle response to changing climate and land cover conditions in the cultivated Sahel

C. Velluet, J. Demarty, B. Cappelaere, I. Braud, N. Boulain, G. Charvet, J.-P. Chazarin, M. Oï, N. Benarrosh, I. Mainassara, M. Ibrahim, H. B.-A. Issoufou, H. Yahou, M. Boucher, D. Ramier



CATCH

RBV RÉSEAU DES BASSINS VERSANTS

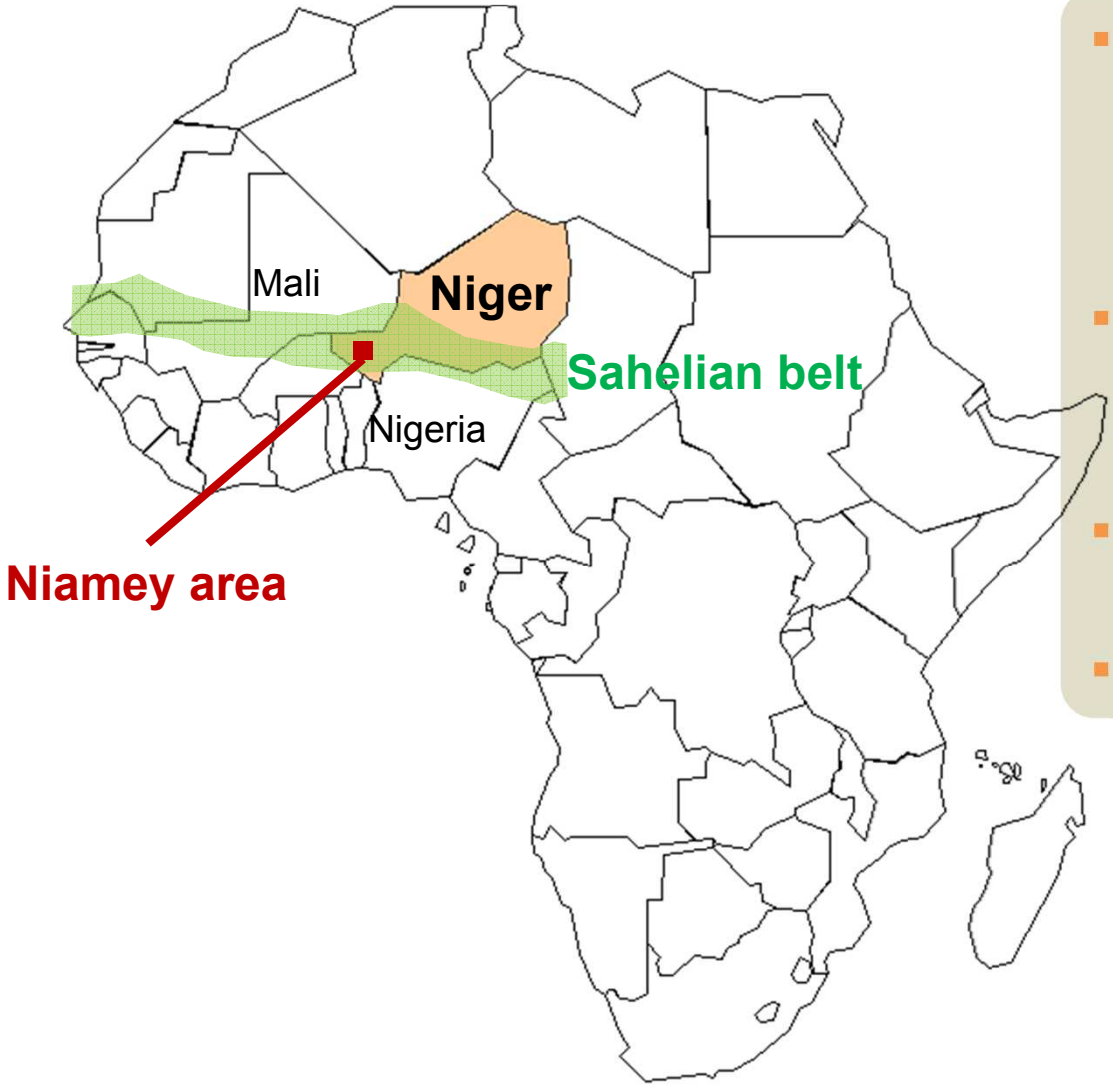
HSM

IRD Institut de recherche pour le développement

um2 UNIVERSITÉ MONTPELLIER 2 SCIENCES ET TECHNIQUES

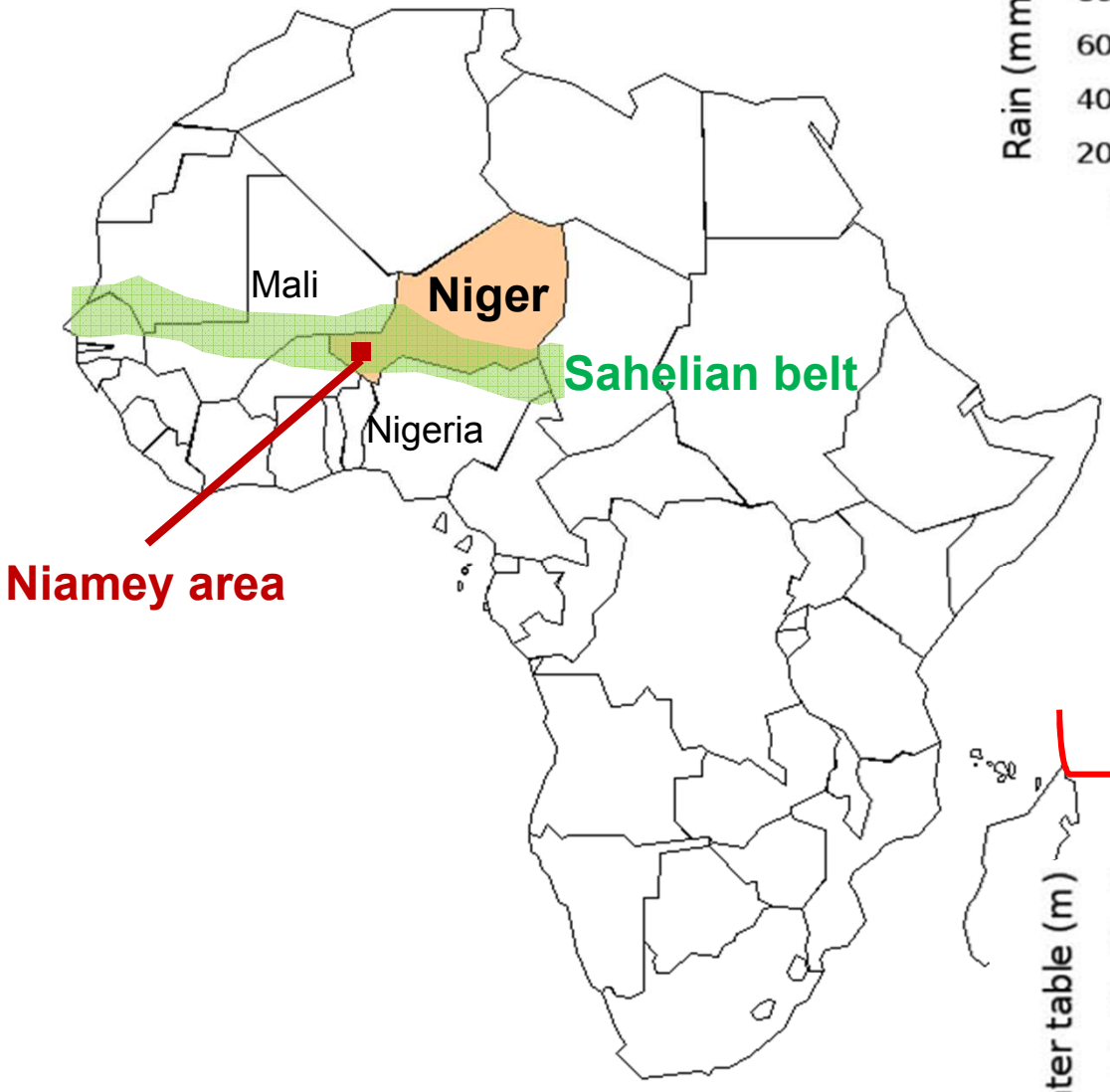
UNIVERSITÉ ABDOU MOUMOUNI

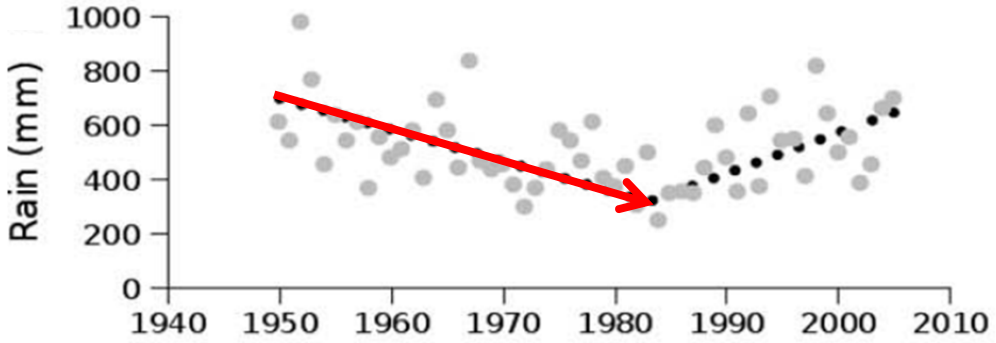
# Cultivated Sahel

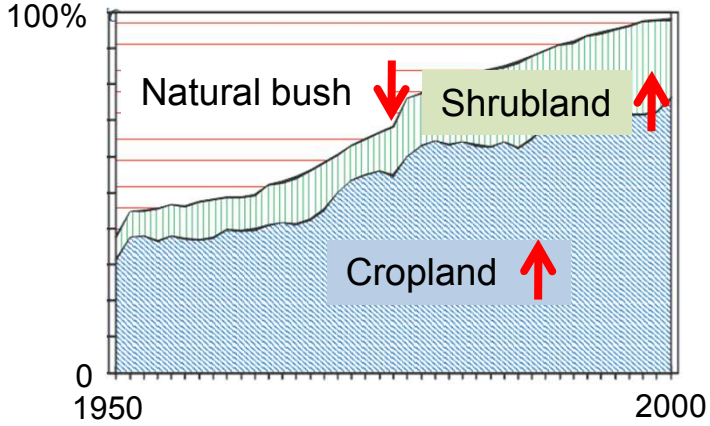


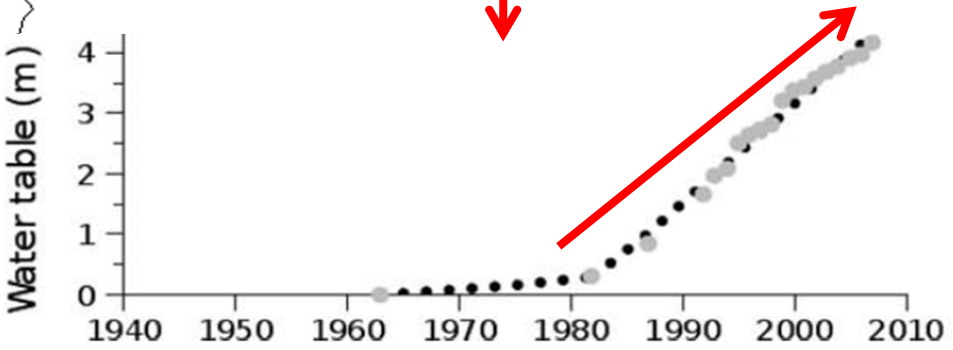

- **Climate:** Sahel – tropical semi-arid
  - **Rainfall**: 400-600 mm/yr
  - **PET**: 2 300 mm/yr
  - **Mean temperature**: ~30°C
- **Ecosystem:**
  - Cropland (millet)
  - Shrubland (fallow savannah)
- **Soils:** sandy soils prone to surface crusting
- **Hydrosystem:** endorheic

# Motivations



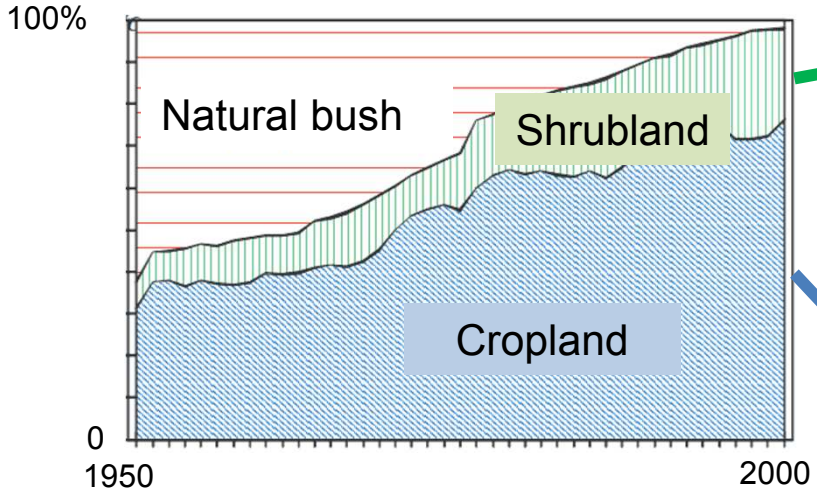




Leduc *et al*., 2001 ; Cappelaere *et al.*, 2009

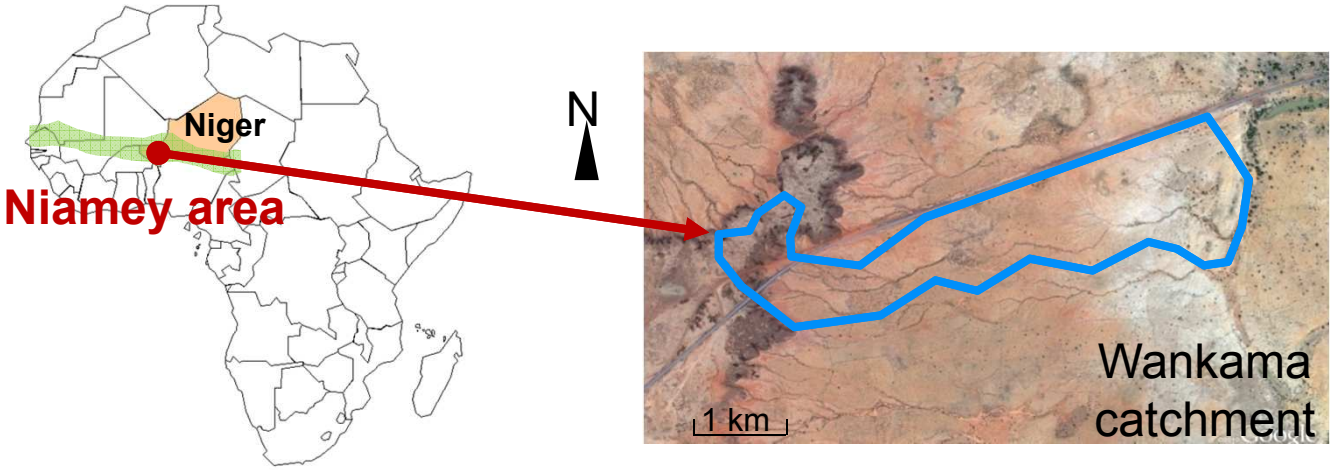
# Objective






➡ **Evaluate the differences in the local processes on a fallow and a millet field with a process-based LSM**

# Tools: Data



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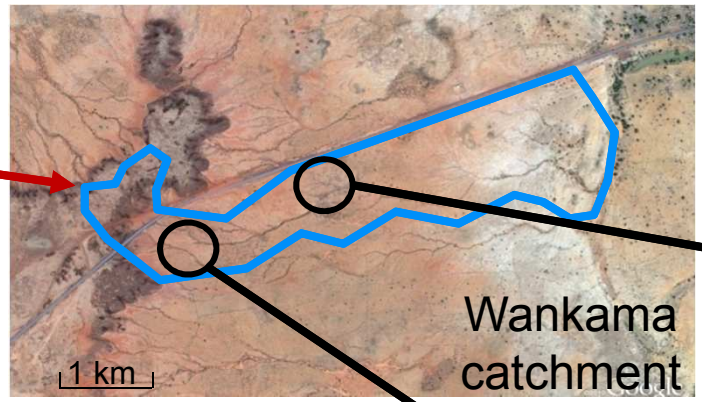


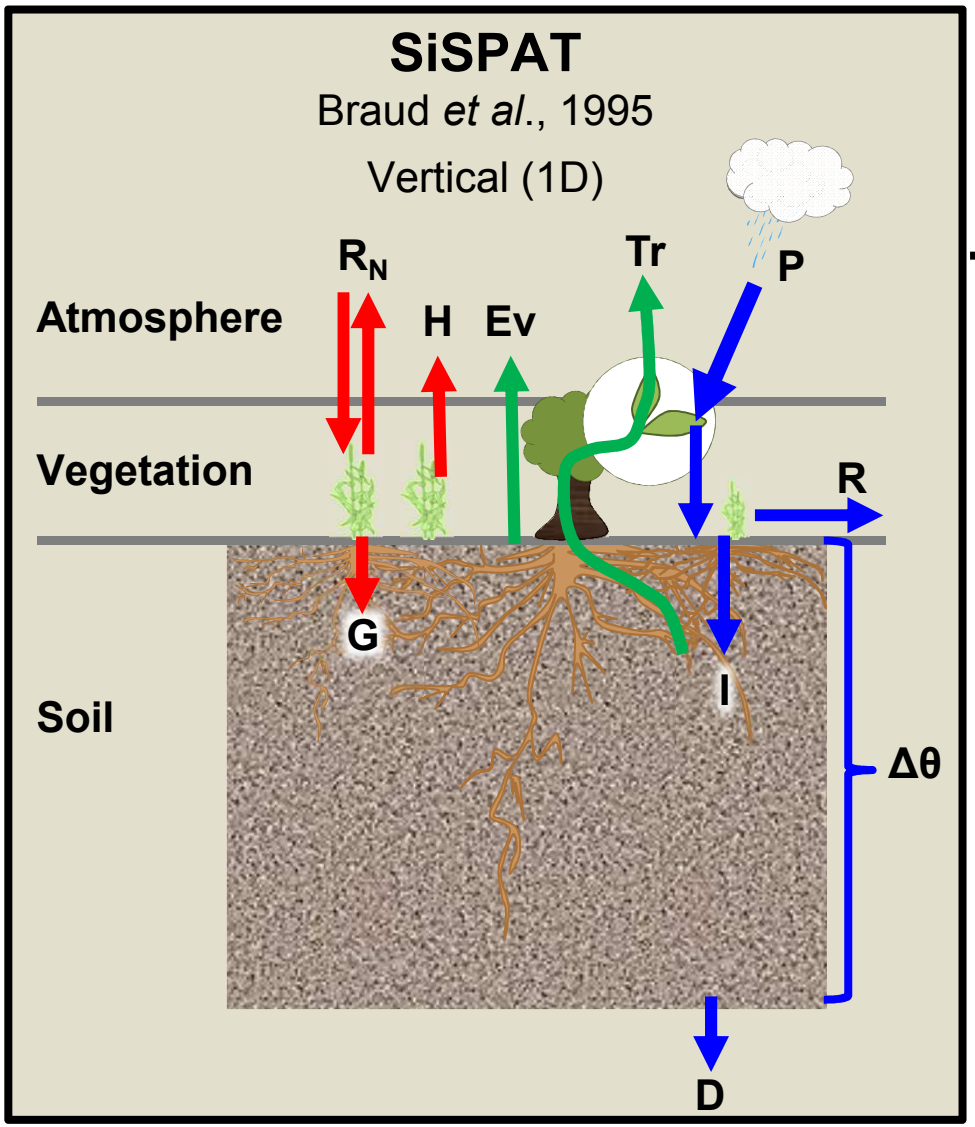

Fallow savannah ~5 ha

Millet field ~5 ha

**AMMA-CATCH Niger observatory:**

- **Meteorology:**
  rainfall, wind speed, air moisture,…
- **Phenology**:
  vegetation height, LAI
- **Soil and surface properties**: granulometry, density, albedo
- **Water and energy fluxes and storages**:
  net radiation, sensible heat flux, soil heat flux, evapotranspiration,
  soil moisture and temperature profiles

# Tools: Simple Soil Plant Atmosphere model




**Water and energy fluxes and storages:**

- Runoff (R)
- Drainage (D)
- Water storage (Δθ)
- Evapotranspiration (ET)
- Net Radiation ($R_N$)
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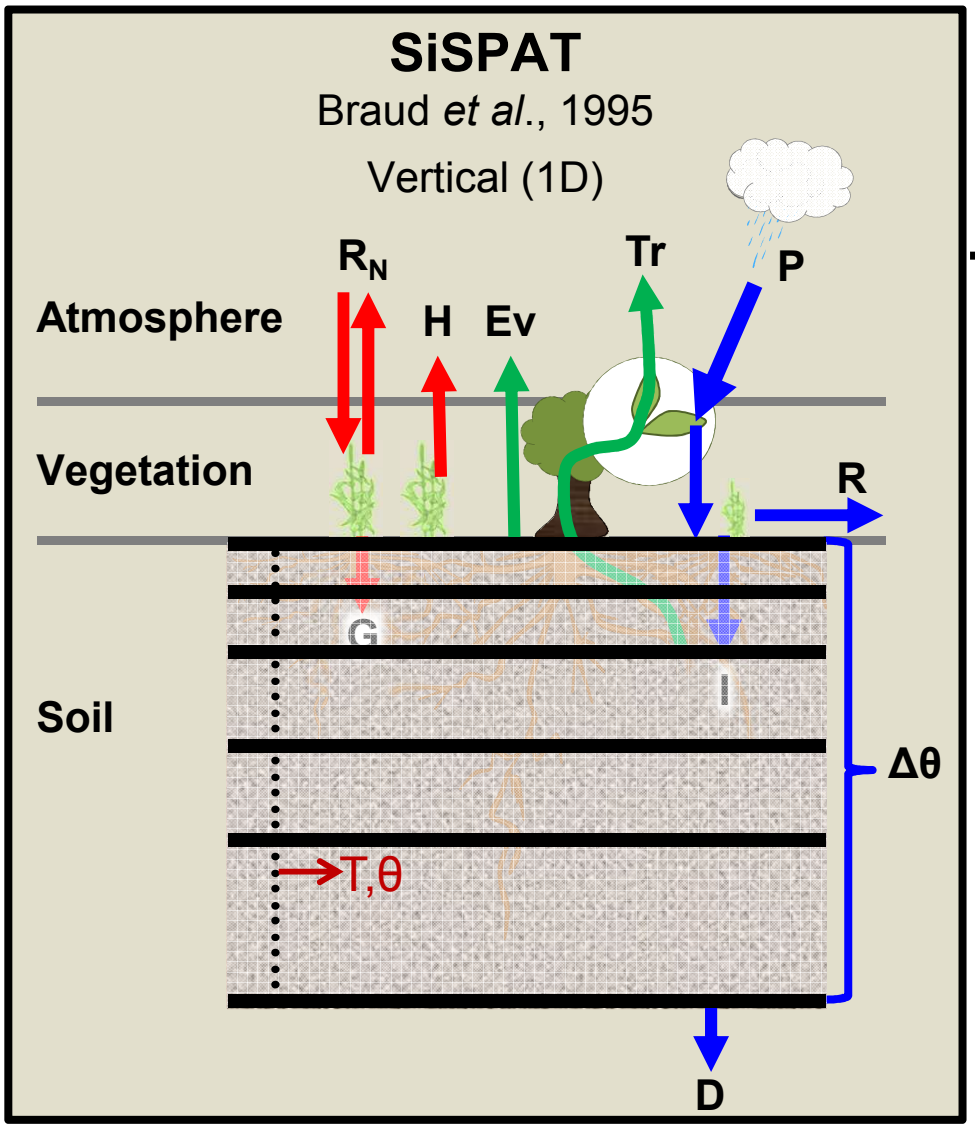


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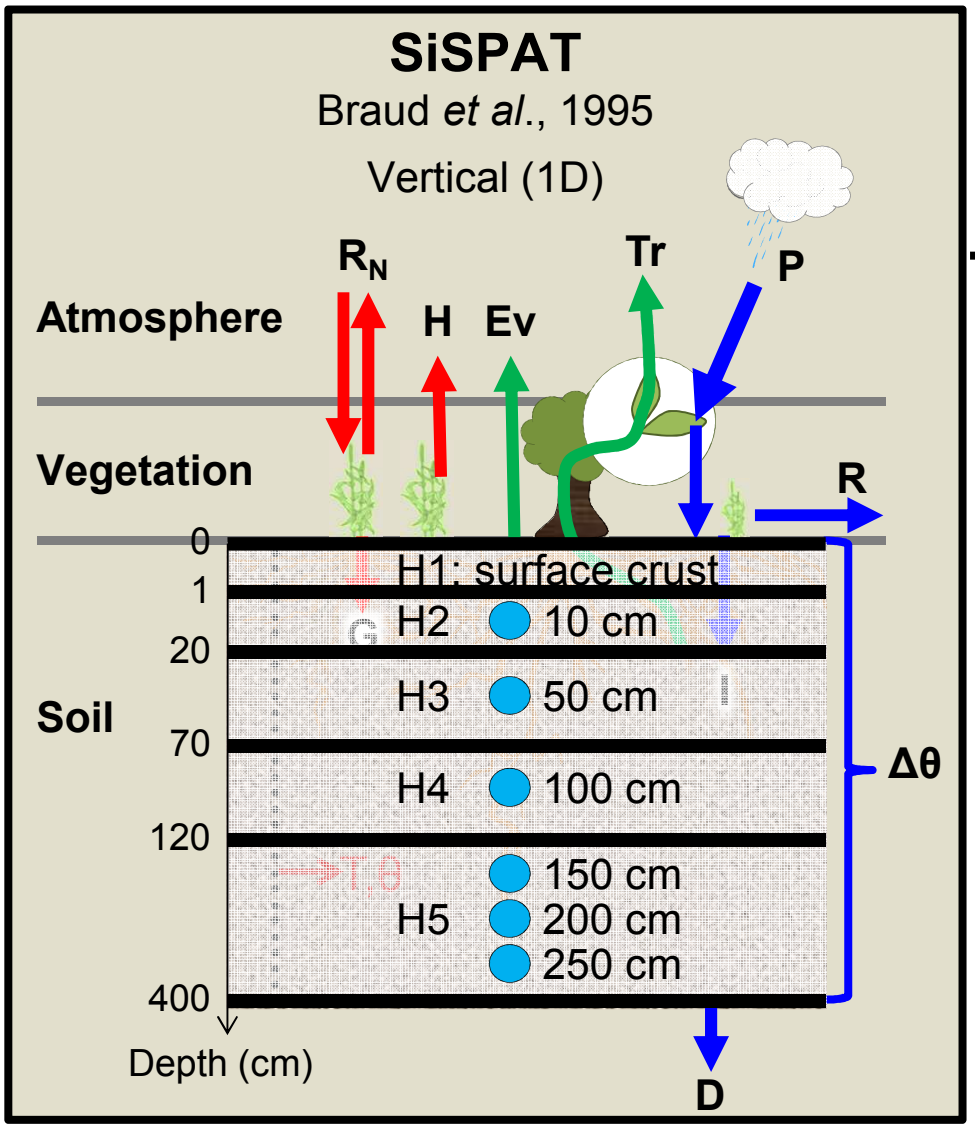
# Modelling

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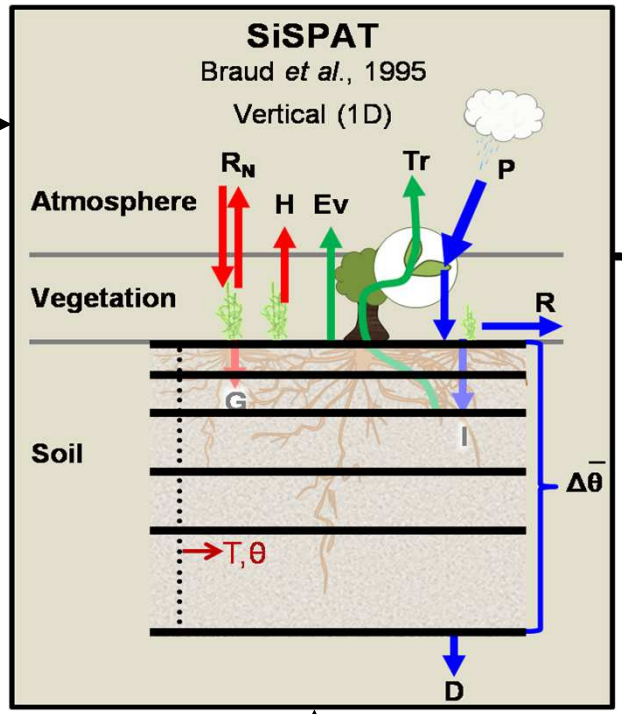
Obs (θ, T)

# Modelling

**Initial conditions** $T_i$ et $\theta_i$

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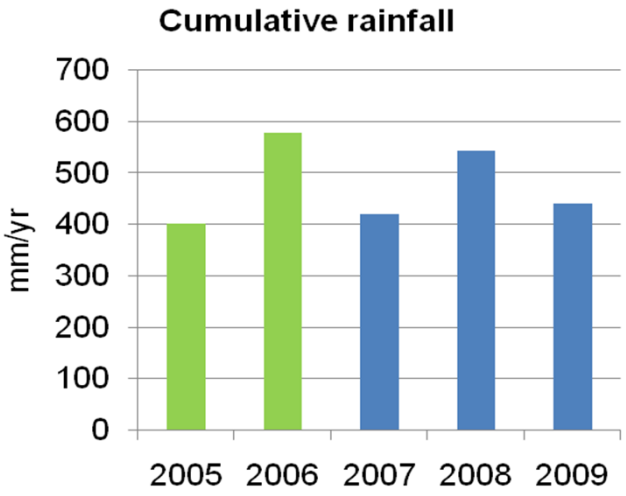
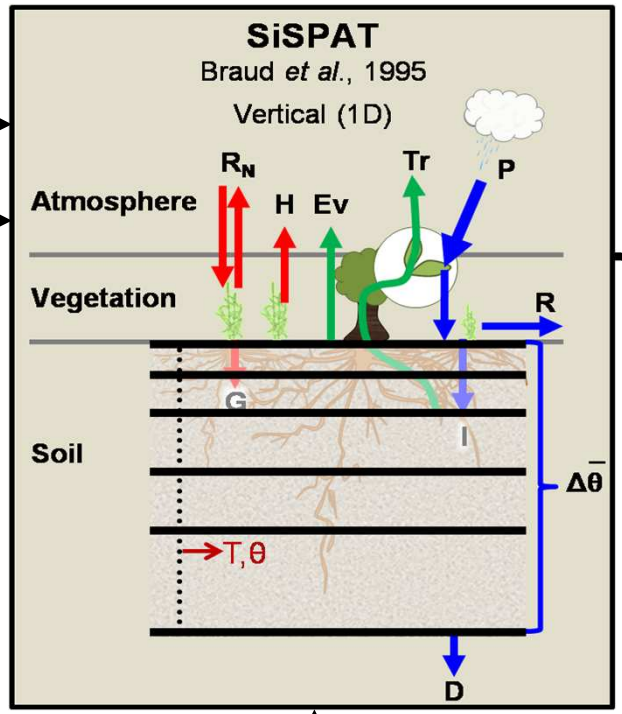
**Parameters:**
Soil and vegetation properties

# Modelling

**Initial conditions** $T_i$ et $\theta_i$

**Meteorological forcing**

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- **Validation:** 3 years (2007-2009)

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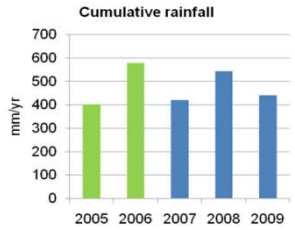
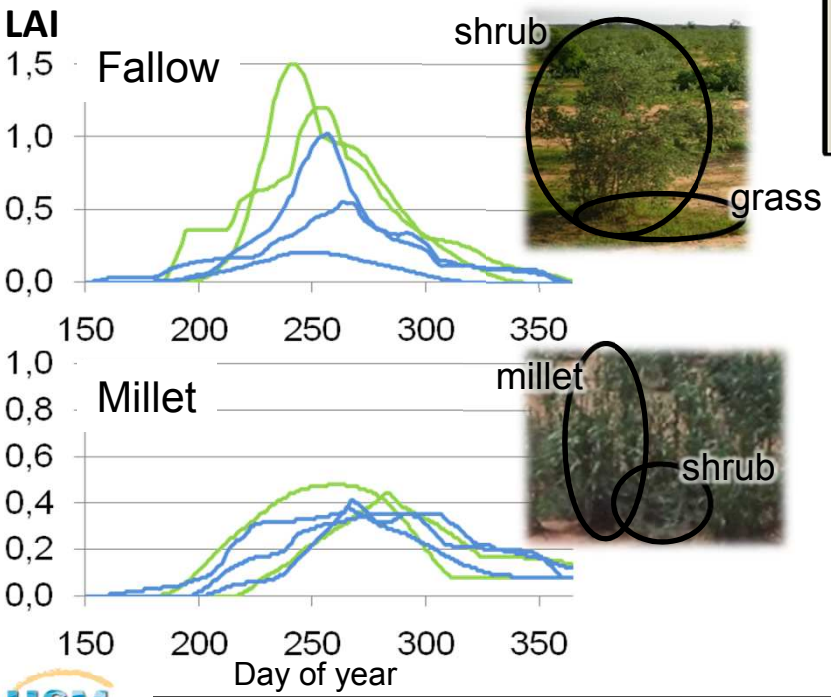
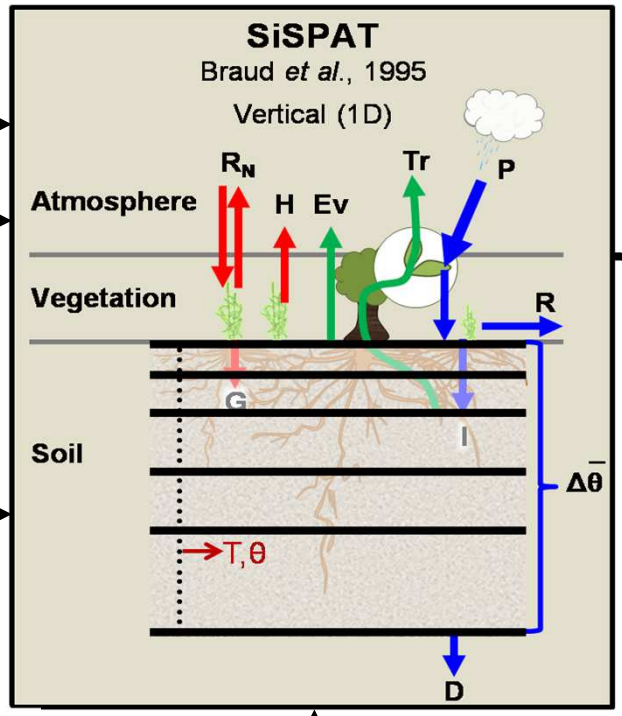



**Phenology forcing**

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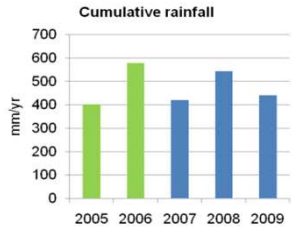


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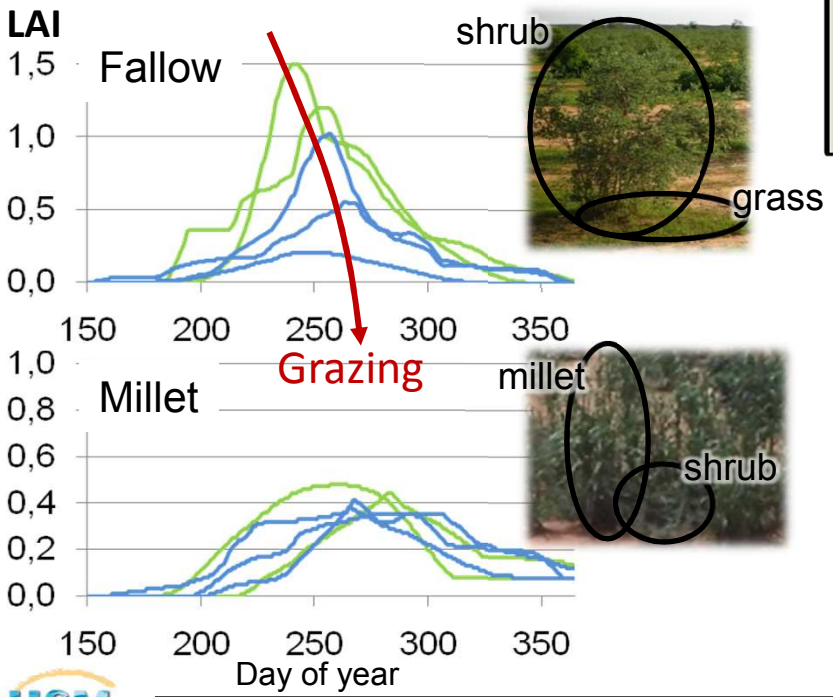


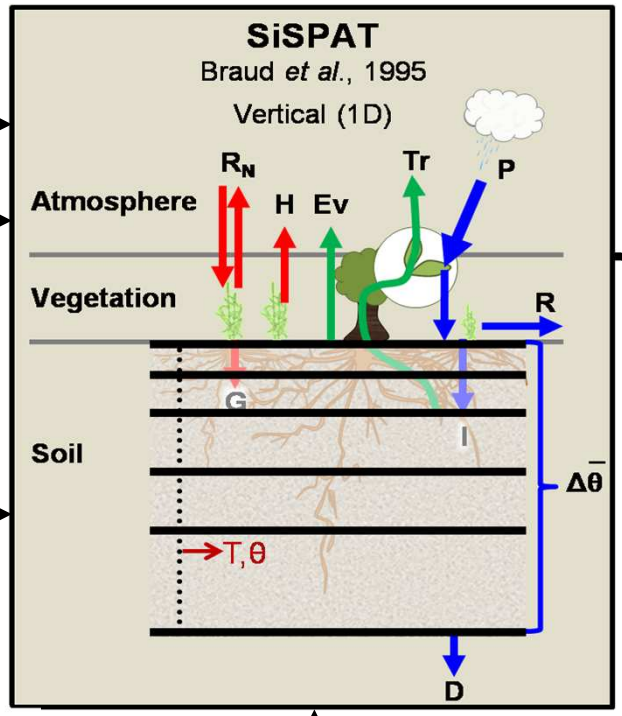


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# Calibration: Hydrodynamic properties

**Retention capacity**:
van Genuchten (1980)

$$\theta = \theta_r + \frac{\theta_{sat} - \theta_r}{\left[1 + \left(h / h_g\right)^n\right]^{1-2/n}}$$

**Hydraulic conductivity**:
Brooks & Corey (1964)

$$K(\theta) = K_{sat}\left(\frac{\theta}{\theta_{sat}}\right)^{\beta}$$

| $h_g$ | n | $\theta_{sat}$ | $K_{sat}$ | β |
|---|---|---|---|---|
| m | - | $m^3/m^3$ | m/s | - |

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| **Fallow savannah** | | | | | |
| H1: 0-1 cm | -1,20 | 2,7 | 0,30 | $9.10^{-8}$ | 6,0 |
| H2: 1-20 cm | -0,50 | | | $9.10^{-6}$ | 5,0 |
| H3: 20-70 cm | -0,28 | | | $5.10^{-6}$ | |
| H4: 70-120 cm | | 2,6 | | $9.10^{-6}$ | |
| H5: 120-400 cm | | | | $3.10^{-5}$ | |
| **Millet field** | | | | | |
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- **Parameters**:
  - Physically realistic
  - Similar for both sites

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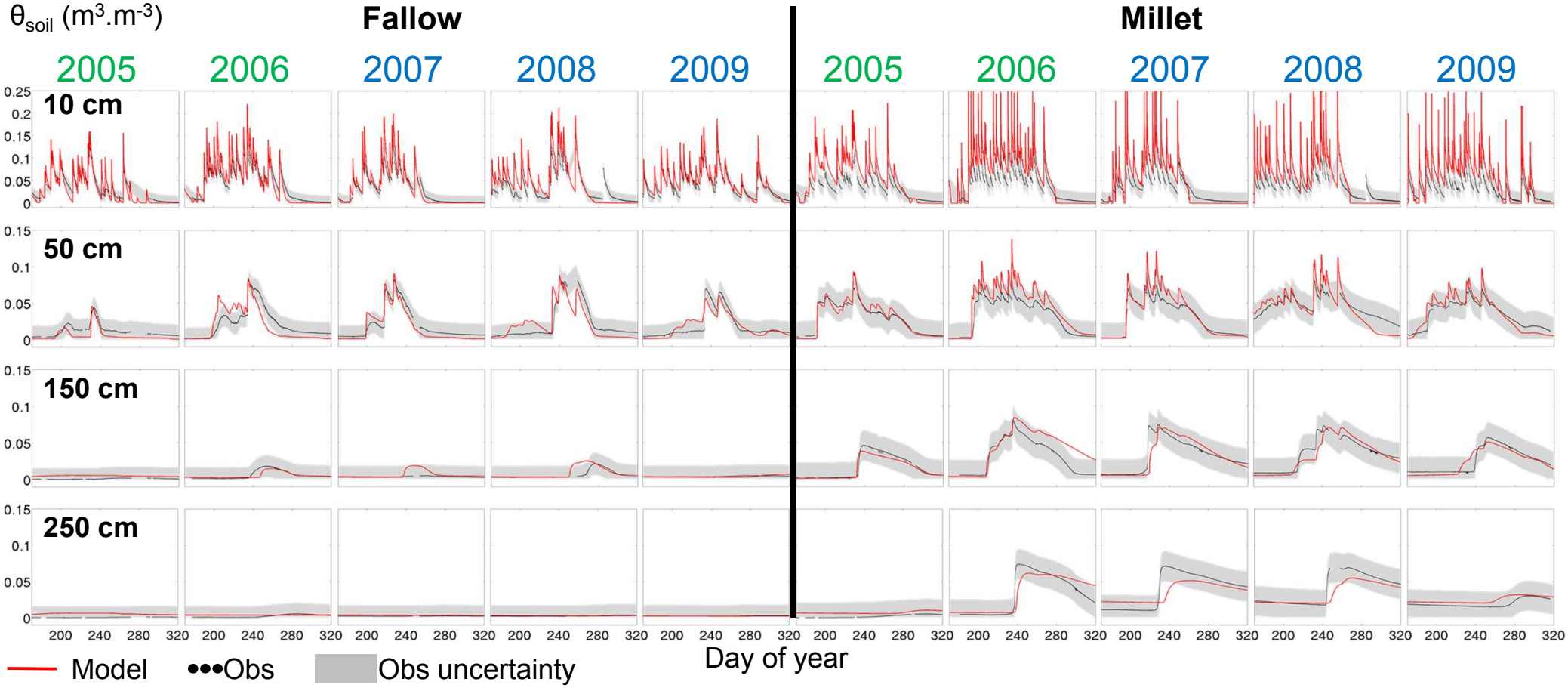
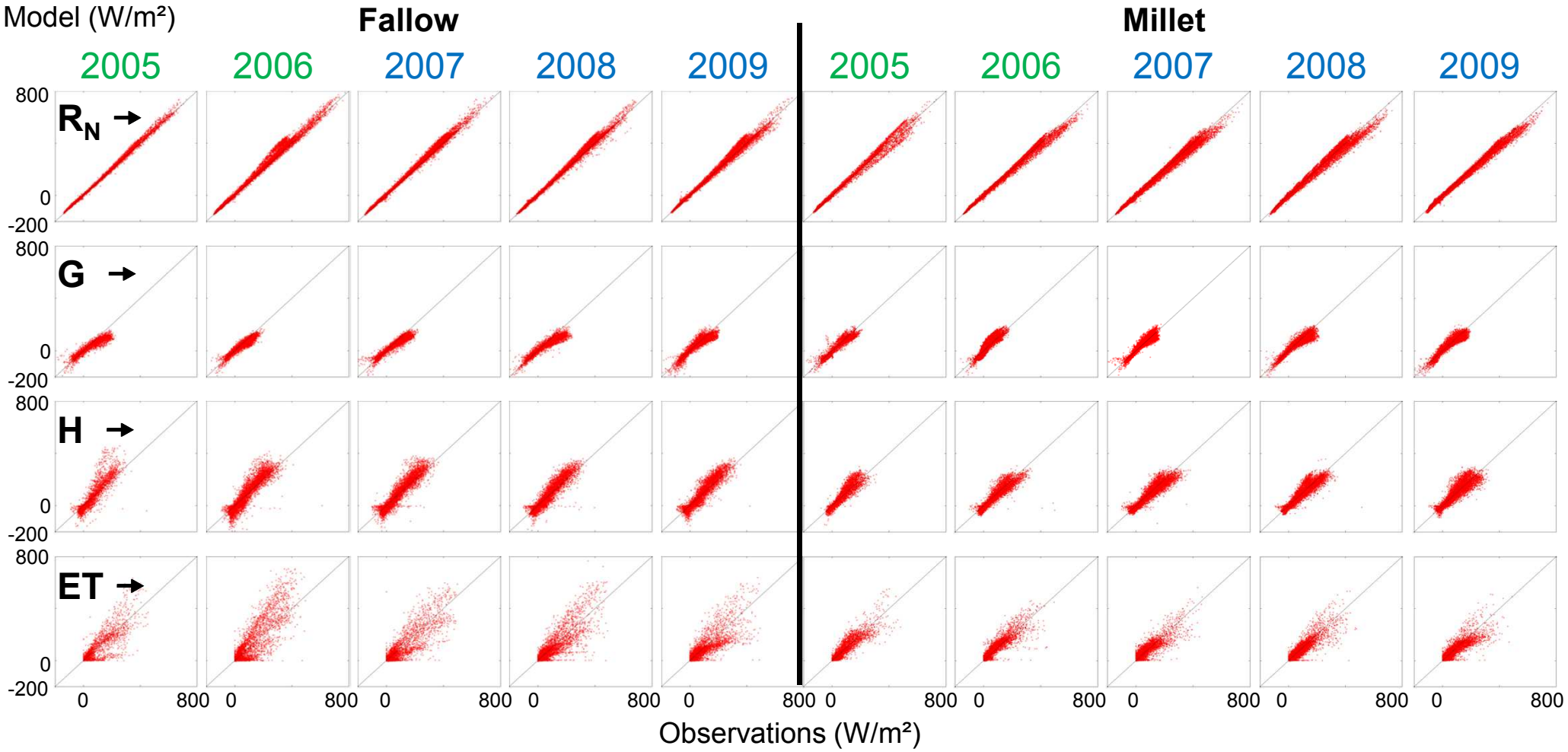
- **Parameters**:
  - Physically realistic
  - Similar for both sites, except at surface
  - Stronger surface crust on fallow

# Calibration-Validation: Soil moisture




- **Model Performance**:
  - Satisfactory for both sites, wet & dry years
  - Similar for calibration & validation
  - Better for fallow site
- **Highlights:**
  - Fallow: little infiltration below 1m
  - Millet: infiltration through the whole profile

# Calibration-Validation: Energy fluxes



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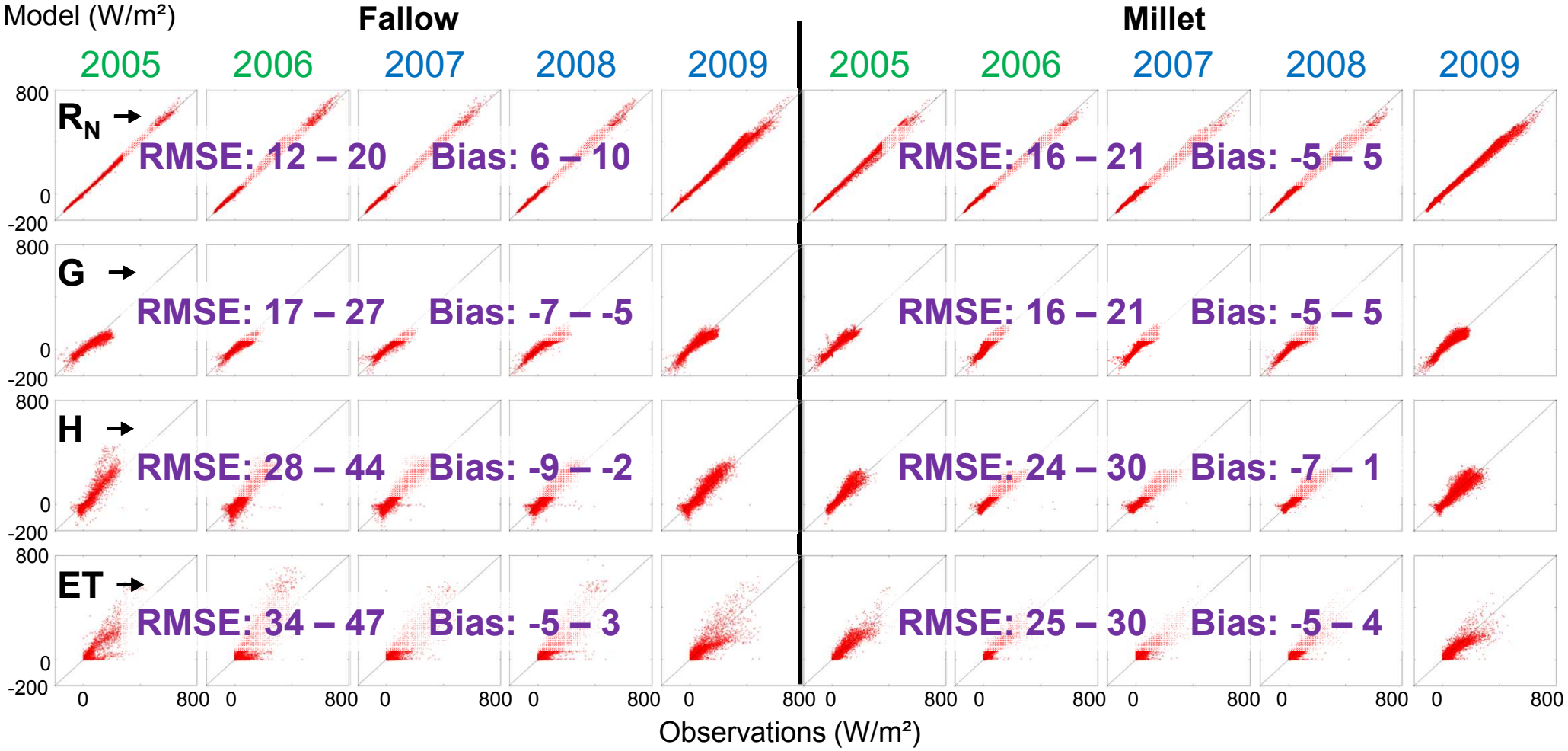
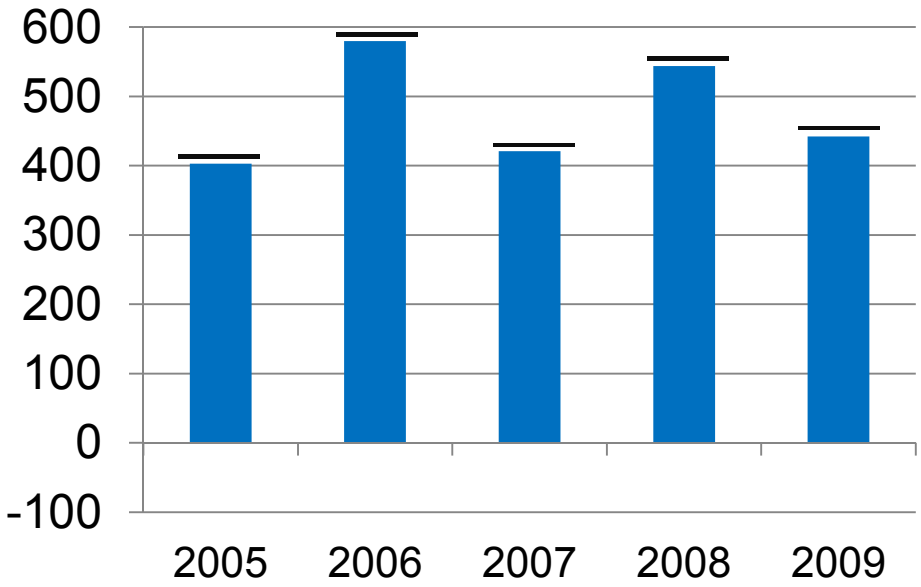
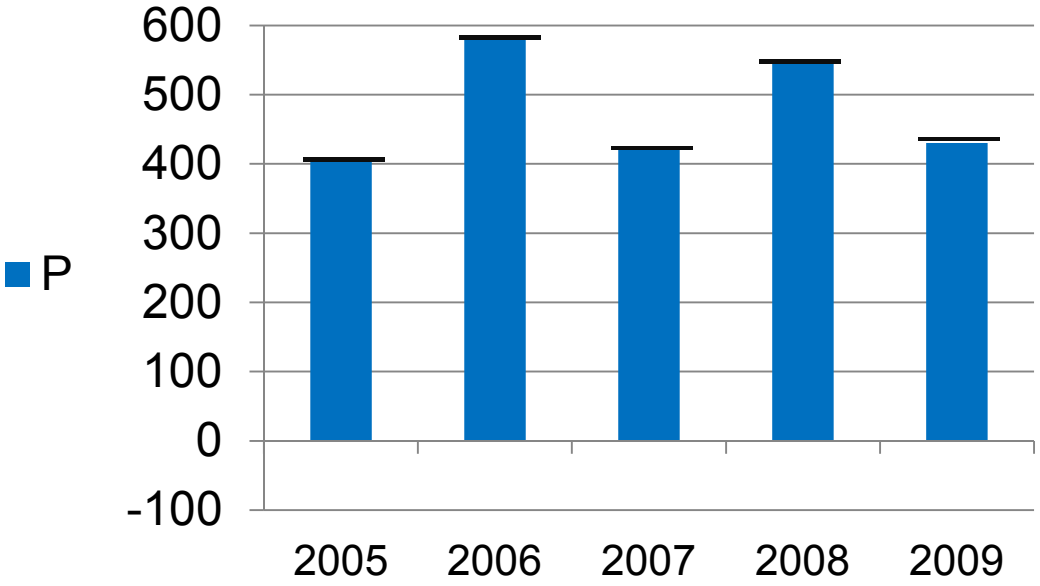



- **Model Performance**:
  - Satisfactory for both sites, wet & dry years
  - Similar for calibration & validation
  - Very good for $R_N$
  - Good for **G**
  - Better **H & ET** for millet site

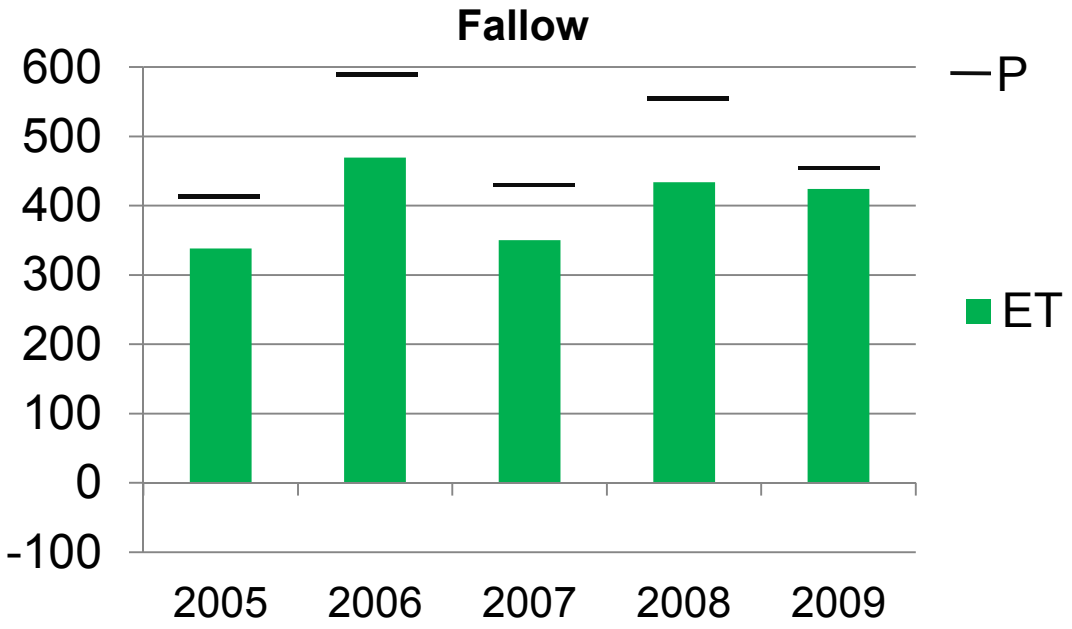
# Results: Annual water budget

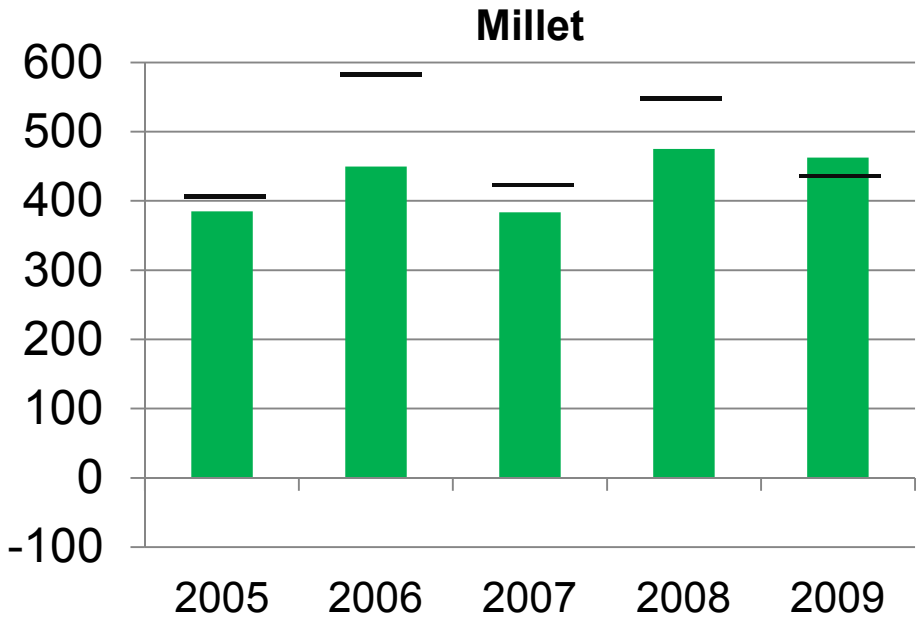



- **Rainfall variability**: P=420–580 mm/yr

# Results: Annual water budget




- **Rainfall variability**: P=420–580 mm/yr
- **Evapotranspiration** (ET):

Fallow: 80–95% of P

Millet: 85–110% of P

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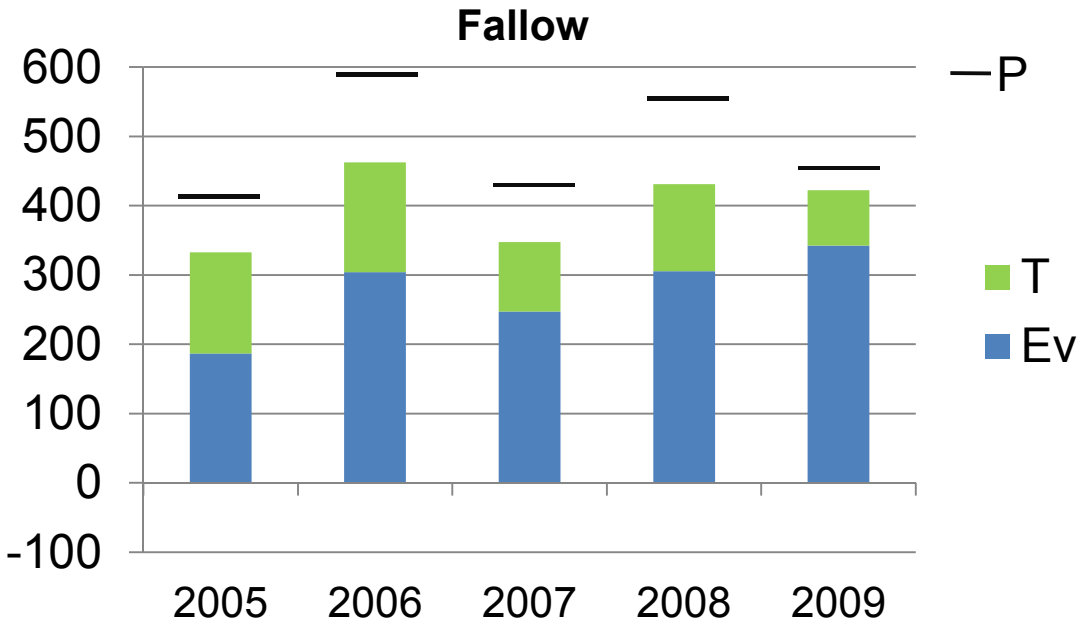


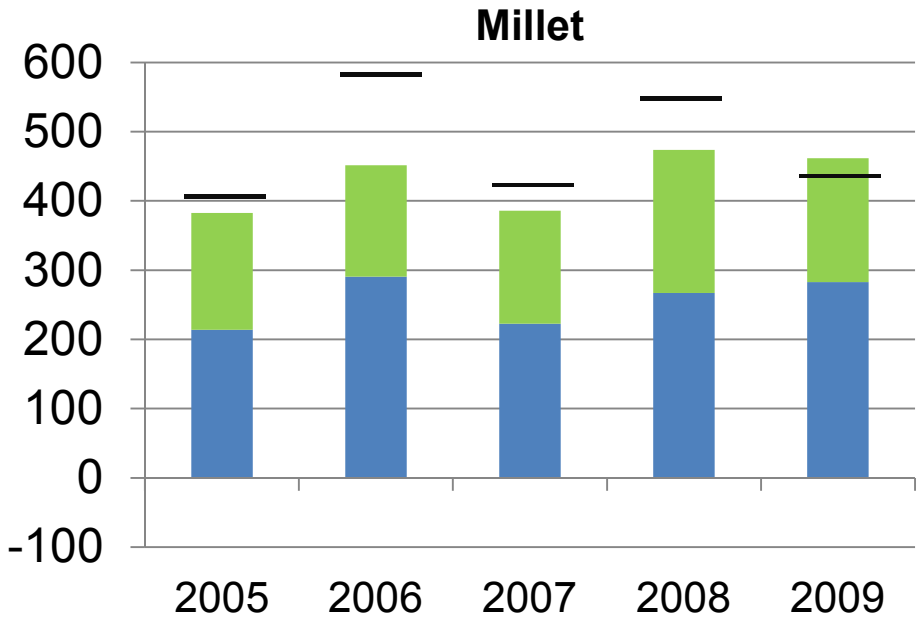


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Ev>Tr

Fallow: T = 20–45% of ET

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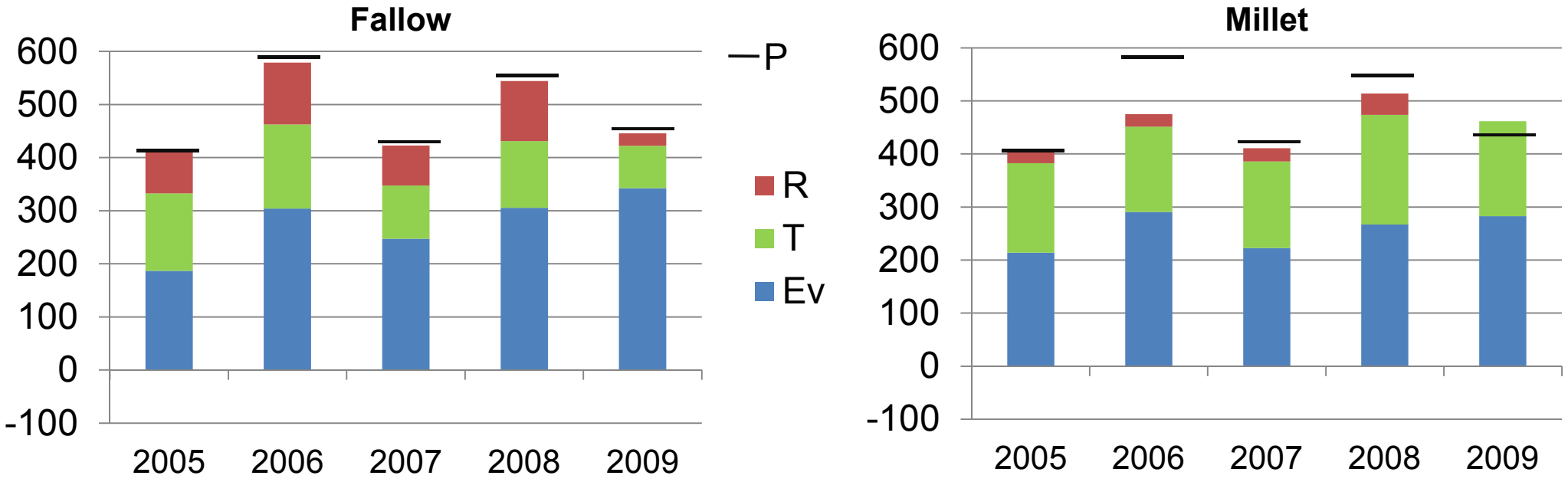


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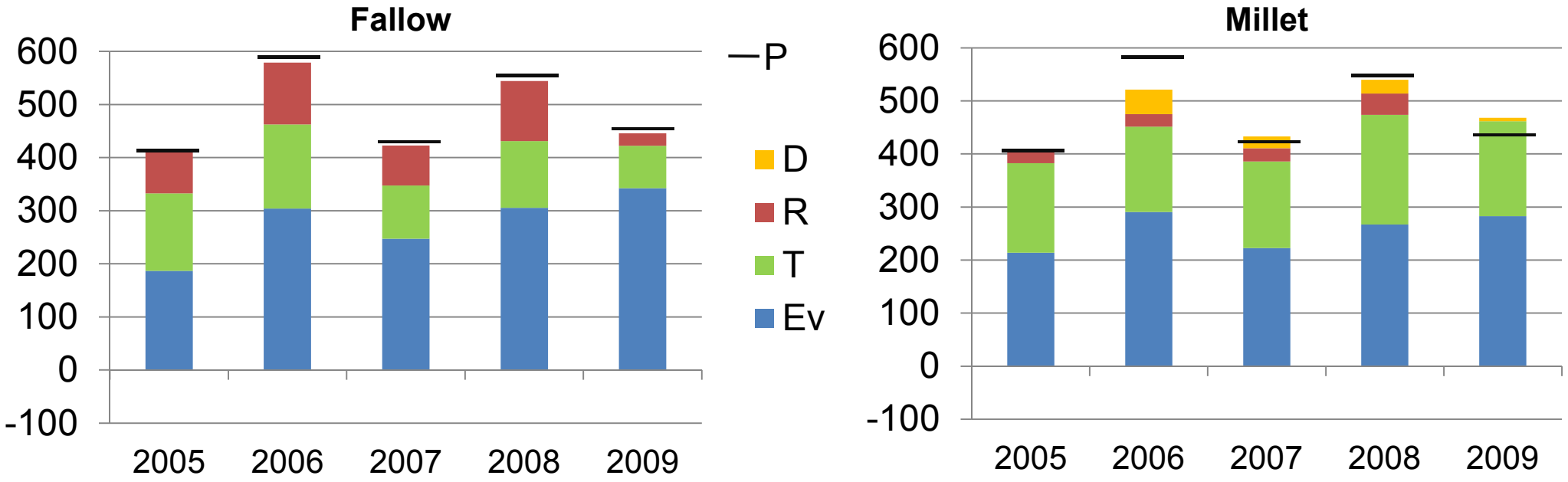


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Fallow: 5–20% of P

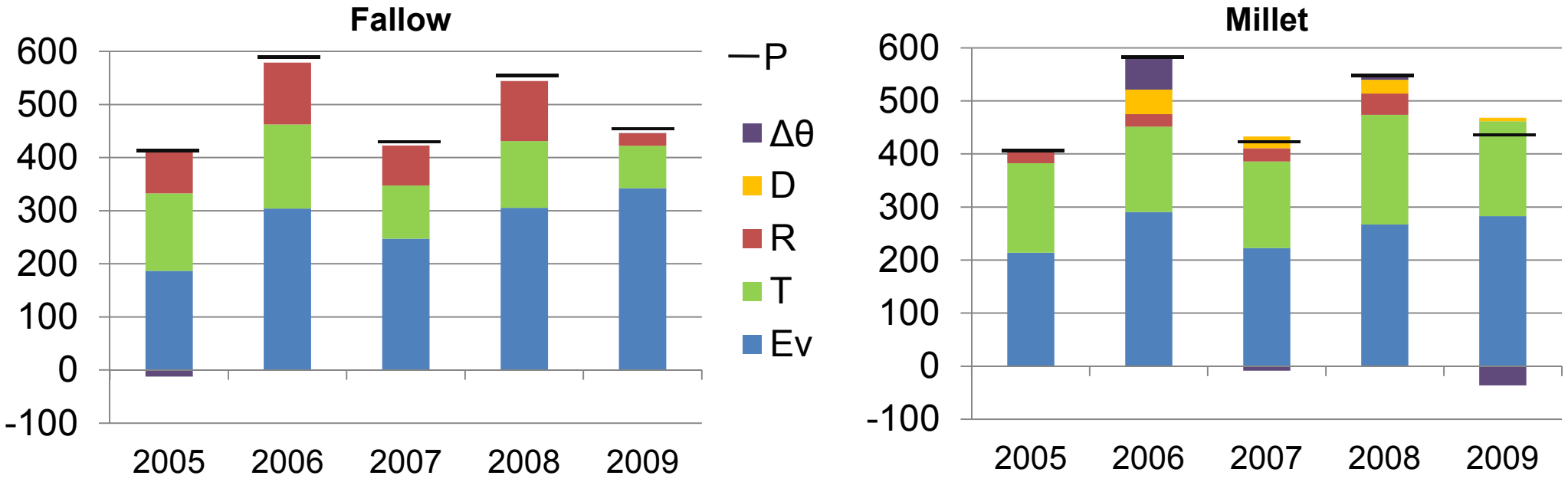
Millet: 2–15% of P

- **Drainage** (D):

Fallow: no drainage

Millet: 0-5% of P → GW recharge

# Results: Annual water budget

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- **Evaporation vs.Transpiration:**

Ev>Tr

Fallow: T = 20–45% of ET

Millet: T = 40–47% of ET

- **Runoff** (R):

Fallow: 5–20% of P

Millet: 2–15% of P

- **Drainage** (D):

Fallow: no drainage

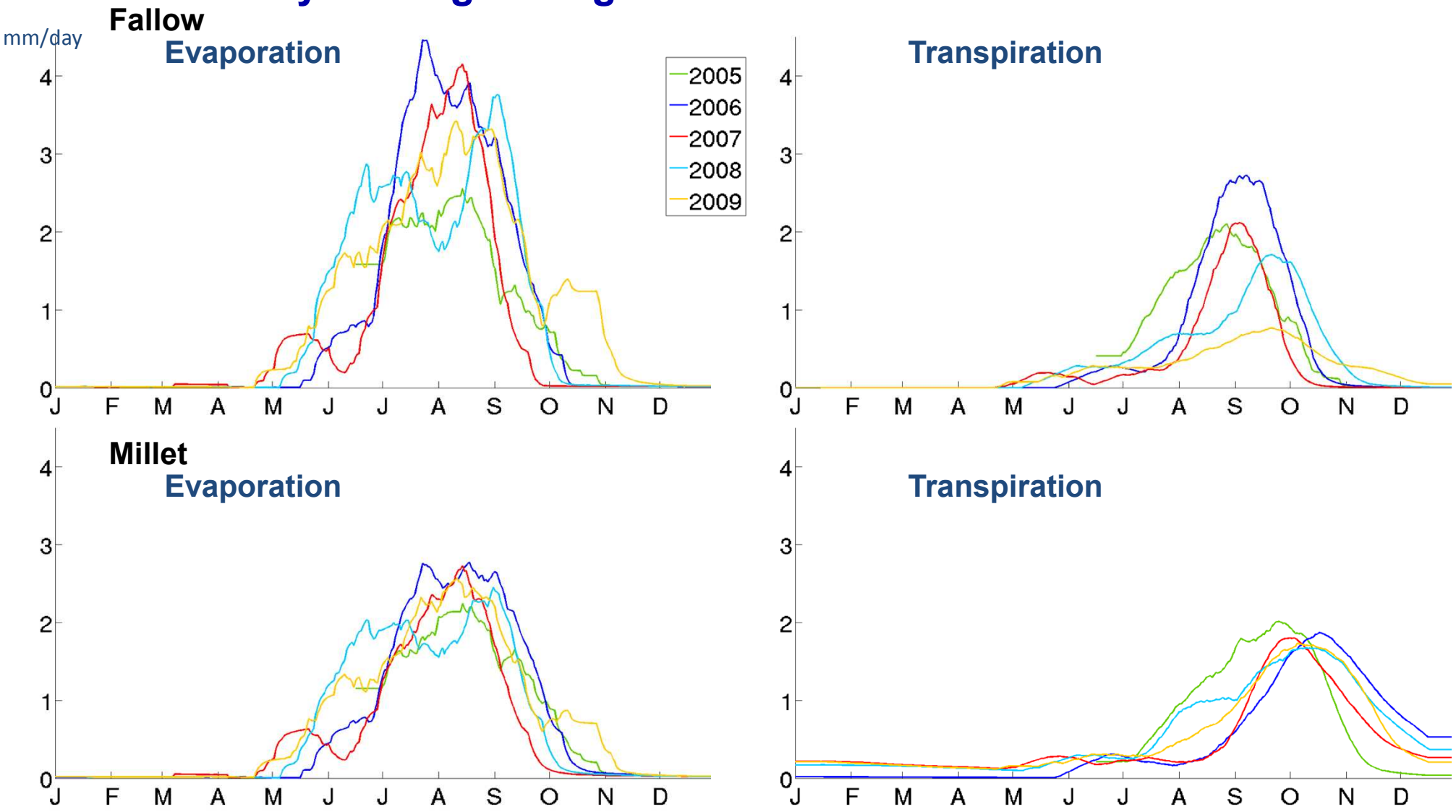
Millet: 0-5% of P → GW recharge

- **Water storage** (Δθ):

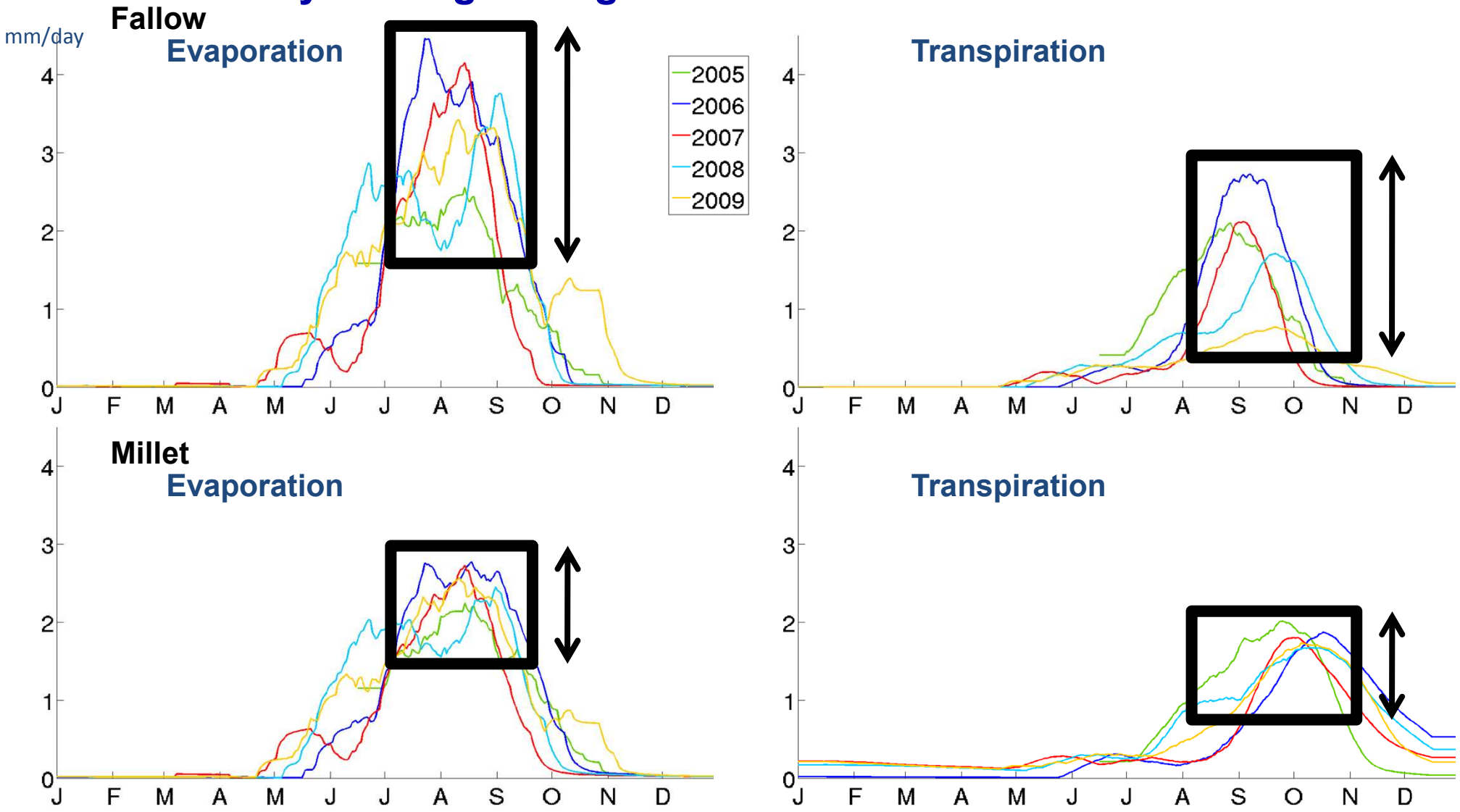
Fallow: no interannual storage Δθ=0mm

Millet: Δθ = -25–+63 mm/yr

# Results: 30-day moving average

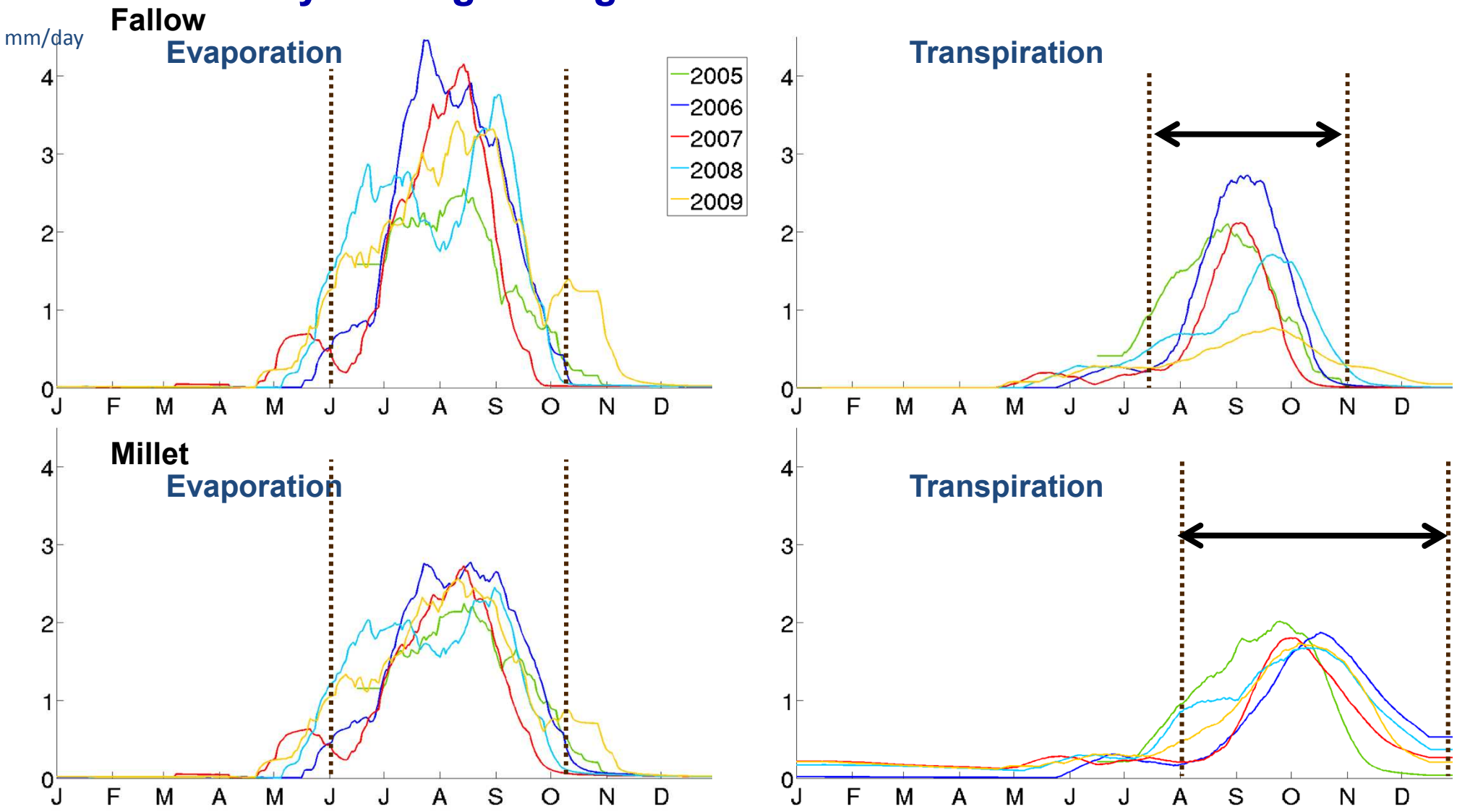


# Results: 30-day moving average



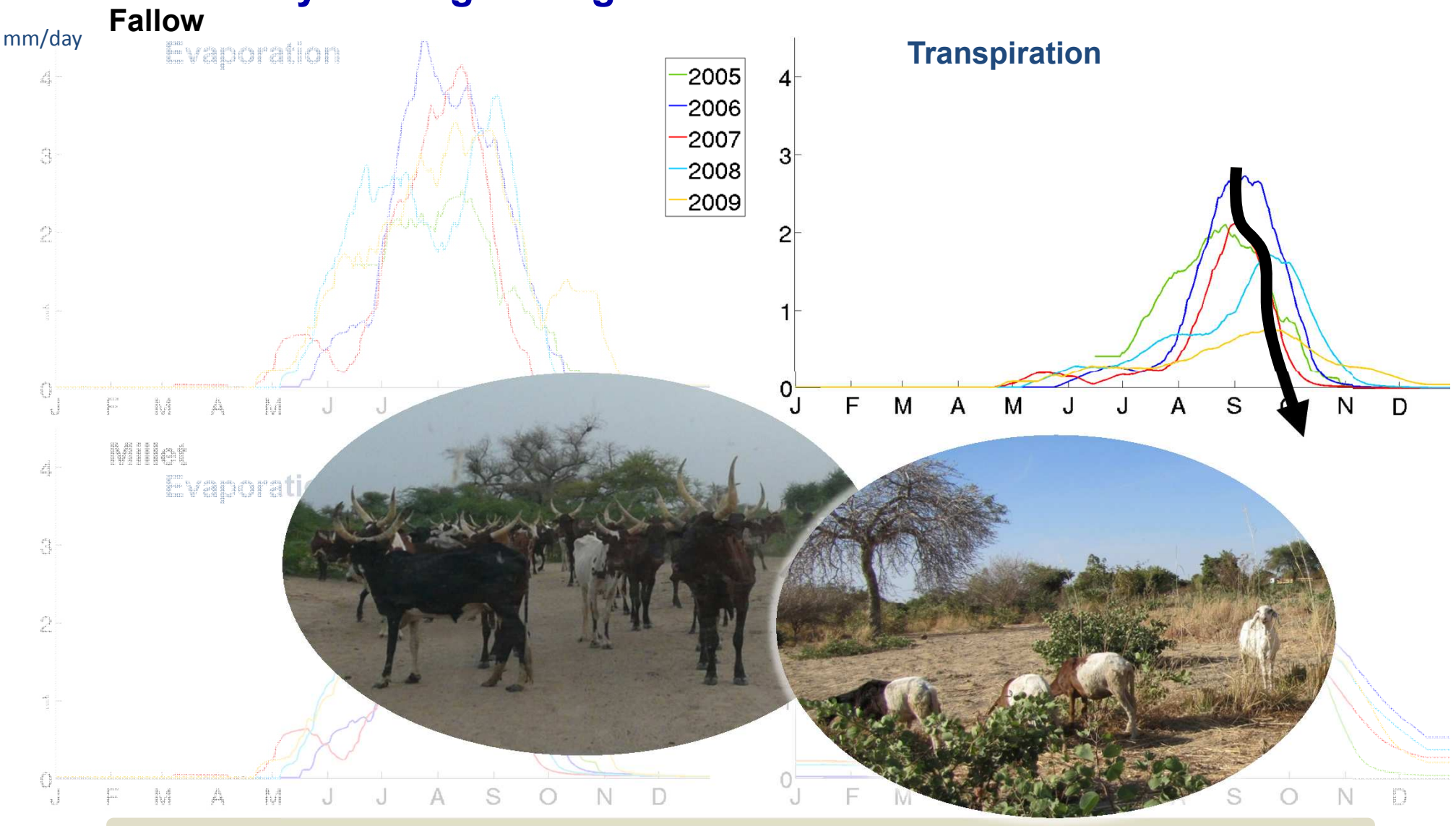

- Stronger inter-annual variability on the fallow

# Results: 30-day moving average




- Stronger inter-annual variability on the fallow
- Different seasonal distribution

# Results: 30-day moving average




- Stronger inter-annual variability on the fallow
- Different seasonal distribution
- Sheep and cow have more effect than the climate !

## Conclusions

➡ **Evaluate the differences in the local processes on a fallow and a millet field with a process-based model**

- **Model performance**: calibration & validation, satisfactory/stable for wet & dry years, millet & fallow
- **Process-based modeling** → complete, detailed water & energy budgets, for variable meteorological and vegetation conditions
- **Comparison of the millet & fallow water balances (2005-2006** - Ramier *et al*., 2009) → main conclusions confirmed
- **Inter-annual variability** → comparison of land cover types varies with years

## Perspectives

- Longer periods to account for the marked variability of the Sahel climate
- Effects of land management practices (agro forestry, grazing, …) ?
- Impact of uncertainties on inputs and parameters ?

# Thank you for your attention !