Uncertainties in simulated evapotranspiration from SURFEX/ISBA-A-gs over a 14-year Mediterranean crop succession

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Outline

1) Introduction

2) Avignon crop succession dataset

3) Modelling experiment design

4) Results

5) Conclusions

1. Introduction

Introduction (1/2)

➔ **Evapotranspiration** (ET) : **key variable of the energy & water balance** (Seneviratne et al., 2006)

➔ **ET**: most **uncertain term of the water balance of Mediterranean regions** (Dolman et al., 2010 ; Orlowsky et al., 2013)

- **ET dynamics** and **soil/vegetation partitioning** (Sutanto et al., 2014)
- Large **departure between models** (Mueller and Seneviratne., 2014)

➔ Sources of modelling **uncertainties** (Vrugt et al., 2009):

- **Forcing variables** (e.g. climate, vegetation dynamic, land-use)
- **Model parameters** (e.g. soil hydrodynamic properties)
- **Model structure** (e.g. water transfer scheme, energy balance, crop phenology, irrigation...)

Introduction (2/2)

Q.1) How crop succession drives the dynamics of ET, ET soil/vegetation partitioning and drainage ?

Q.2) What are the most influential sources of uncertainties

- **climate,**
- **vegetation dynamic,**
- **irrigation,**
- **soil parameters.**

on ET simulation over a crop succession ?

Q.3) What are the impacts of

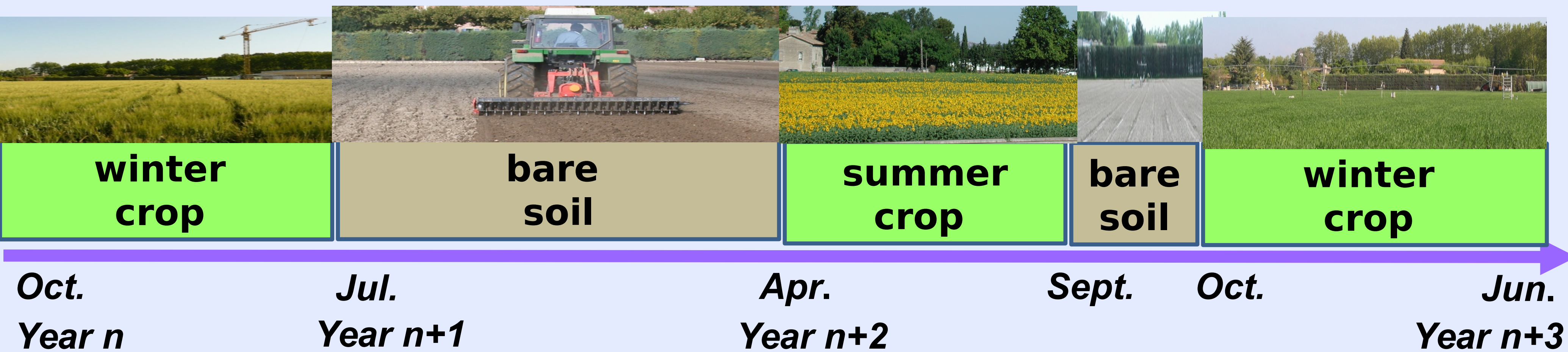
- **errors in soil parameters,**
- **water transfer scheme: Force-Restore vs multi-layer soil diffusion scheme,**

on ET simulation over a crop succession ?

2. Avignon dataset

Representation of crop succession

- **Explicit representation of crop succession in the simulation**
- **Succession of winter (wheat) and summer (maize, sorghum, sunflower) crops**
- **Long period (9 months) of bare soil between winter and summer crops**



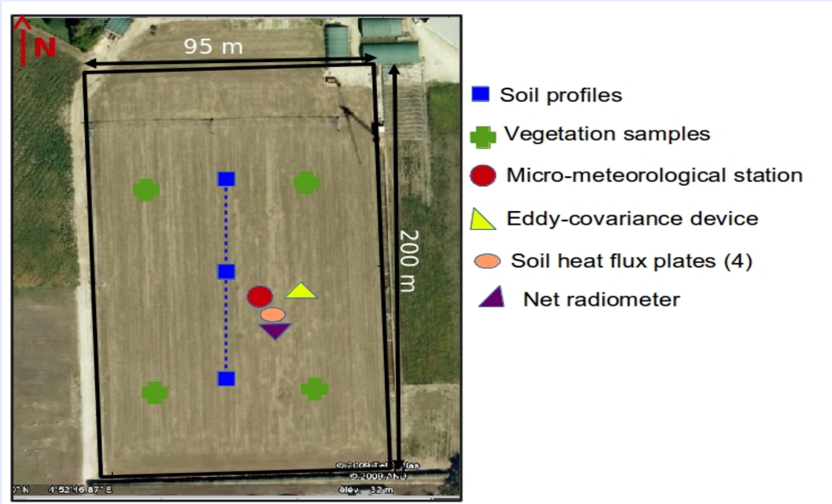
Site and in situ data

➔Avignon Site

- **lower Rhone Valley region**, France (43°55'00'' N , 4°52'47'' E, 32m)
- **Mediterranean climate** (mean annual T°C=14°C and mean precip=~650 mm)
- Texture: 15% of sand, 35% of clay
- **Crops: maize, wheat, sorghum, peas, sunflower**

➔ 14 years of continuous measurements:

- **Fluxes**: Eddy, radiative and soil heat fluxes
- **Soil moisture vertical profiles**
- **Micrometeorological variables**
- **Vegetation** : LAI , height, agricultural practices



3. Modelling experiment design

The ISBA-A-gs model

Noilhan and Planton, 1989
Calvet et al., 1998
Masson et al., 2013

➔ **SURFEX/ISBA-A-gs model**

- Version 8.0 of SURFEX
- **Single energy balance** of soil-vegetation composite
- **Force restore/Multi-layer soil diffusion** for heat and water soil transfers
- **A-gs: mode AST** driven by in situ LAI time series

➔ **Implementation at the Avignon site**

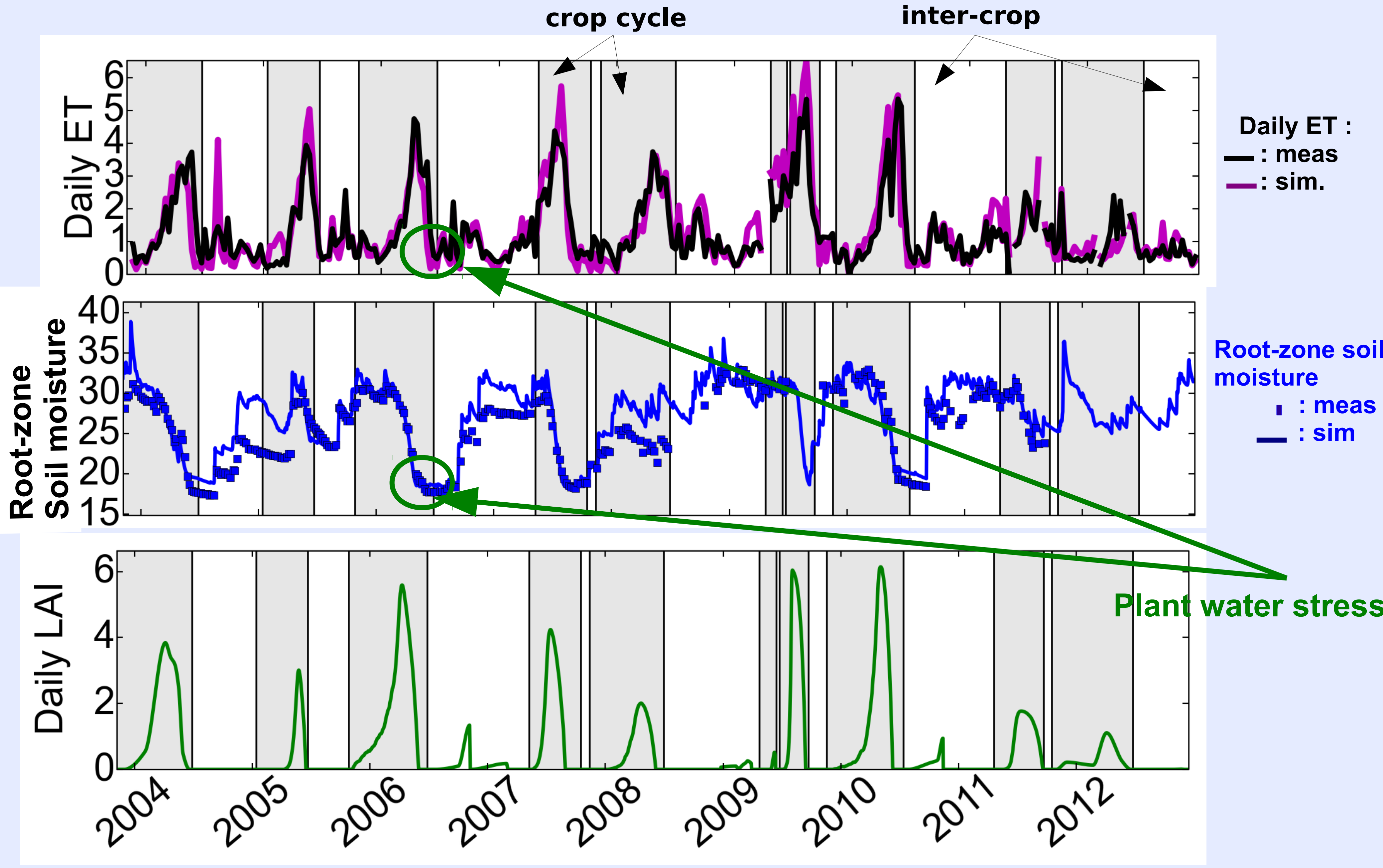
- Continous simulations from **25 April 2001 to 15 March 2015**
- **Explicit representation of crop succession**
  - Crop periods: C3, C4 crop model patch,
  - Inter-crop periods : bare soil model patch.

4. RESULTS

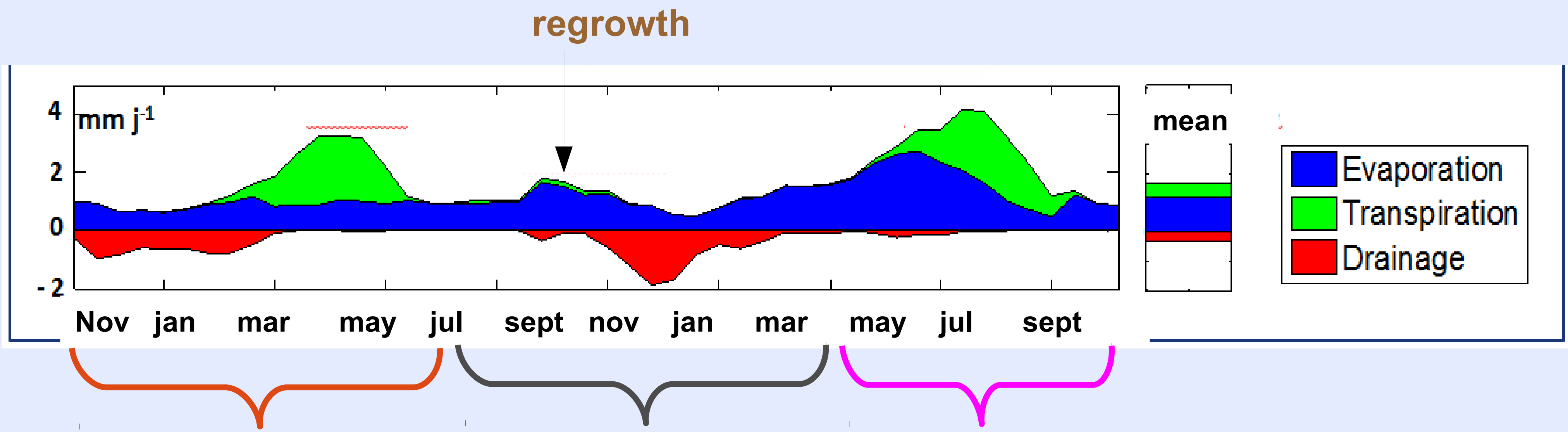
Q1) How crop succession drives the dynamics of ET, ET soil/vegetation partitioning and drainage ?

Garrigues et al., HESS, 2015

Influence of crop rotation on ET and soil moisture dynamics

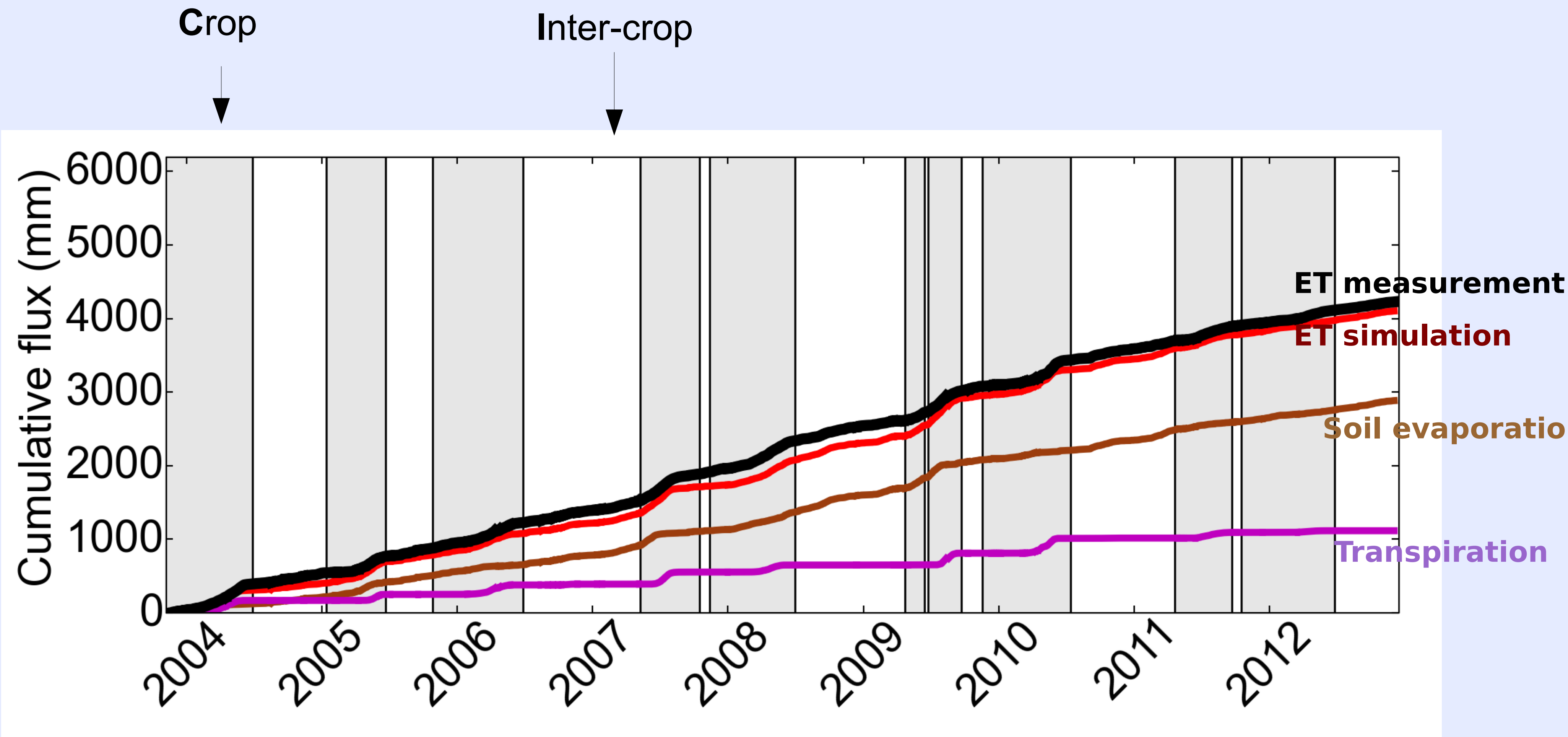


Influence of crop rotation on the water balance dynamic



- **Transpiration : large flux, short period of time**
- **Soil evaporation : lower value but steadier over the crop succession**
- **Drainage : intermediate values during autumn and winter rainy season**

Influence of crop rotation on ET partitioning



➡ **Soil evaporation represents 70 % of cumulative evapotranspiration over 9 years of crop succession**

➡ **Soil evaporation main source of uncertainty in ET**

Q.2) What is the most influential source of uncertainties

- climate,
- vegetation dynamic,
- irrigation,
- soil parameters

on ET simulation over a crop succession ?

Garrigues et al., GMD, 2015

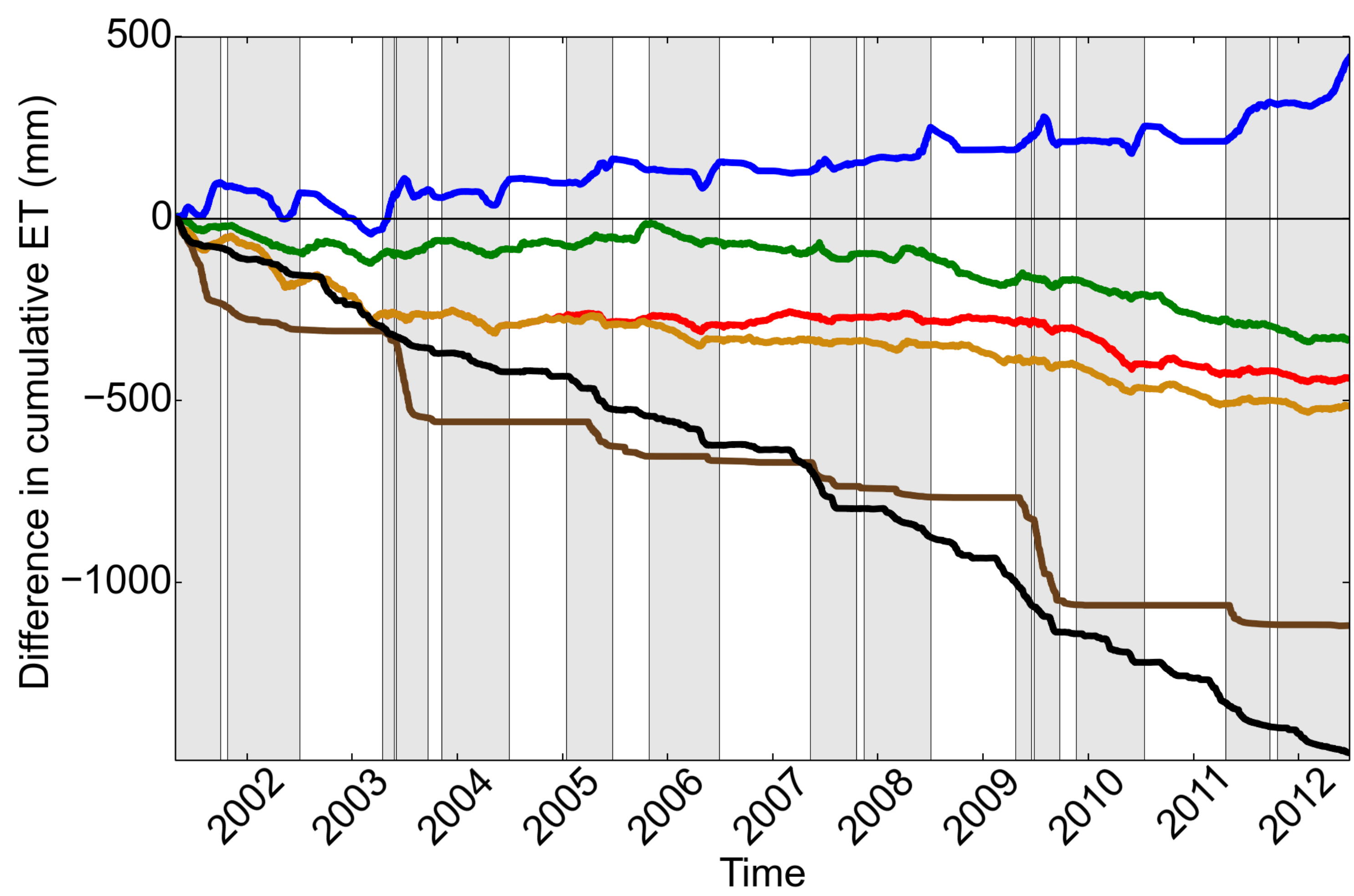
Experiment design

Experiments with local vs standard/large-scale drivers

Experiments	Climate	Vegetation	Soil parameters	Irrigation
CTL	Local	Local	Local	Local
SAFRAN	SAFRAN	Local	Local	Local
ERA-I	ERA-I+GPCC rainfall	Local	Local	Local
SAFRAN+MSG	SAFRAN+MSG radiation	Local	Local	Local
NO IRRIG	Local	Local	Local	No
LAI-ECOCLIMAP	Local	ECOCLIMAP climatology	Local	Local
PTF-SOIL	Local	Local	ISBA Pedotransfer	Local

Sensitivity of ET to driver uncertainties

Difference in cumulative ET between each experiment and the control run (CTL)



Sources of uncertainties

Vegetation : LAI (6 %)

ERA-I
SAFRAN
SAFRAN+ MSG

Climate (5-7%)

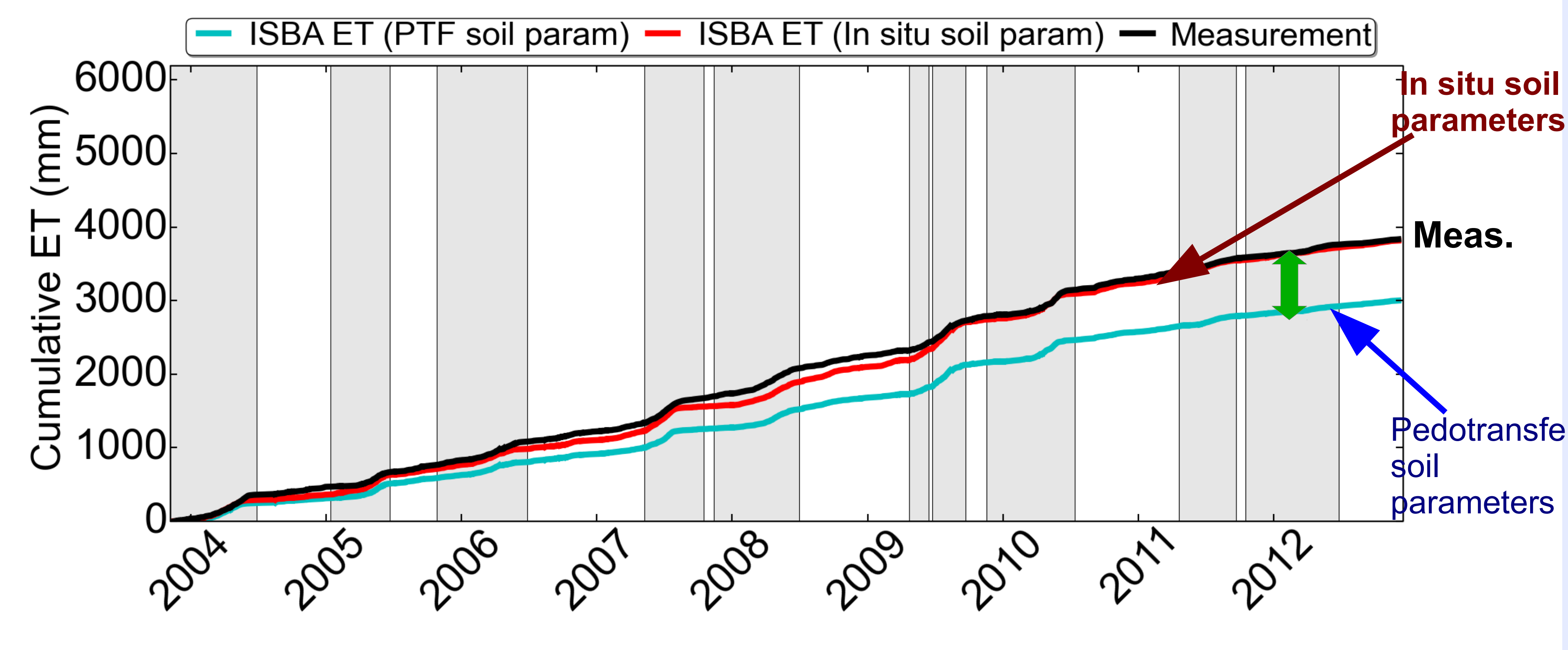
No Irrigation (15%)

Soil parameters (20%)

Errors in soil parameters and having no irrigation are the most influential drivers on ET

Impact of errors in soil hydrodynamic parameters

Pedotransfer (PTF) versus in situ soil parameters (derived from soil moisture meas.)



- PTF parameters: ~800 mm deficit (20%) in cumulative ET over 9 years

- In situ soil parameters: bias reduced by 98 %

- Available soil water content for the plant → transpiration
- Soil moisture at saturation and field capacity→ soil evaporation

Q.3) What are the impacts of

- **errors in soil parameters,**
- **water transfer scheme: Force-Restore vs multi-layer soil diffusion scheme,**

on ET simulation over a crop succession ?

Garrigues et al., HESS, 2015

Garrigues et al., GMD, 2017, to be submitted

Experiment design

4 Experiments derived using either :

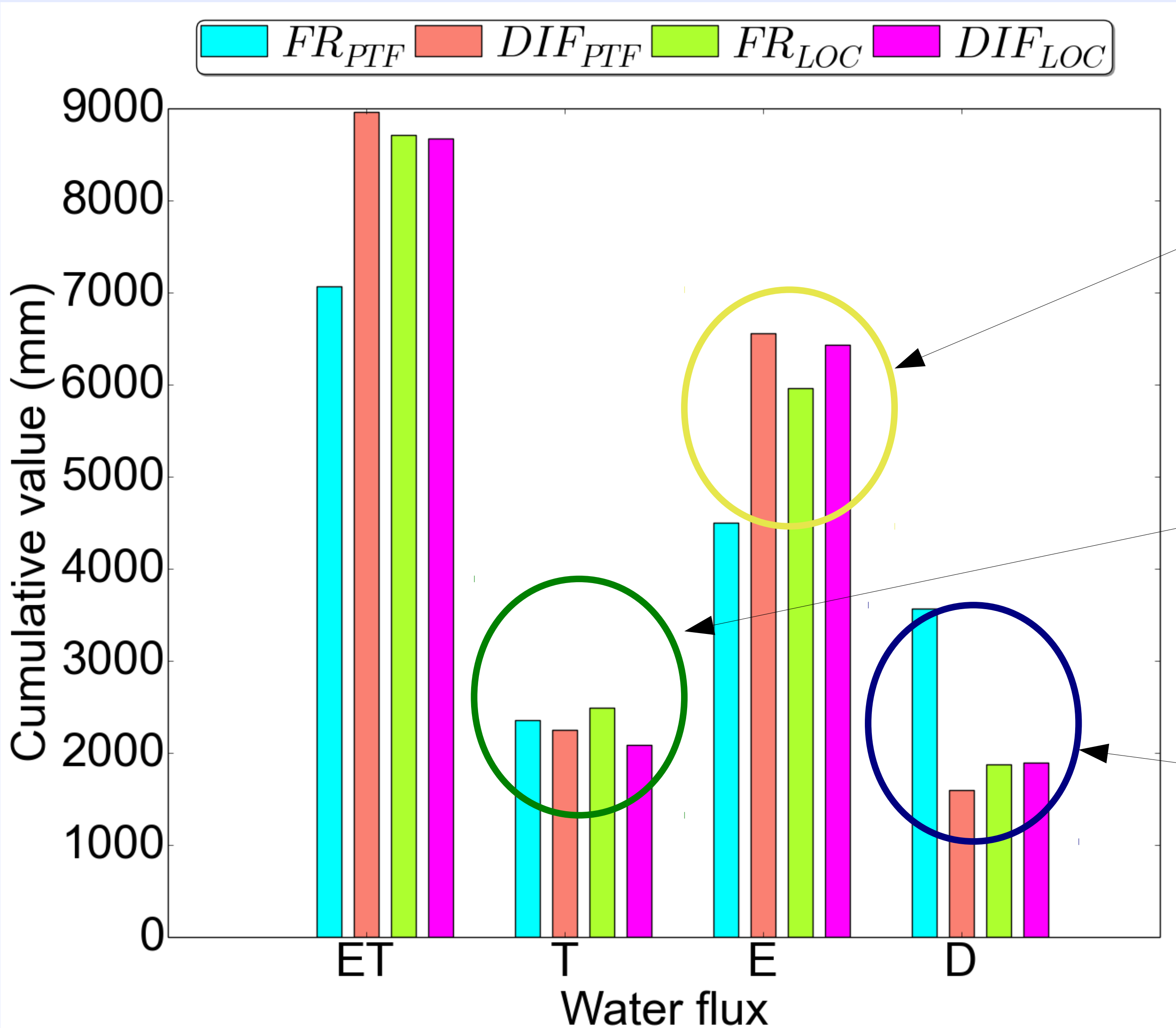
- **Soil parameters: pedotransfer (PTF) vs local estimates**
- **Water transfer schemes: Force-Restore (FR) vs multi-layer soil diffusion (DIF)**

Experiments	model	Soil parameters
FR_{PTF}	Force-Restore	pedotransfer
DIF_{PTF}	Multi-layer soil diffusion	pedotransfer
FR_{LOC}	Force-restore	local
DIF_{LOC}	Multi-layer soil diffusion	local

Soil parameters driving ET uncertainties (Garrigues et al., 2015) :

- **Soil moisture at saturation, field capacity, wilting point**
- **Rooting depth, root profile parameters**

Differences in cumulated soil evaporation, transpiration and drainage between experiments



Impact of soil parameters : PTF vs local

Soil evaporation (E)
FR : increase

DIF : no changes

Transpiration (T)
FR : increase

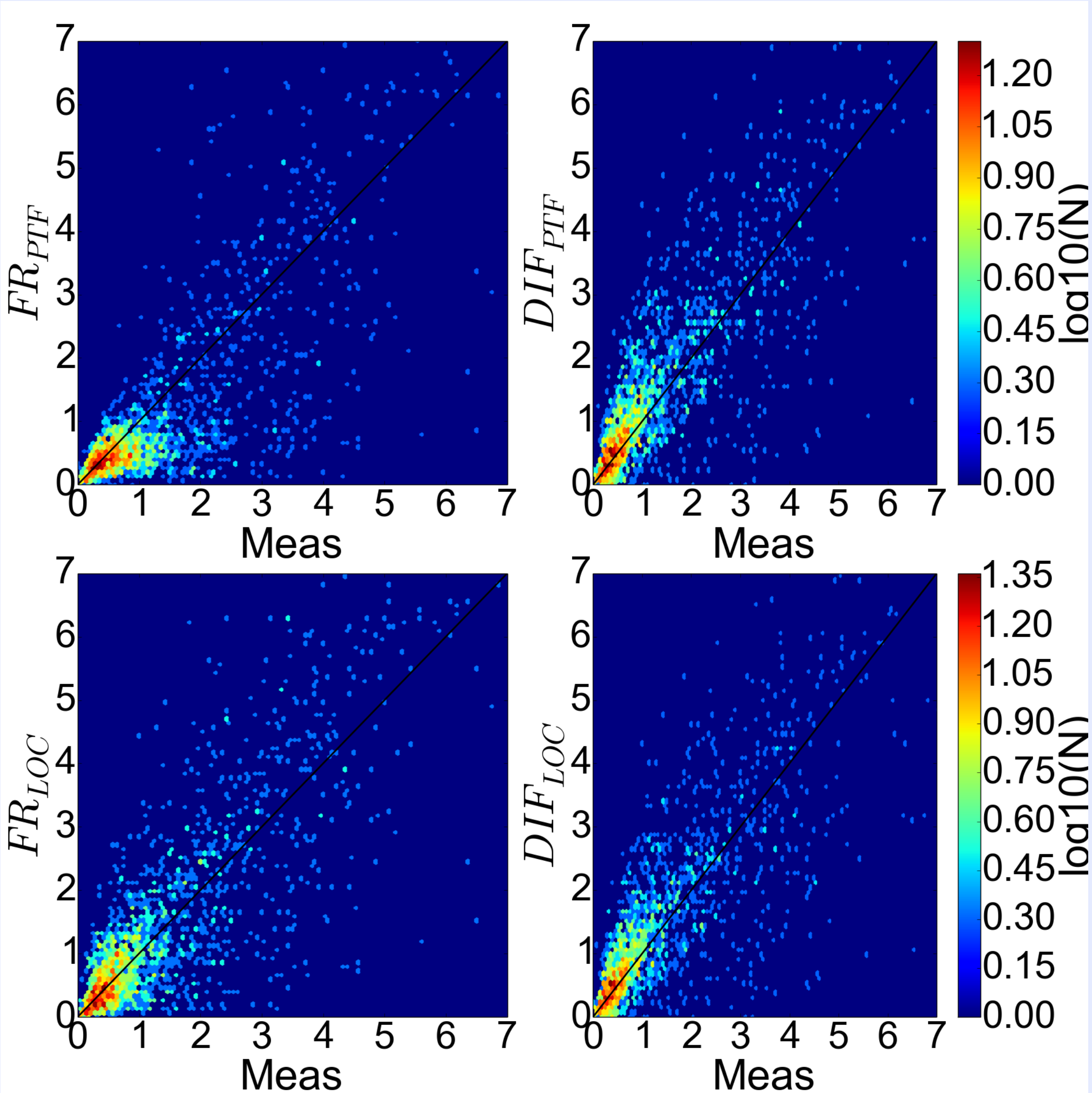
DIF : slight decrease

Drainage (D):
FR : decrease

DIF : no impact

Overall performances of experiments

Daily evapotranspiration (mm.day^{-1})



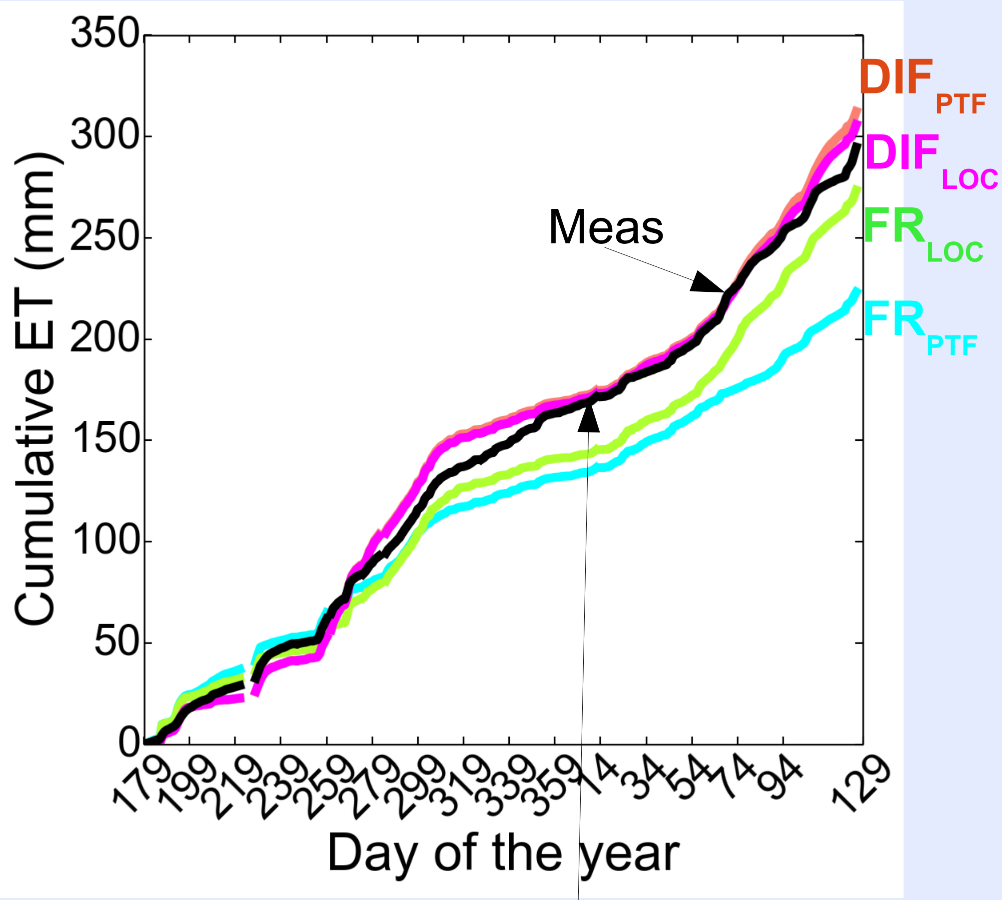
	r	bias	SDD
FR_{PTF}	0.77	-0.26	0.85
DIF_{PTF}	0.80	0.15	0.81
FR_{LOC}	0.80	0.05	0.84
DIF_{LOC}	0.78	0.09	0.82

- **When pedotransfer estimates are used** :
  Best performances for **DIF**

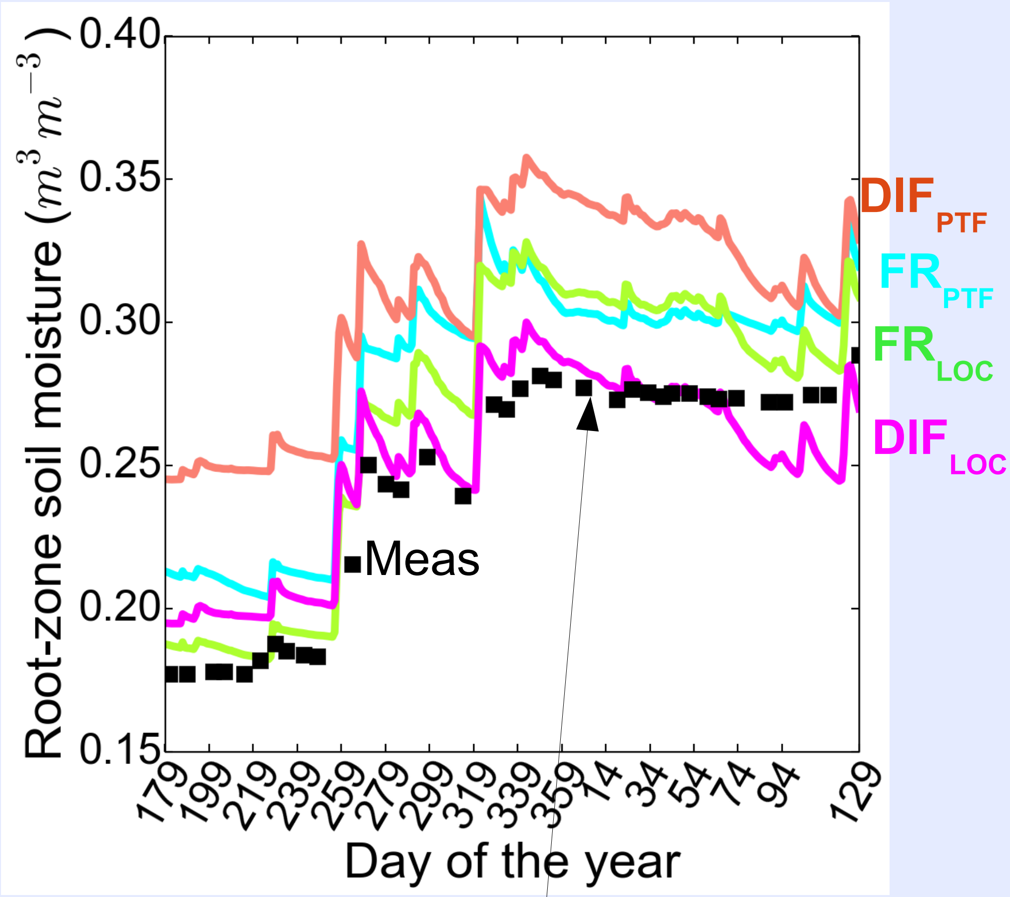
- **When local parameters are used** :
  Best performances for **FR**

Evaluation over bare soil period

Evapotranspiration



Root-zone soil moisture

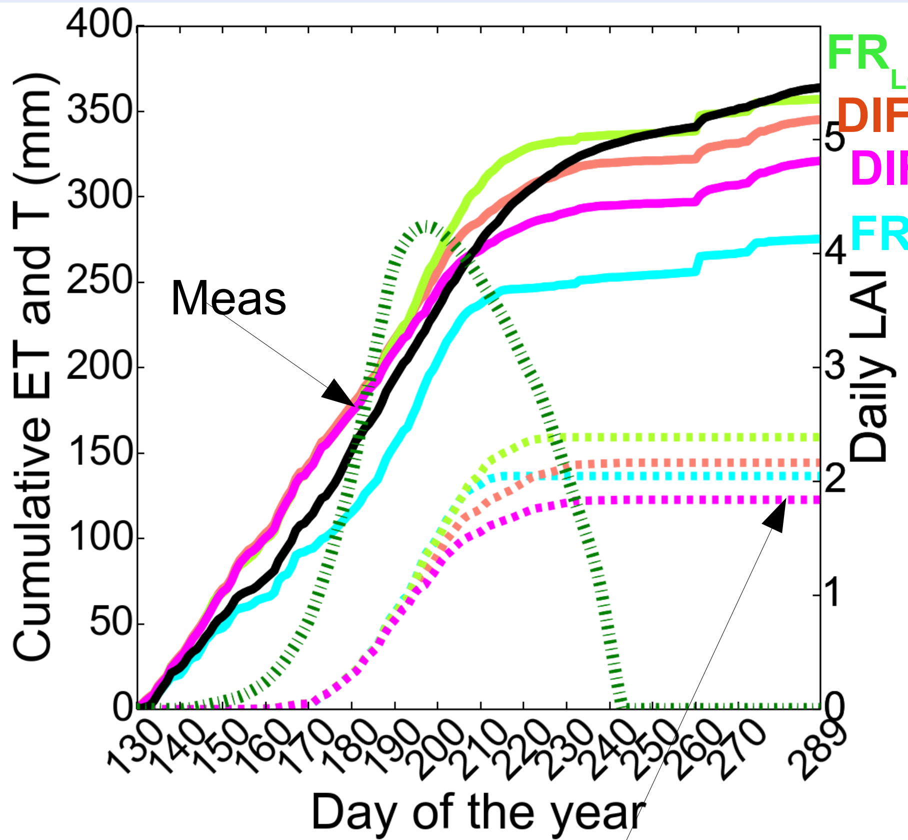


DIF : Accurate simulation of soil evaporation

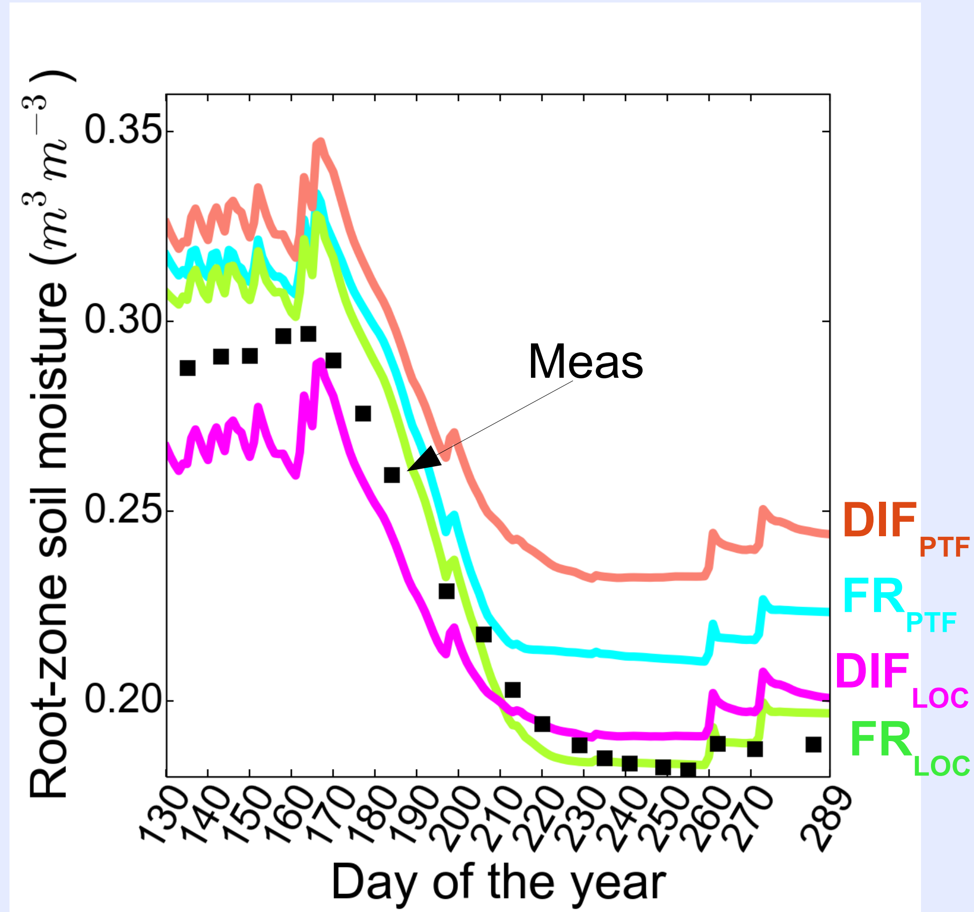
Accurate simulation of soil moisture

Evaluation over crop period

Evapotranspiration



Root-zone soil moisture



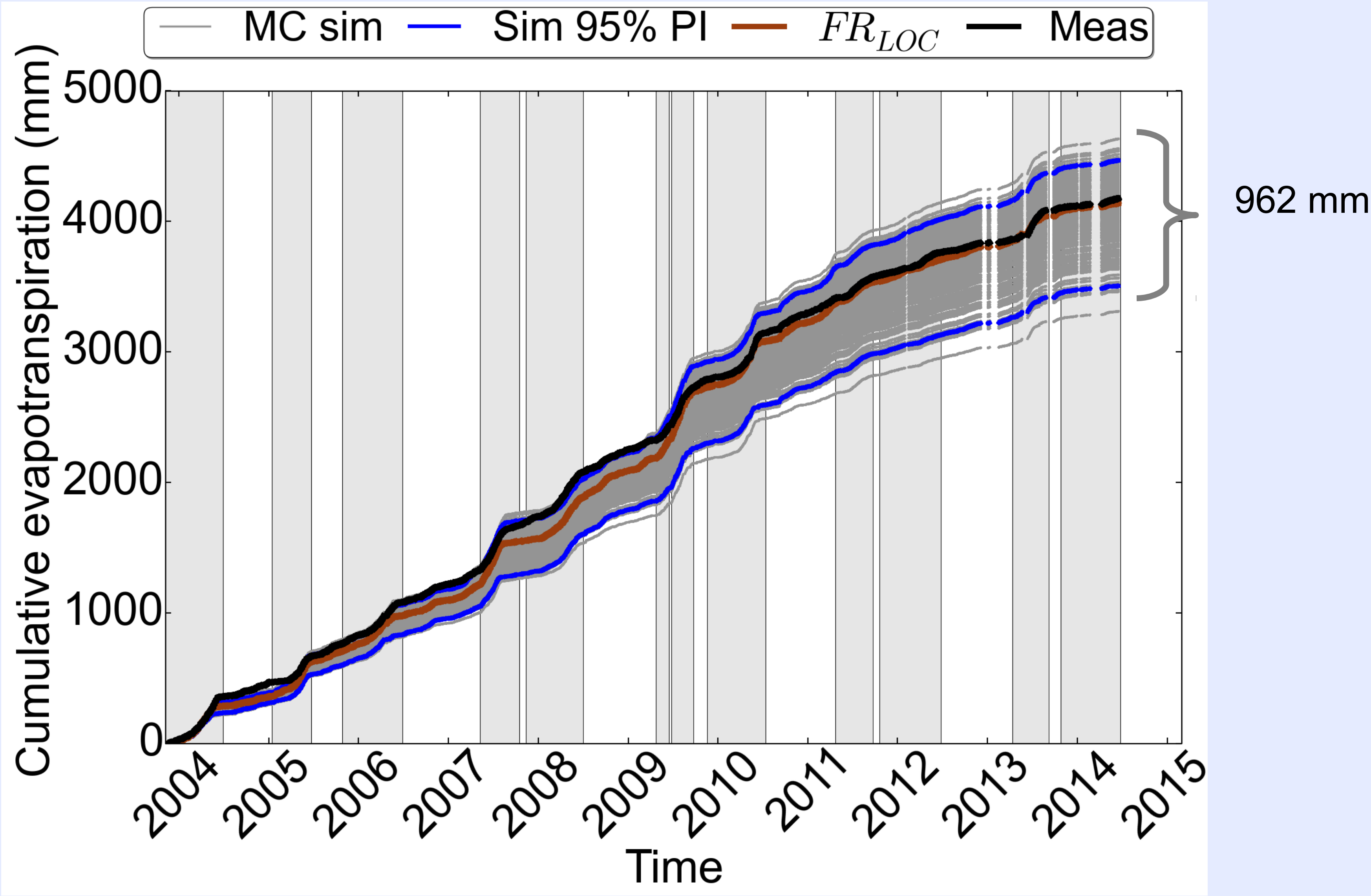
Underestimation of transpiration by DIF with local soil parameters

Uncertainties in root-profile parametrization

Sensitivity to uncertainties in soil parameters

Monte-Carlo analysis

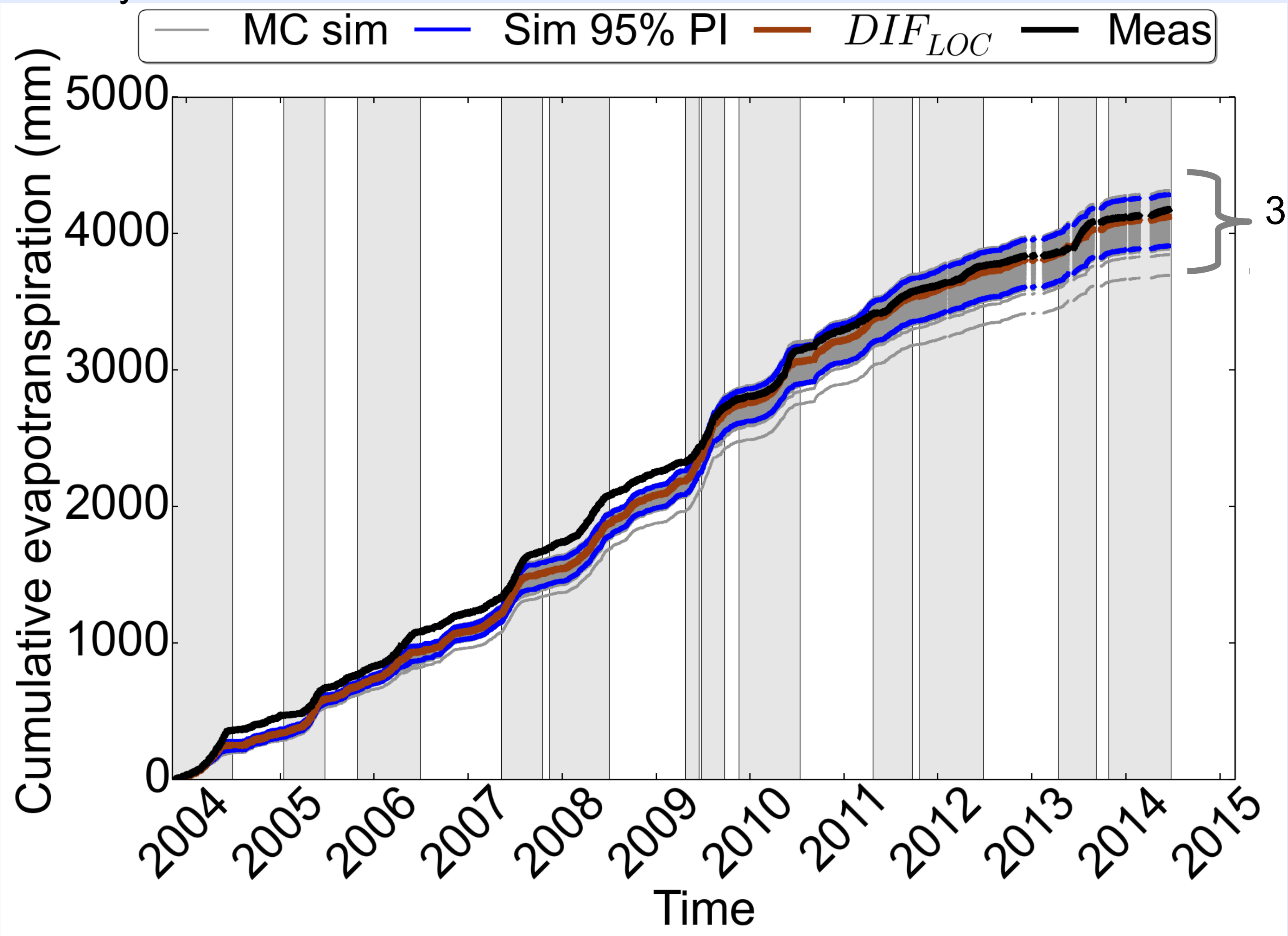
FORCE-RESTORE



Sensitivity to uncertainties in soil parameters

MULTI-LAYER SOIL DIFFUSION SCHEME

Monte-Carlo analysis



5. CONCLUSIONS

Conclusions (1/2)

➔ **Impact of Mediterranean crop succession on ET dynamics**:

- **Soil evaporation is the main ET component**
- **Uncertanties mainly driven by soil evaporation parameters**

➔**Most influential sources of uncertainties on ET**:

- **First order :**
  - ✗ **soil hydrodynamic parameters**
  - ✗ **Irrigation**
- **Second order:**
  - ✗ **vegetation dynamic**
  - ✗ **climate.**

Conclusions (2/2)

➔ **Impact of errors in soil parameters and water transfer scheme**

- Multi-layer soil diffusion scheme more robust to uncertainties in soil parameters
- Force-Restore easier to calibrate at local scale
- Soil evaporation
  - ✗ DIF: accurate simulation of soil evaporation
  - ✗ FR: highly sensitive to soil moisture at field capacity and saturation
- Transpiration
  - ✗ DIF,FR: sensitive to available water content for the plant
  - ✗ DIF: Influence of root-profile parametrization on simulation of water stress

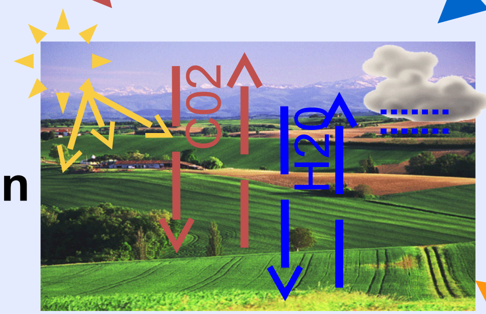
Additional slides

Introduction (1/3): climate change context

Likely increase in evaporative demand (rise in temperature and radiations)

Likely decrease in soil moisture availability (5 to 30 % decrease in rainfall)

Mediterranean



cropland

Changes in vegetation processes :
- stomatal conductance
- crop phenology

Adaptations of agricultural practices:
- irrigation calendar
- early sowing date
- Intermediate crop in winter

Modifications of long-term dynamics of evapotranspiration (ET)

How improving the representation of ET in land surface models ?

Introduction (2/3)

Sources of uncertaities in modelled ET

- **Representation of crop phenology**
  - Emergence date
  - Winter/summer crops
- Water stress :
  - type of stress function
  - Implementation in the A-gs model
- **Energy budget :**
  - **single source vs dual source**
  - **heterogeneous crops**
- **Soil water transfer**
  - **Force-restore vs Multi-layer soil diffusion scheme**
  - **Hydraulic parameters**
  - **spatial distribution**
- **Irrigation**:
  - timing
  - variability of practices

Force-restore model

➔ **Bulk reservoir scheme** with 2 or 3 reservoirs

➔**Force-restore approach from Deardorff (1977)**:

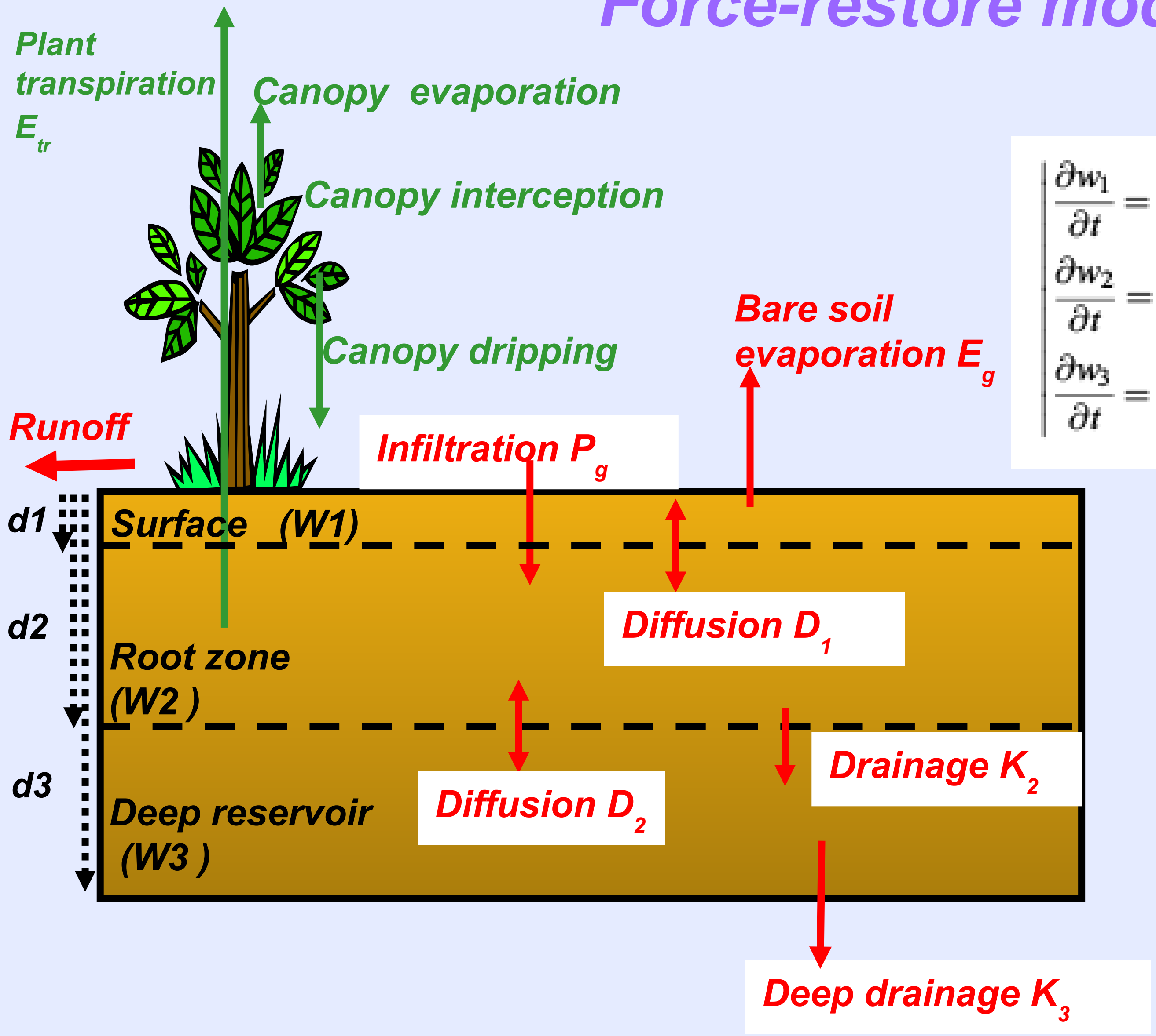
- Based on by Bhumralkar (1975) and Blackadar (1976) approach for heat transfer
- the superficial soil moisture content is forced by the soil evaporation minus precipitation and restored toward the total moisture content of the soil reservoir.

➔Water transfers simulated according to **moisture content gradient**

➔Main assumption: **homogeneous soil profile**

➔**Few parameters**: advantage for coupling with atmospheric models

Force-restore model



$$
\begin{cases}
\dfrac{\partial w_1}{\partial t} = \dfrac{C_1}{\rho_w d_1}\left(P_g - E_g\right) - \dfrac{C_2}{\tau}\left(w_1 - w_{eq}\right) & \forall w_1 \leq w_{sat} \\
\dfrac{\partial w_2}{\partial t} = \dfrac{1}{\rho_w d_2}\left(P_g - E_g - E_{tr}\right) - K_2 - D_2 & \forall w_2 \leq w_{sat} \\
\dfrac{\partial w_3}{\partial t} = \dfrac{d_2}{(d_3 - d_2)}(K_2 + D_2) - K_3 & \forall w_3 \leq w_{sat}
\end{cases}
$$

Multi-layer soil diffusion model

➔ Multi-layer (N) soil discretization

➔ Explicit representation of mass-diffusive equations (Richard's equation)

$$\frac{\partial w_i}{\partial t} = -\frac{\partial q(z)}{\partial z} \Leftrightarrow \frac{\partial w_i}{\partial t} = -\frac{\partial}{\partial z}\left[k\left(\frac{\partial \psi}{\partial z} + 1\right)\right]$$

Soil moisture time course

Matric potential

hydraulic conductivity

➔ Representation of soil vertical heterogeneity

- Vertical **gradient in soil texture and soil texture**: impact on evaporation and infiltration
- Account for **upward diffusion** from shallow **water table** : impact on soil evaporation
- **Root profile**: improve the representation of the plant response to soil water stress

Multi-layer soil diffusion model

Source/sink term

Matric potential gradient between 2 layers

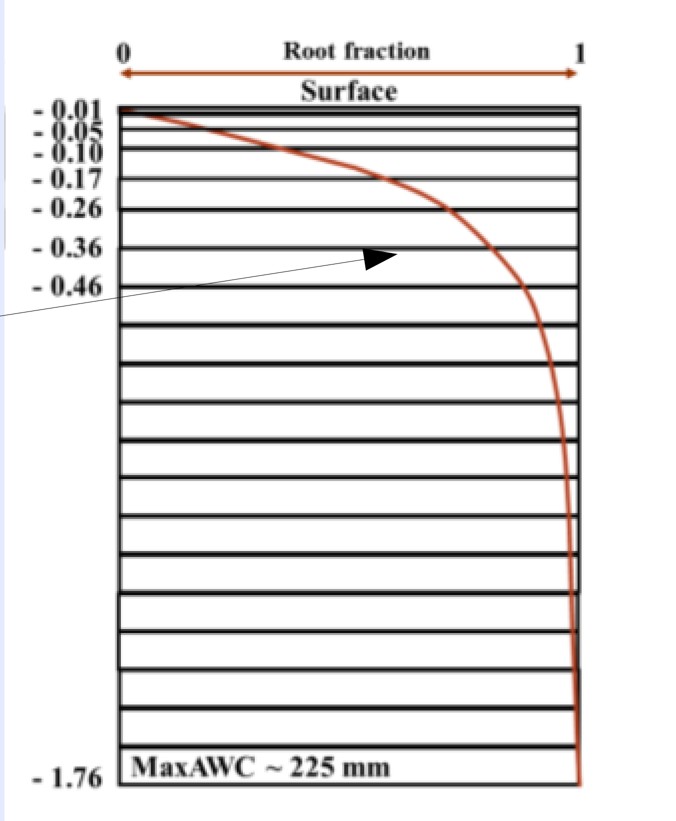
$$\frac{\partial w_i}{\partial t} = \frac{1}{\Delta z_i}\left[F_{i-i} - F_i + \frac{S_i}{\rho_w}\right] \quad \text{with} \quad F_i = \bar{k}_i\left(\frac{\psi_i - \psi_{i+1}}{\Delta \bar{z}_i} + 1\right) + \bar{\nu} i\left(\frac{\psi_i - \psi_{i+1}}{\Delta \bar{z}_i}\right),$$

Mean hydraulic conductivity

Layer width

Mean isothermal vapor conductivity

Soil moisture tendency



Root profile :
e.g. exponential model from
Jackson et al. model (1996)

$$Y\left(d_k\right) = \left(1 - R_e^{100\times d_k}\right) / \left(1 - R_e^{100\times d_R}\right),$$

Root extinction coefficient

Cumulative root fraction between surface and depth d_k

Soil hydraulic characteristics

➔ Soil water-retention curve and soil water conductivity curve: van Genuchten, (1980); Brooks and Corey. (1966)

e.g. Brooks and Corey, 1966 (residual soil moisture=0)

Slope of the water-retention curve

$$\psi(w) = \psi_{sat}\left(\frac{w}{w_{sat}}\right)^{-b} \quad \text{and} \quad k(\psi) = k_{sat}\left(\frac{\psi}{\psi_{sat}}\right)^{-\frac{2b+3}{b}}$$

Matric potential at saturation

Hydraulic conductivity at saturation

Soil moisture at saturation

➔ Model coefficients and hydraulic properties estimated using pedotransfer functions (PTF) of soil texture

e.g ISBA: continuous relationships derived from the Brooks and Corey. (1966) model and the Clapp and Hornberger (1978) parameters

Multi-layer soil diffusion model

➔Multi-layer soil discretization

➔Explicit solve mass-diffusive equations (Darcy's law and Richard's equation)

➔ Representation of soil vertical heterogeneity

- Vertical gradient in soil texture and soil texture: impact on evaporation and infiltration
- Root profile: improve the representation of the plant response to soil water stress

Source/sink term

Matric potential gradient between 2 layers

$$\frac{\partial w_i}{\partial t} = \frac{1}{\Delta z_i}\left[F_{i-i} - F_i + \frac{S_i}{\rho_w}\right] \quad \text{with} \quad F_i = \bar{k}_i\left(\frac{\psi_i - \psi_{i+1}}{\Delta \bar{z}_i} + 1\right) + \bar{\nu}i\left(\frac{\psi_i - \psi_{i+1}}{\Delta \bar{z}_i}\right),$$

Soil moisture tendency

Layer width

Mean hydraulic conductivity

Mean isothermal vapor conductivity

Experiment design

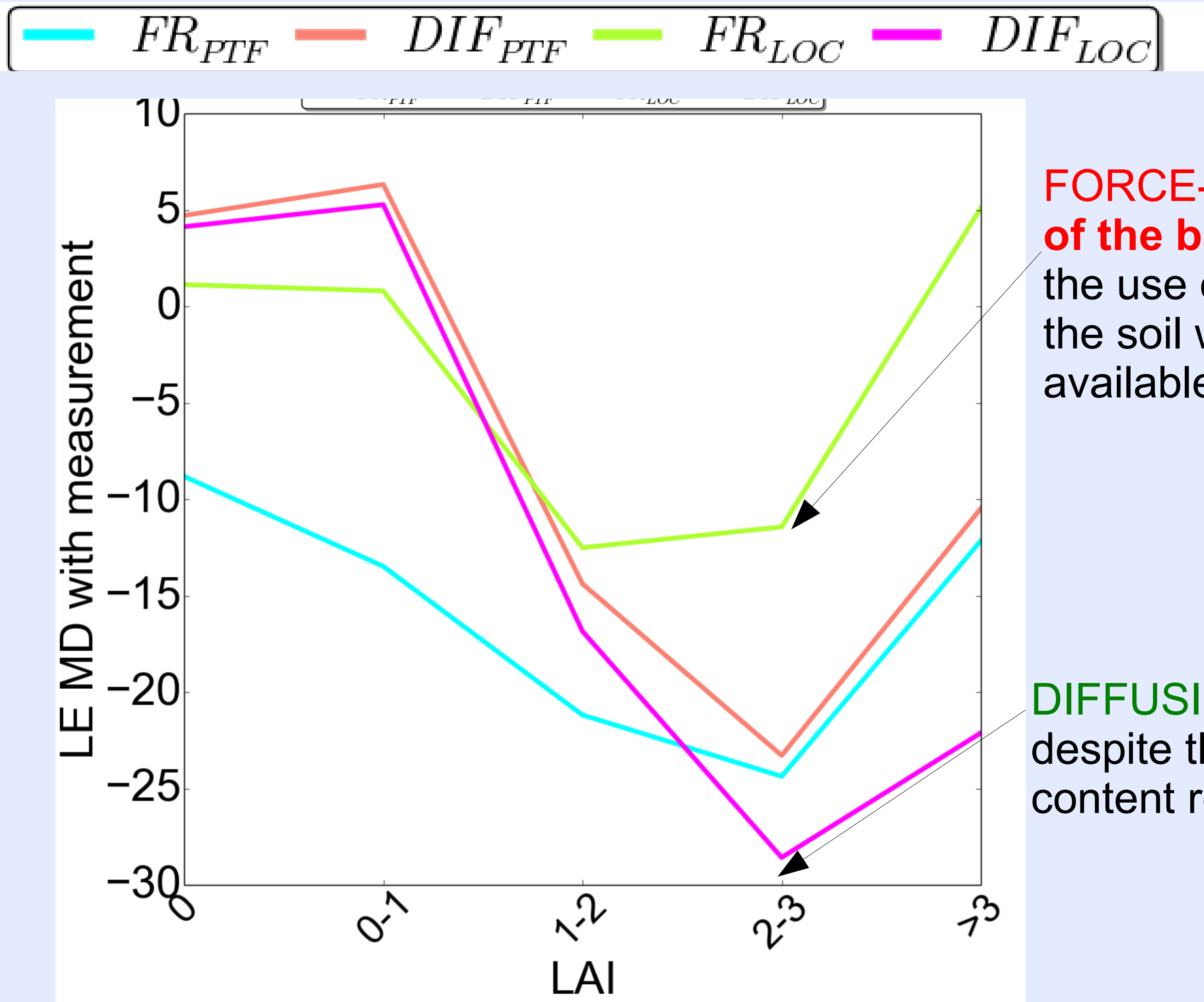
➔ **Control run** (CTL):

- Local climate
- Local LAI
- Local soil parameters (FC, WP, SAT) derived from soil moisture measurements
- Irrigation added to rainfall

➔ **7 Experiments derived from CTL** by replacing local values by :

- **Climate** :
  - SAFRAN reanalysis (8km, 1-h)
  - ERA-I/GPCC reanalysis (0.5°, 3-h)
  - SAFRAN&MSG radiations (3 km,0.5 h)
- **Irrigation**
  - No irrigation
  - Simulated irrigation
- **ECOCLIMAP-II LAI :** monthly climatology derived from MODIS data (Faroux et al, 2013)
- **Soil parameters** : derived from ISBA pedotransfer functions using soil texture

ET performances for different LAI ranges

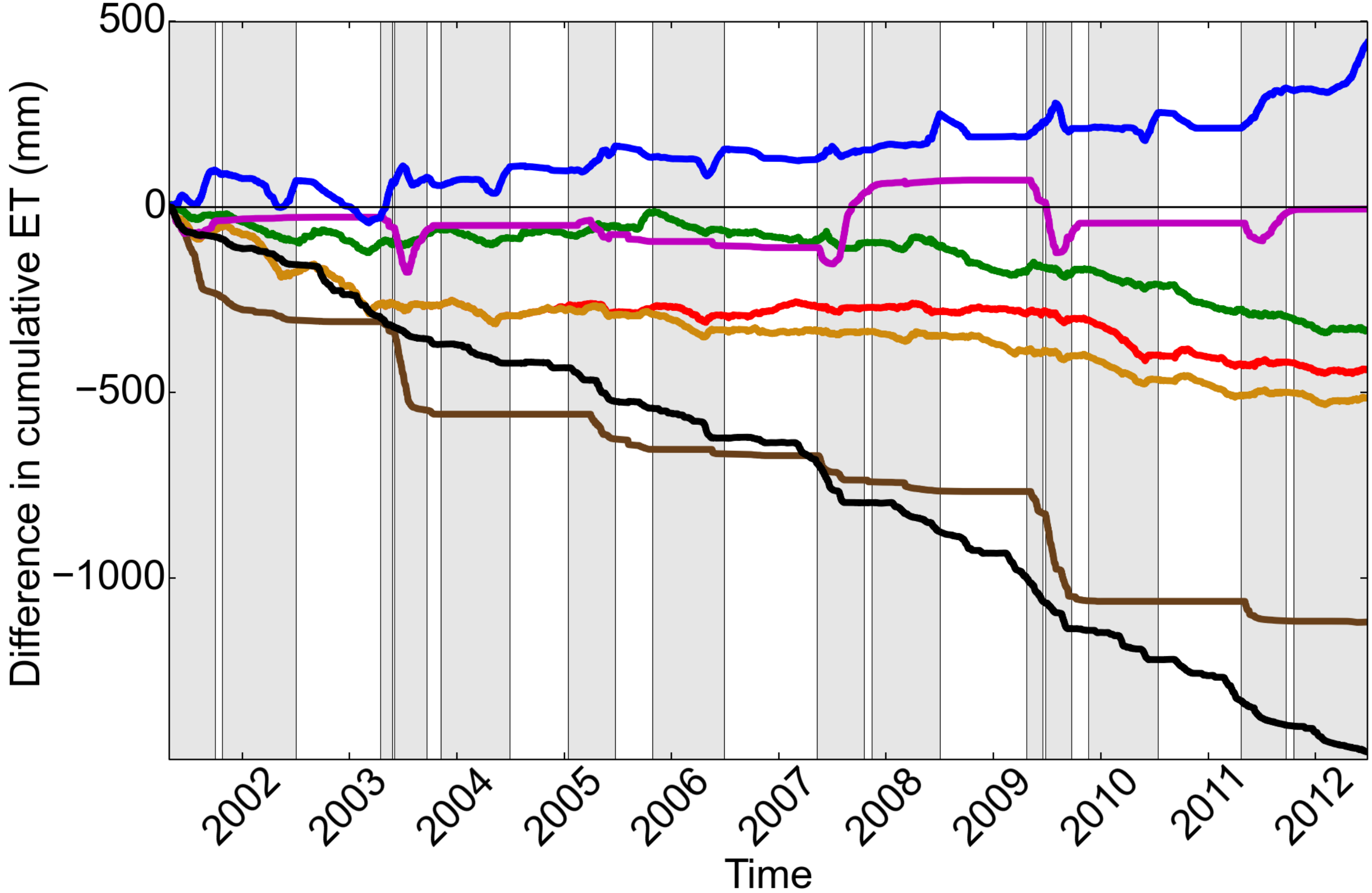


FORCE-RESTORE : **strong reduction of the bias at large LAI** in response to the use of more accurate estimate of the soil water content reservoir available for the crop.

DIFFUSION SCHEME : large bias despite the use of the proper water content reservoir

Results

Difference in cumulative ET between each experiment and the control run (CTL)



Sources of uncertainties

LAI (6 %)

Modeled Irrig (0 %)

ERA-I
SAFRAN
SAFRAN+
MSG

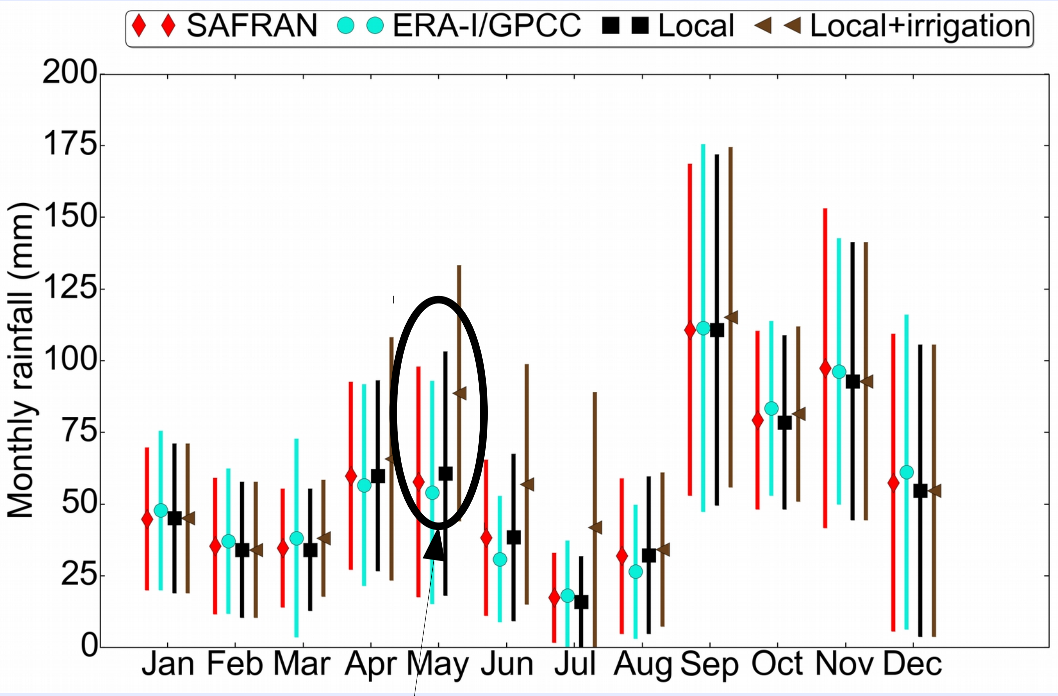
Climate (5-7%)

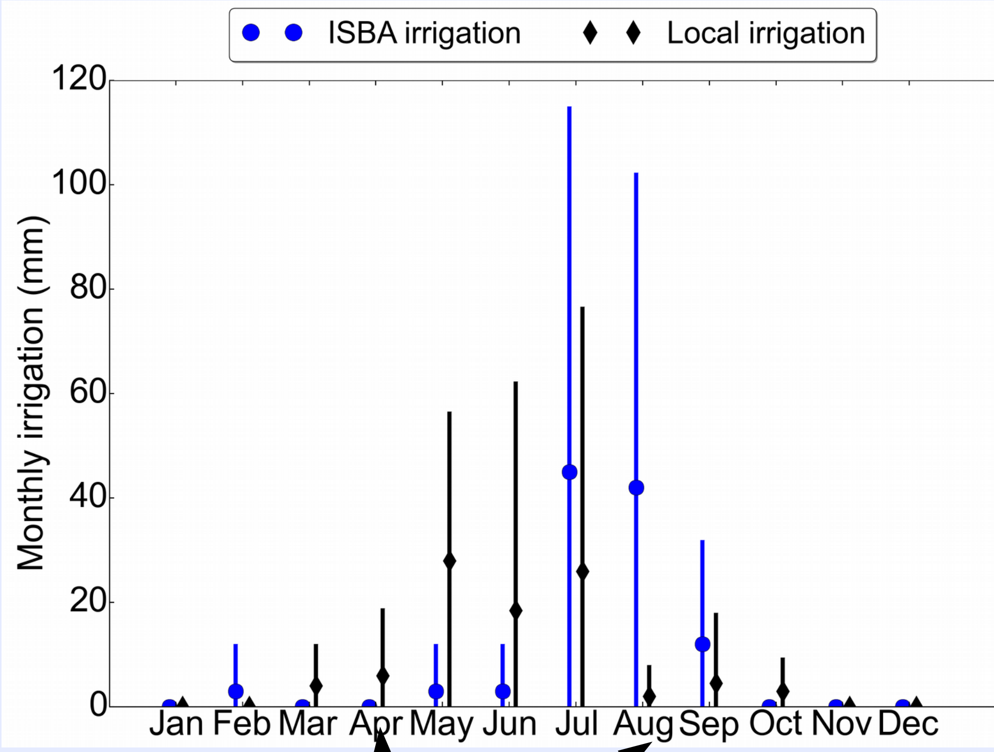
No Irrigation (15%)

Soil parameters (20%)

Errors in soil parameters and having no irrigation are the most influential drivers on ET

Impact of uncertainties in irrigation





Lack of irrigation generates larger variations than differences in rainfall between climate data sets

Inaccurate timing of modeled irrigation

- underestimation in early stage of the crop cycle
- overestimation during senescence

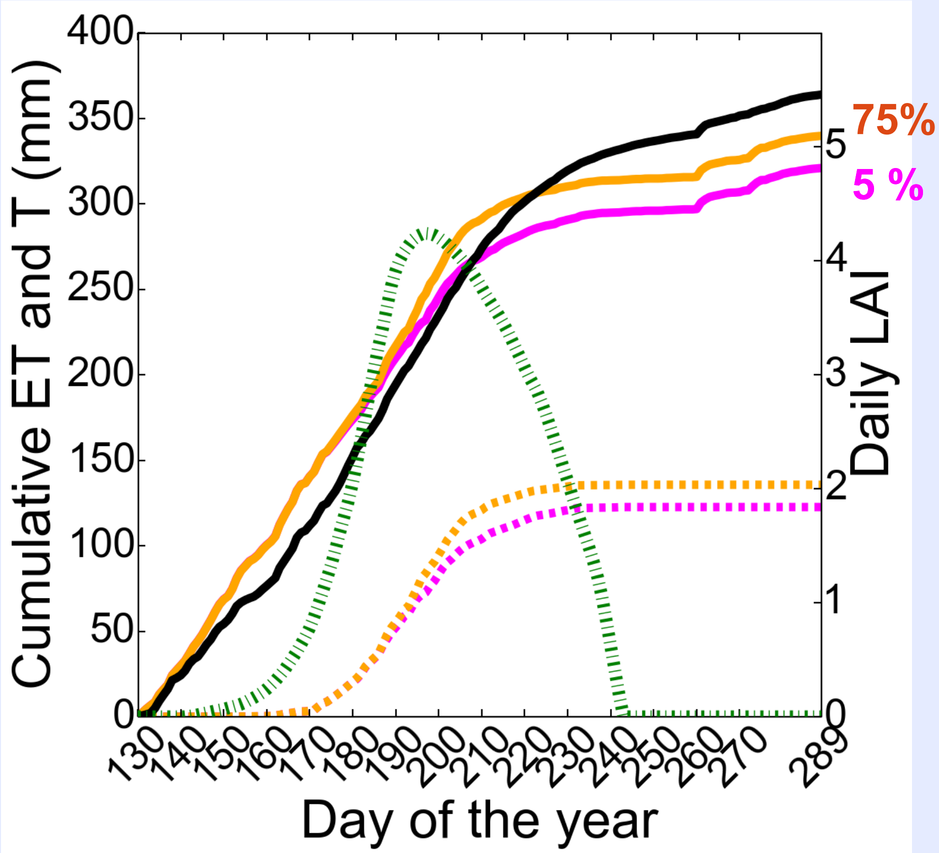
Introduction (2/3)

Sources of uncertainties in modelled ET

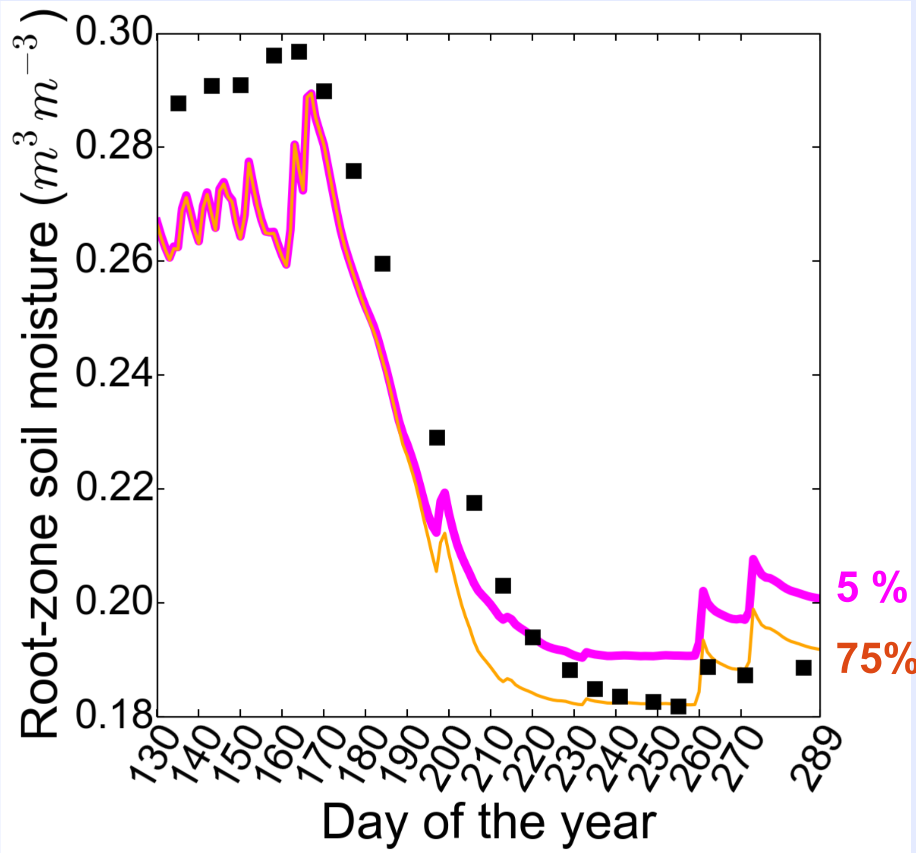
- **Representation of crop phenology**
  - emergence date
  - winter/summer crops
- Water stress :
  - stress function
  - implementation in the A-gs model
- **Energy budget :**
  - **sparse vegetation**
  - **single source vs dual source**
- **Soil water transfer**
  - **Force-restore vs Multi-layer soil diffusion scheme**
  - **spatial distribution of hydraulic parameters**
- **Irrigation**:
  - timing
  - variability of practices

Impact of exponential vs homogeneous root distribution

Evapotranspiration



Root-zone soil moisture



Slight impact of root-profile parametrization

Smaller impact than the differences between FR and DIF