Sensitivity of soil moisture related drought indices to calibration data

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Problem position

- Modelling time distribution of soil moisture is a key issue for natural vegetation and crop survey and is often adopted when deriving drought awareness indices.
- In drought risk analysis, it is very important to analyze uncertainty in model outputs

Climatic context: Average annual P, R_n ETR estimation

based on dryness index P/R_n or P/ETP

Budyko (1974) approximation of the solution of 1LWBM (P/R_n)

$$\mathrm{ETR} = [Rn/P \tanh(\frac{P}{Rn})(1-\cosh(\frac{Rn}{P})+\sinh(\frac{Rn}{P}))]^{\frac{1}{2}}$$

Hsuen Chun HC (1999) Approximation of Budyko model (P/ETP)

$$\mathrm{ETR} = \mathrm{ETP}\left[\frac{(P/ETP)^K}{1+(P/ETP)^K}\right]^{\frac{1}{K}}$$

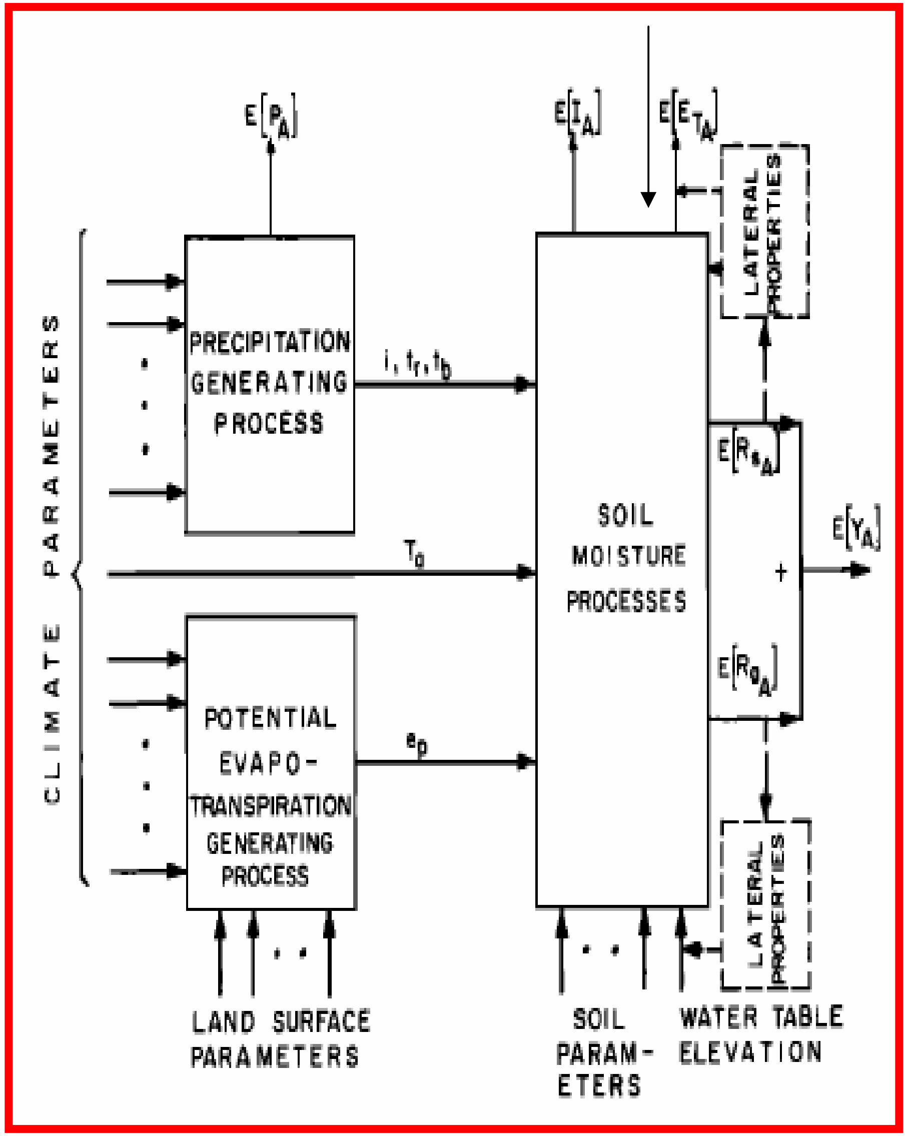
Budyko model is adopted to estimate average annual ETR using a hydrometeorological network composed by 18 stations and to derive average annual regional runoff Rs **(Av P = Av ETR + Av Rs)**

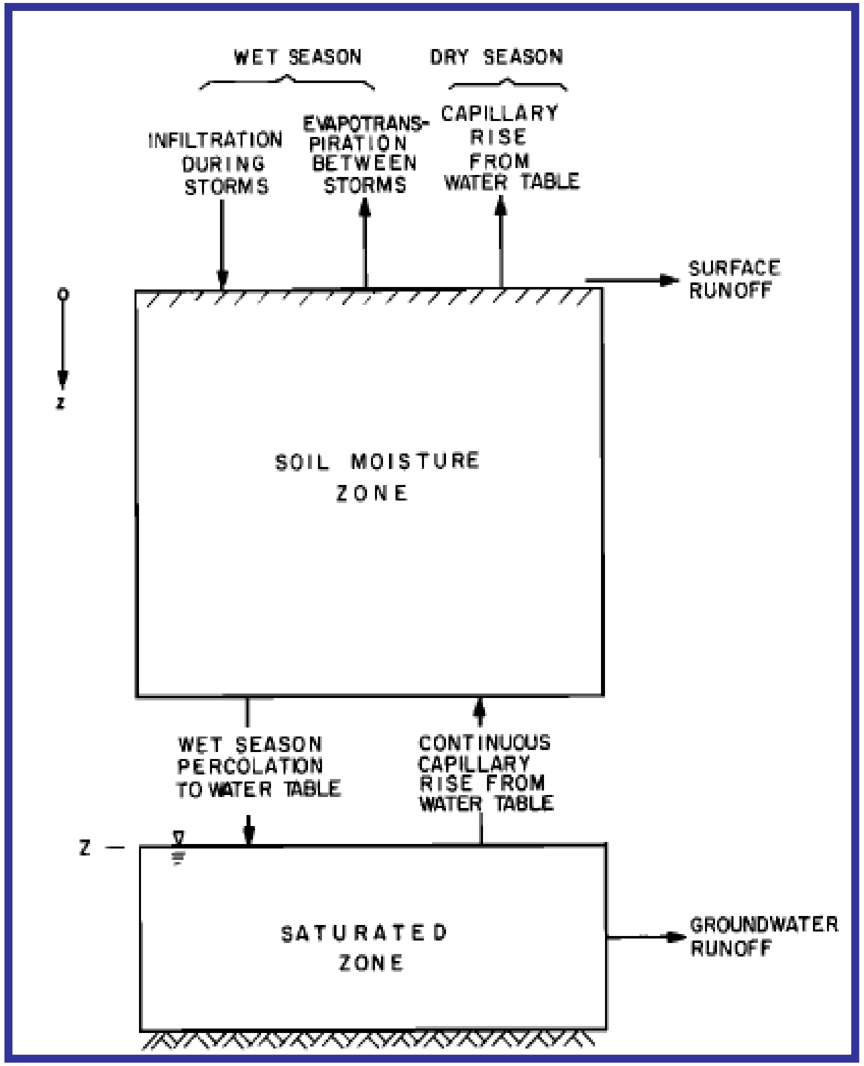
According to observations from **18 gauged basins** estimated Rs match observed Rs for **k=1.5**

Models of soil moisture dynamics

- (Eagleson (1978), Milly (1993), Milly (1994), Rodriguez-Iturbe et al. (1999) and Rodriguez-Iturbe (2002)).
- Evaluation of soil moisture and evapotranspiration in terms of :
  - soil and vegetation parameters
  - climatic variables
    - storm depth and duration,
    - dry season length,
    - average annual potential evapotranspiration

Water balance representation EAGLESON, P. S. (1978).Climate, Soil, and Vegetation. Dynamics of the Annual Water Balance. W. R. R VOL. 14, 5, 749, 764





- A one layer vertically averaged water budget over the root zone taking into account
- infiltration, runoff, drainage, leakage, evapotranspiration losses and capillary rise

Water balance representation Rodriguez-Iturbe et al. (1999) Probabilistic modelling of water balance at a point: the role of climate, Soil, and Vegetation. Proc. R. Soc. London A (1999) 455, 3789-3805.

$$nZ_r \frac{dS}{dt} = I(S,t) - L(S) - E(S)$$

Rates of Infiltration I; Leakage L (deep infiltration); evapotranspiration E, relative soil moisture S

n porosity; Zr soil depth,

Loss from leakage and capillary rise

$$L(S) = K_{sat} \frac{e^{B(S-S_{FC})} - 1}{e^{B(1-S_{FC})} - 1}$$

conductivity K_{sat}

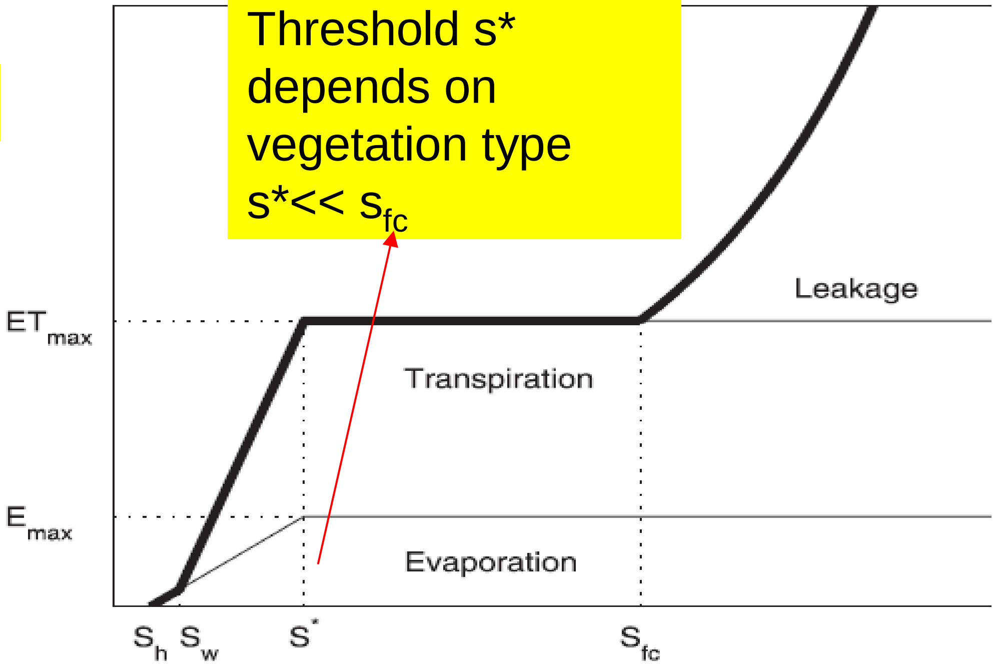
Field capacity S_{FC} :

G_d= exp((nS-a)/b) - c

a, b, c (K_{sat}, S_{FC}, B)

capillary rise component **(Kobayachi et al., 2001)**

Threshold s* depends on vegetation type s*<< s_{fc}



Runoff dependence from soil moisture

- Whenever the soil have enough available storage to accommodate the rainfall infiltrating the soil, it results an increment n soil moisture.
- Whenever the rainfall depth exceeds the available storage, the excess water is converted to excess runoff.

Runoff computation

For $S=W_{BC}$

if $P(t)>ETR(t)+Gd(t)$

$Rs(t)=P(t)-ETR(t)-Gd(t)$

else $Rs(t)=0$

For $S < WBC$

if $P(t)>ETR(t)+Gd(t)+(W_{BC}-S)$

$Rs(t)= P(t)-ETR(t)-Gd(t)-(W_{BC}-S)$

else $Rs(t)=0$

with $W_{BC = \eta*}W_{max}$

Capillary rise component of Kobayachi model Linkage with pedo transfer parameters and

- 0< σ <1 ; 0 < η < 1

$$a = W_{max}[-\frac{1}{B} Ln(K_{sat} \frac{1}{e^{B(1-S_{FC})} - 1}) + S_{FC}]$$

$$b = W_{max} \frac{1}{B}$$

$$c = K_{sat} \frac{1}{e^{B(1-S_{FC})} - 1}$$

Model parameters

- (1) soil water retention curve shape parameter *B*, slope of log ψ versus $\log(\theta/\theta_s)$ regression.
- (2) saturated hydraulic conductivity K_s,
- (3) saturated soil water content θ_s (volume/volume).
- (4) σ resistance of vegetation to evapotranspiration
- (5) η the moisture retaining capacity

- **Parameters estimation:**
- (1) to (3) are evaluated after Cosby et al. (1984)

Multiple linear regression analysis of parameters by textural class (%Clay, %Sand, %Silt)

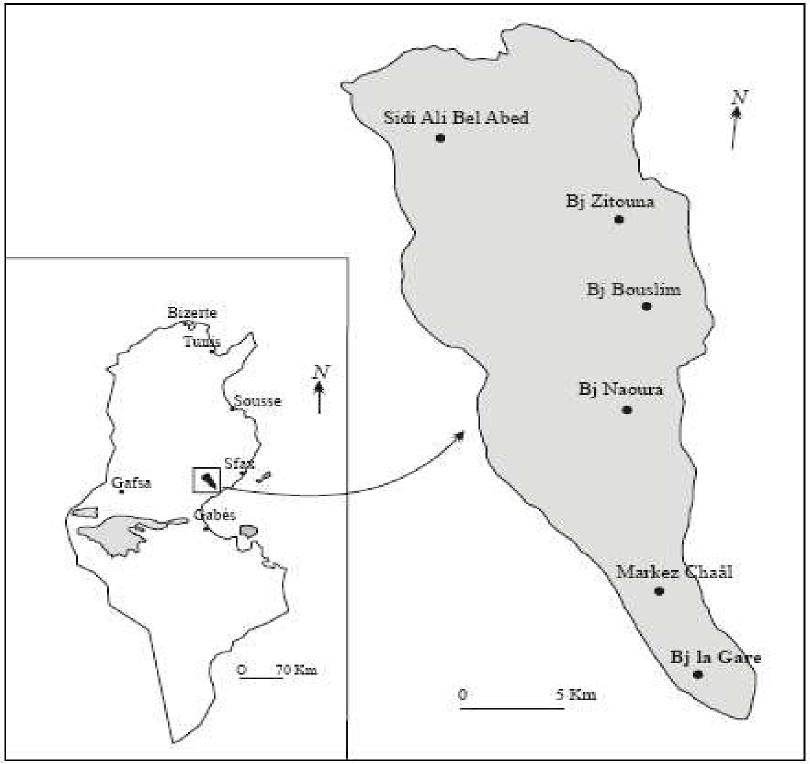
- (4) and (5) are **data driven**

Case study

- To illustrate the methodology, a case study of a basin with an area of 250 km² in arid area of South Tunisia is presented.
- Vegetation is mainly olives, with no irrigation.
- The soil type is sandy.

P=0.34; %S=93.3; %C=6.

- Climate: arid



Data

- Meteorological data : (at Chaal meteo station 30 km far).
- T, V, H (1989-1990, 2003-2004, 2004-2005
- Pan evaporation (3 years), Piche evapotranspiration (17 years)
- P (17 years); (1989-2005)
- Profiles of soil temperature (3 years)

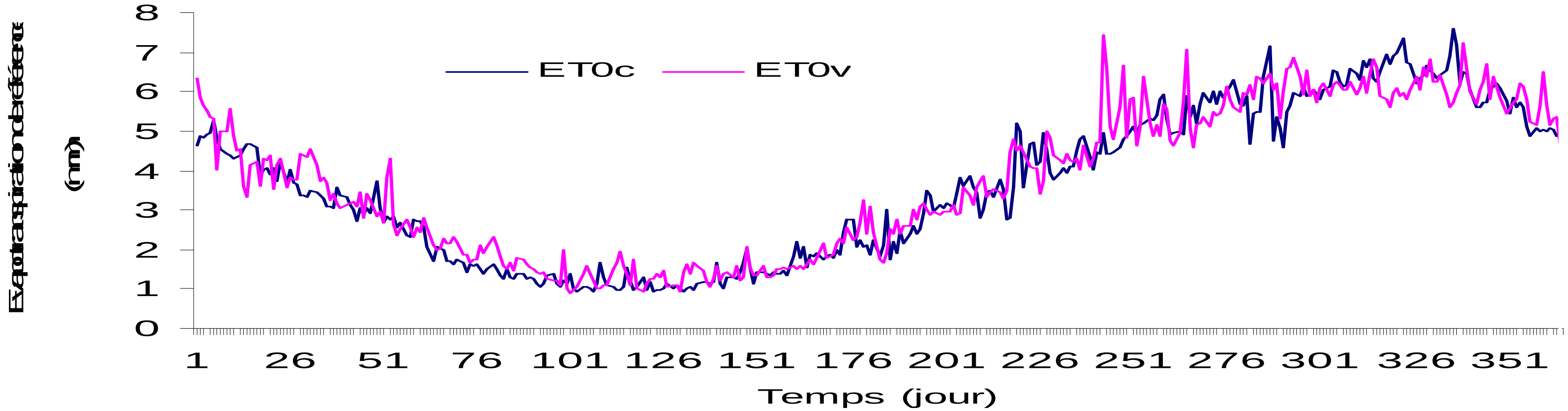
- Basin Hydrometeometeorological data
- Ten years of P and R_s (1990-1999)

time series

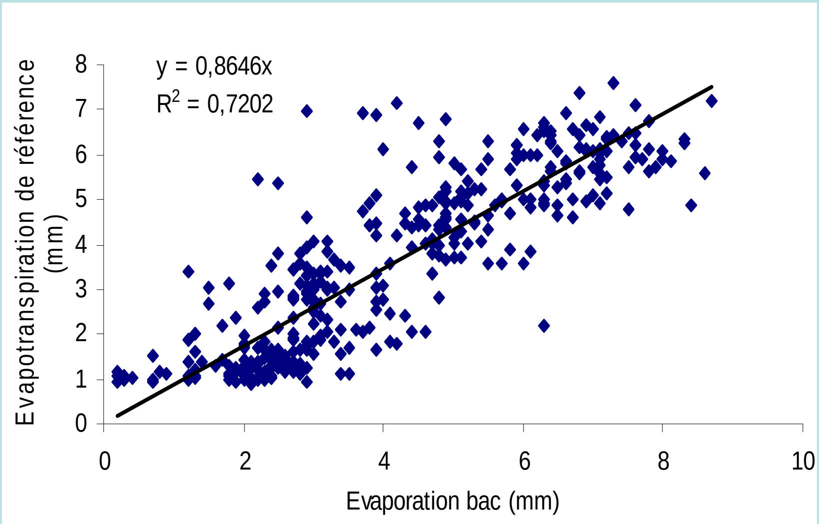
- A time series of meteorological observations allow quantifying the reference crop evapotranspiration ET0.
- Model inputs are daily average basin rainfall and daily ET0 over 10 years (1989-90, 1998-1999).
-
- Average long term rainfall is 228 mm/an.
- According to Budyko model, average ETR = 213 mm/an.

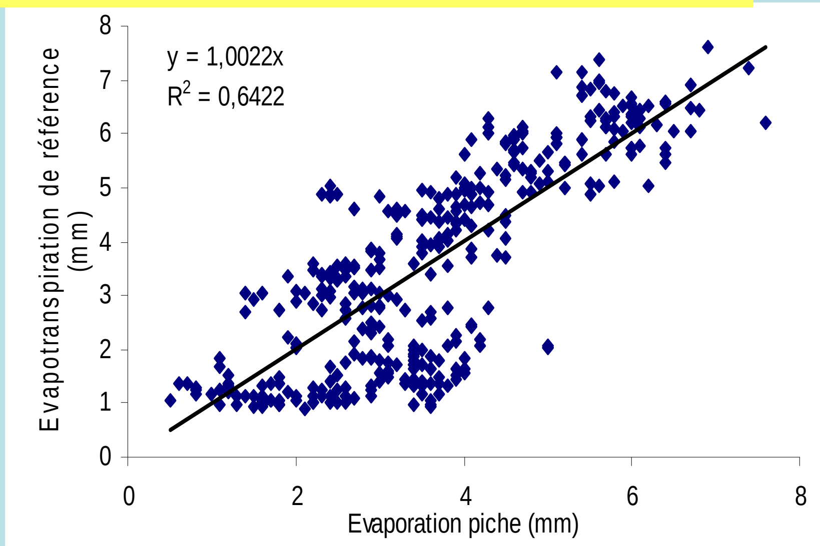
- Average basin precipitation during the study period varies from 55 mm (1994-95) to 398 mm (1989-90).
-

E_{pan}, E_{piche} et ET0 (meteo station)

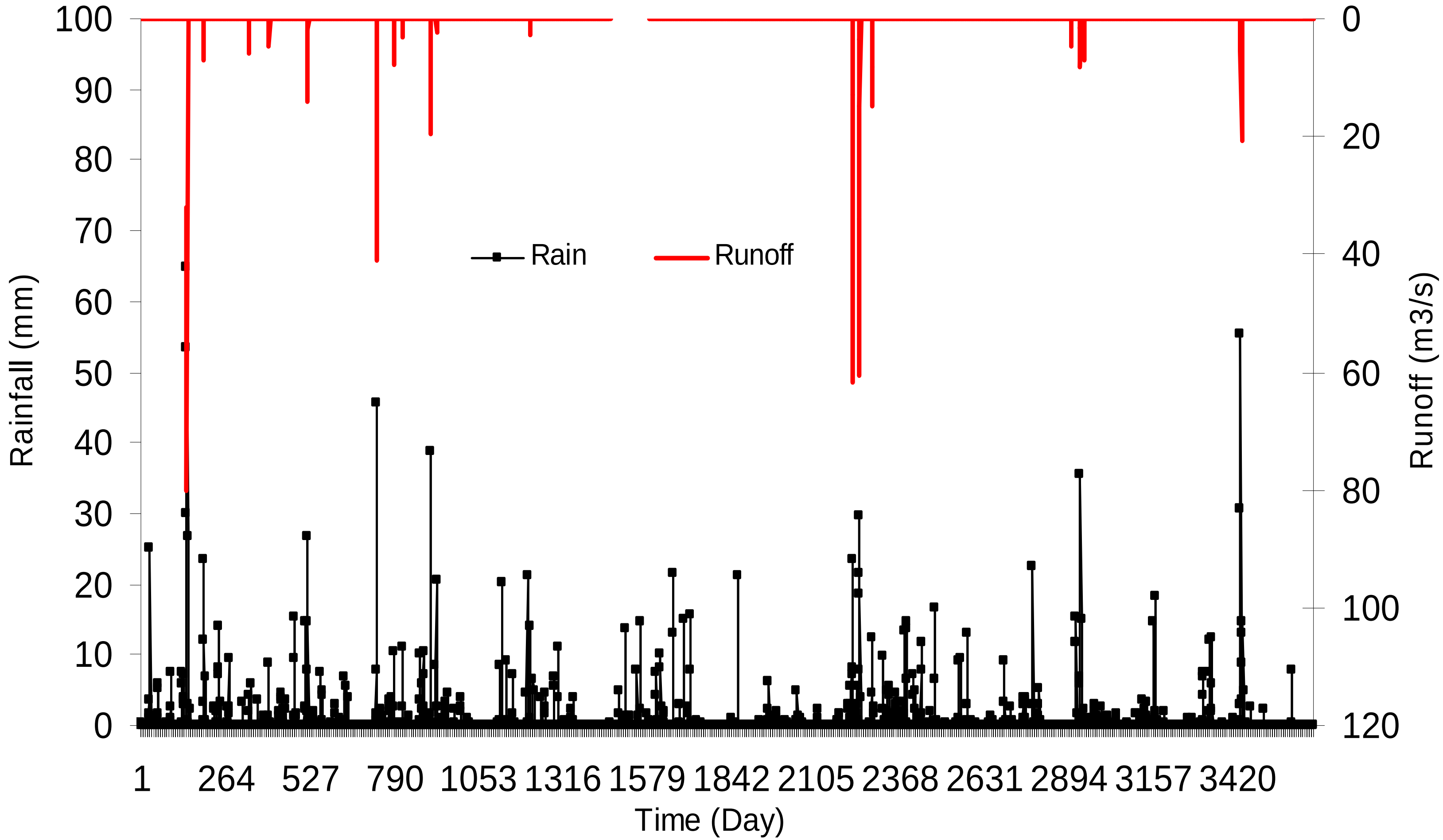


ET0 = 1325mm (2004-2005) ; 1368mm (2003-2004)





Daily Rainfall and runoff (1990-1999)



Calibration strategy

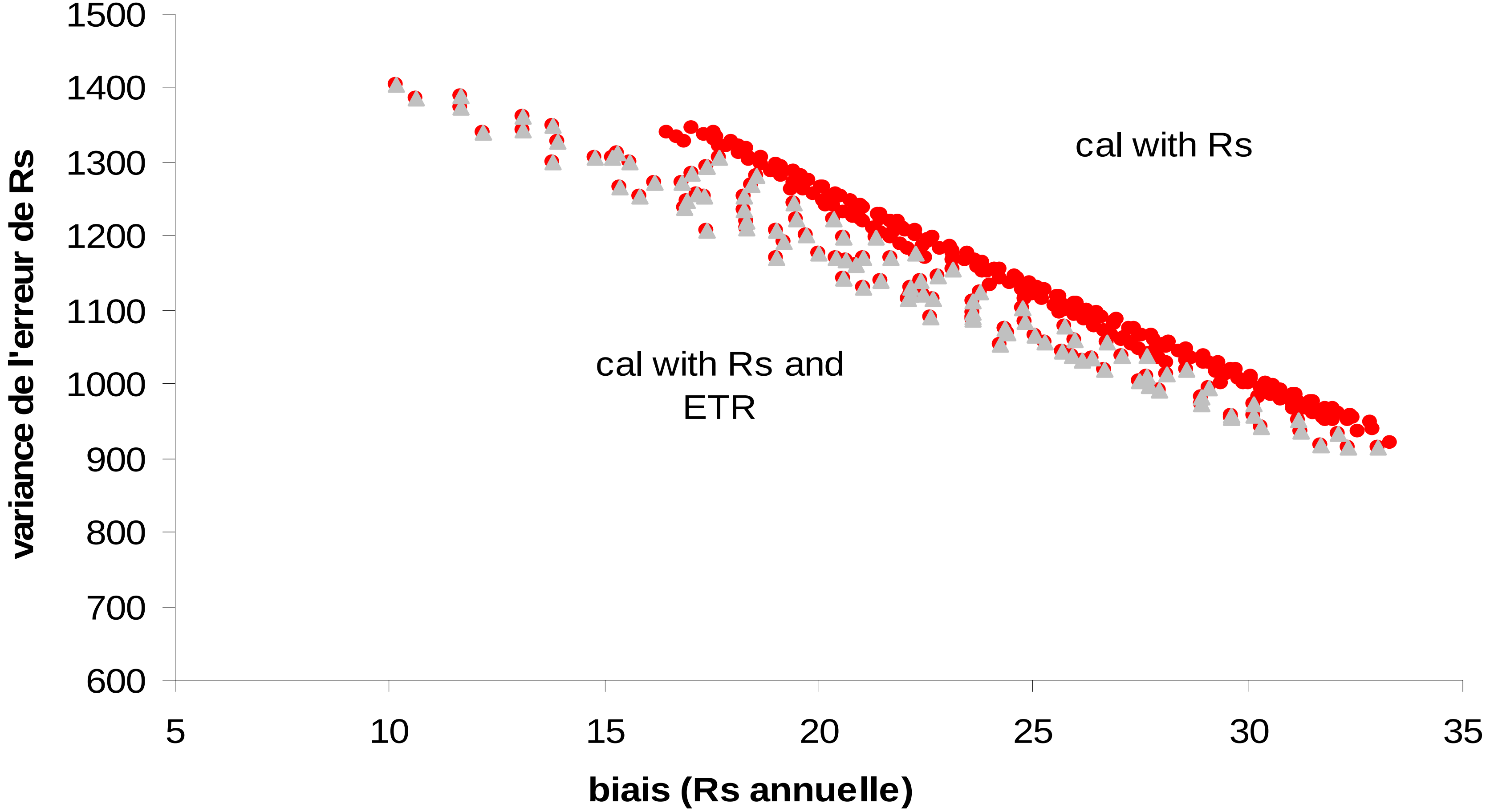
- the model is calibrated on the basis of observed runoff at the basin outlet.
- However, it is proposed to also constraint the model outputs on the basis of on average annual evapotranspiration (regional climatic information).

Calibration strategy

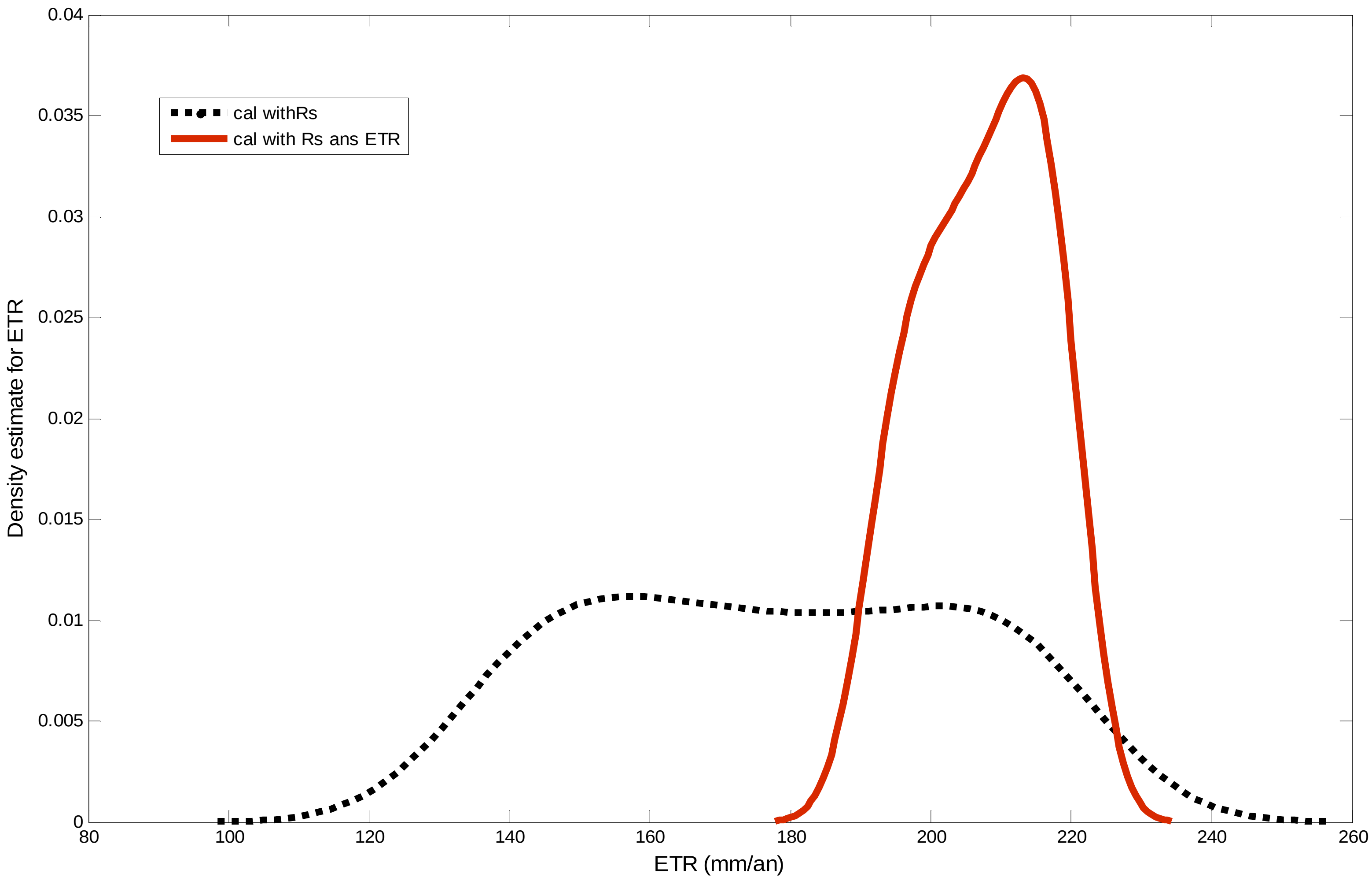
- Grid (σ,η) with **$\delta\sigma$ = ; δ *η = 0.01***
- Objective function: error Bias and Variance

- Equifinality so,
  - Consider Bias and Variance of average annual Rs error
  - Limit **absolute Bias** of average annual Rs error to 10% **(local data control based on Rs)**
  - Limit **absolute Bias** of average annual ETR to 10% **(regional data control based on ETR_{Budyko})**

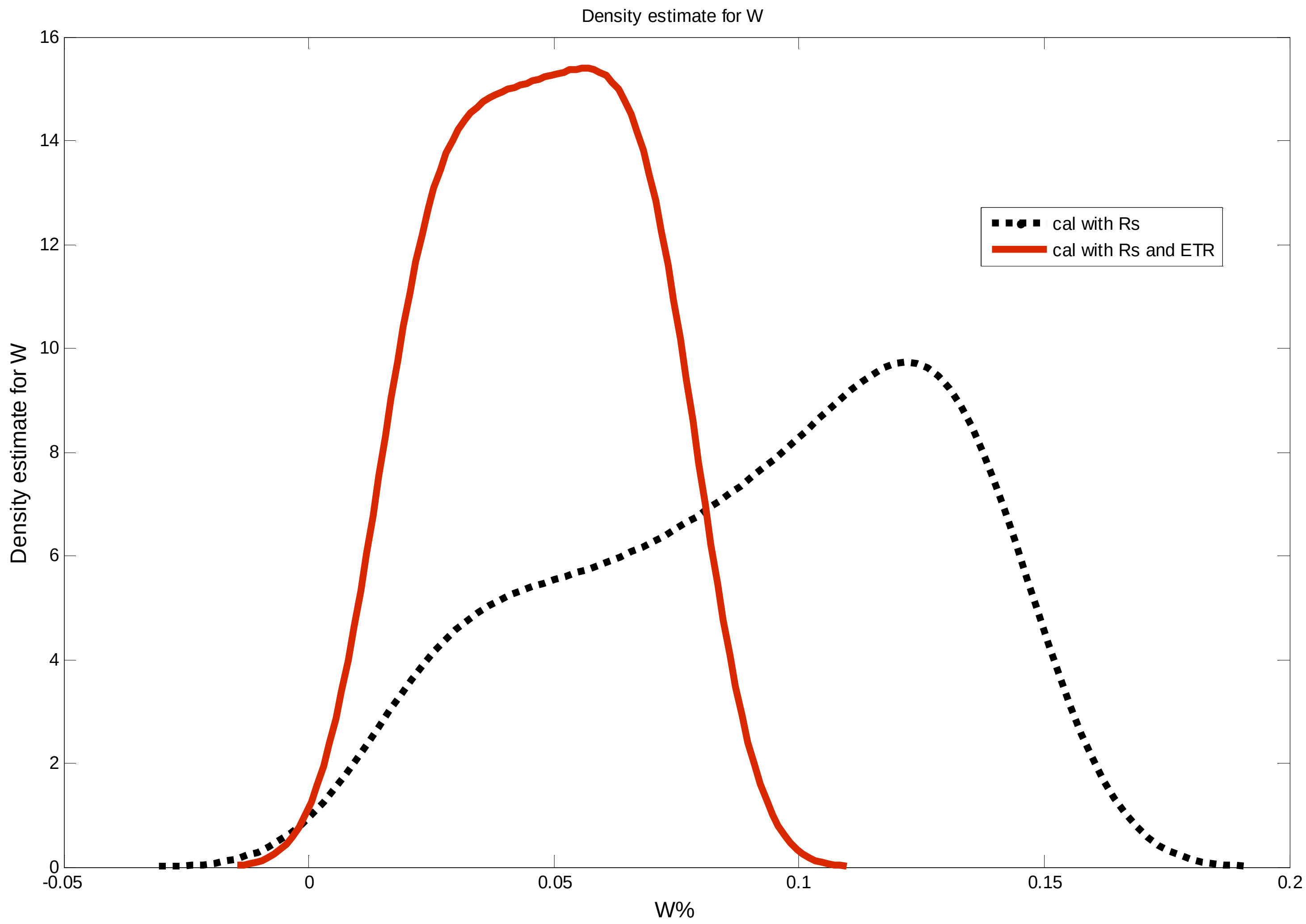
Error Bias and variance



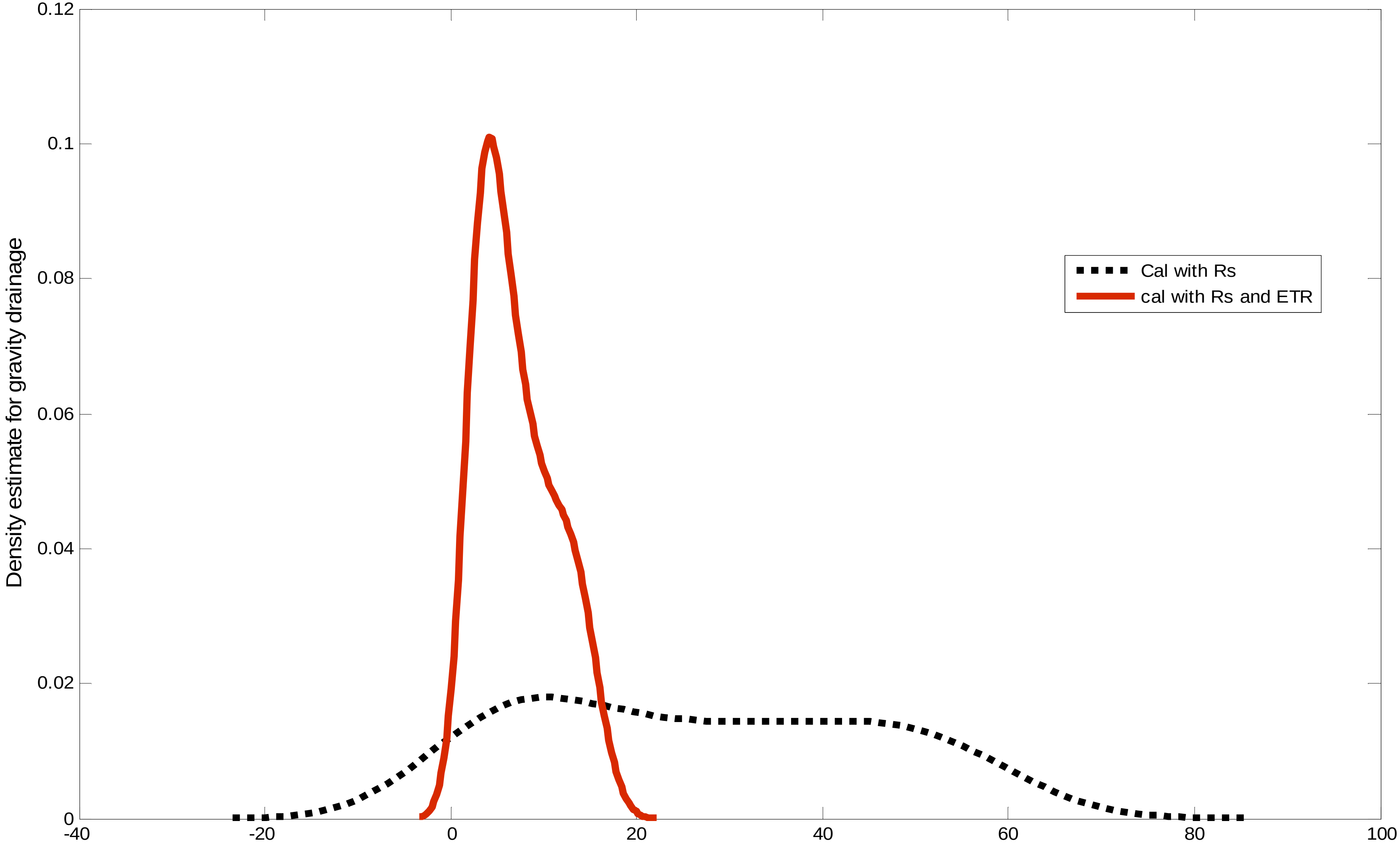
Kernel distribution of ETR



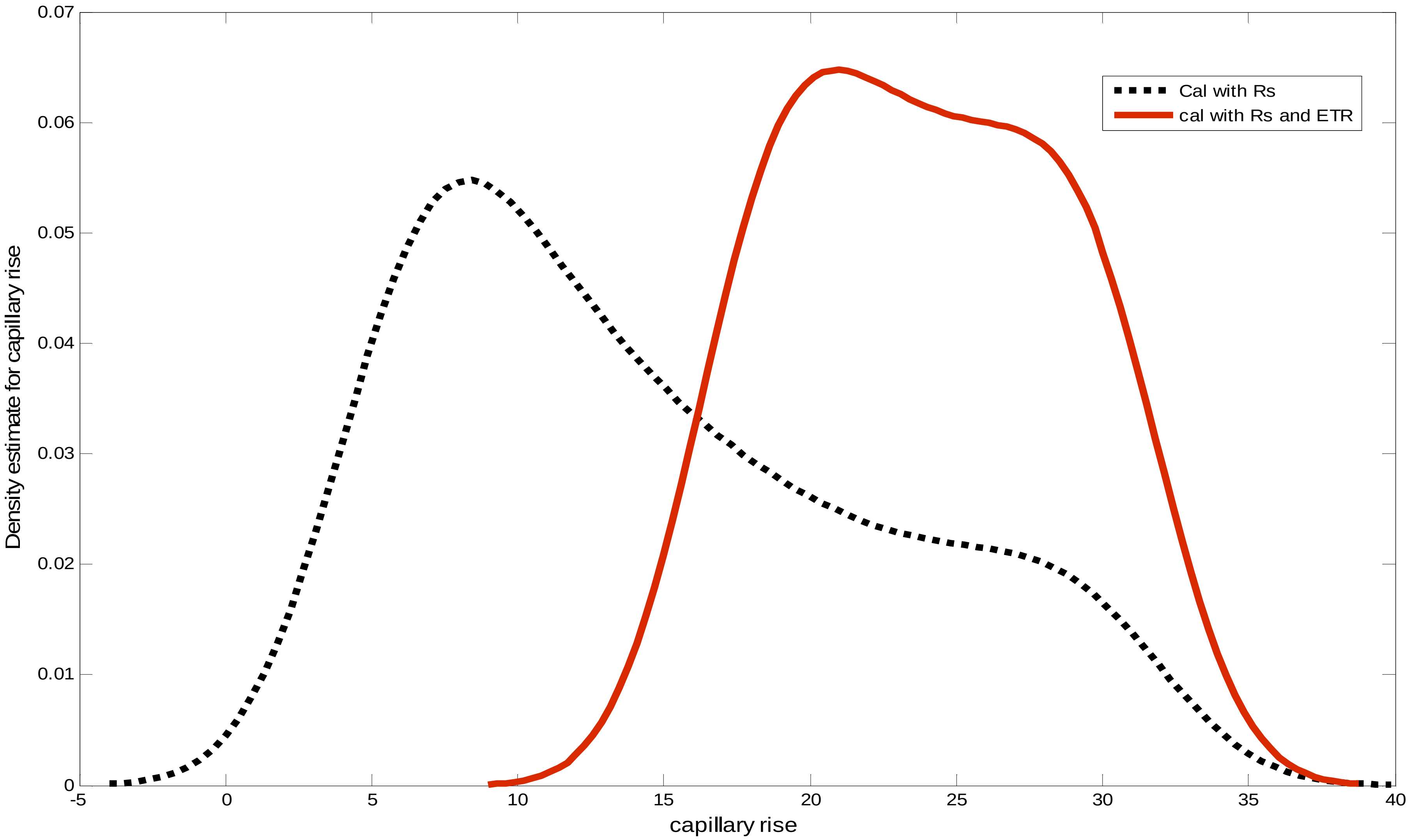
Kernel distribution of the relative soil moisture



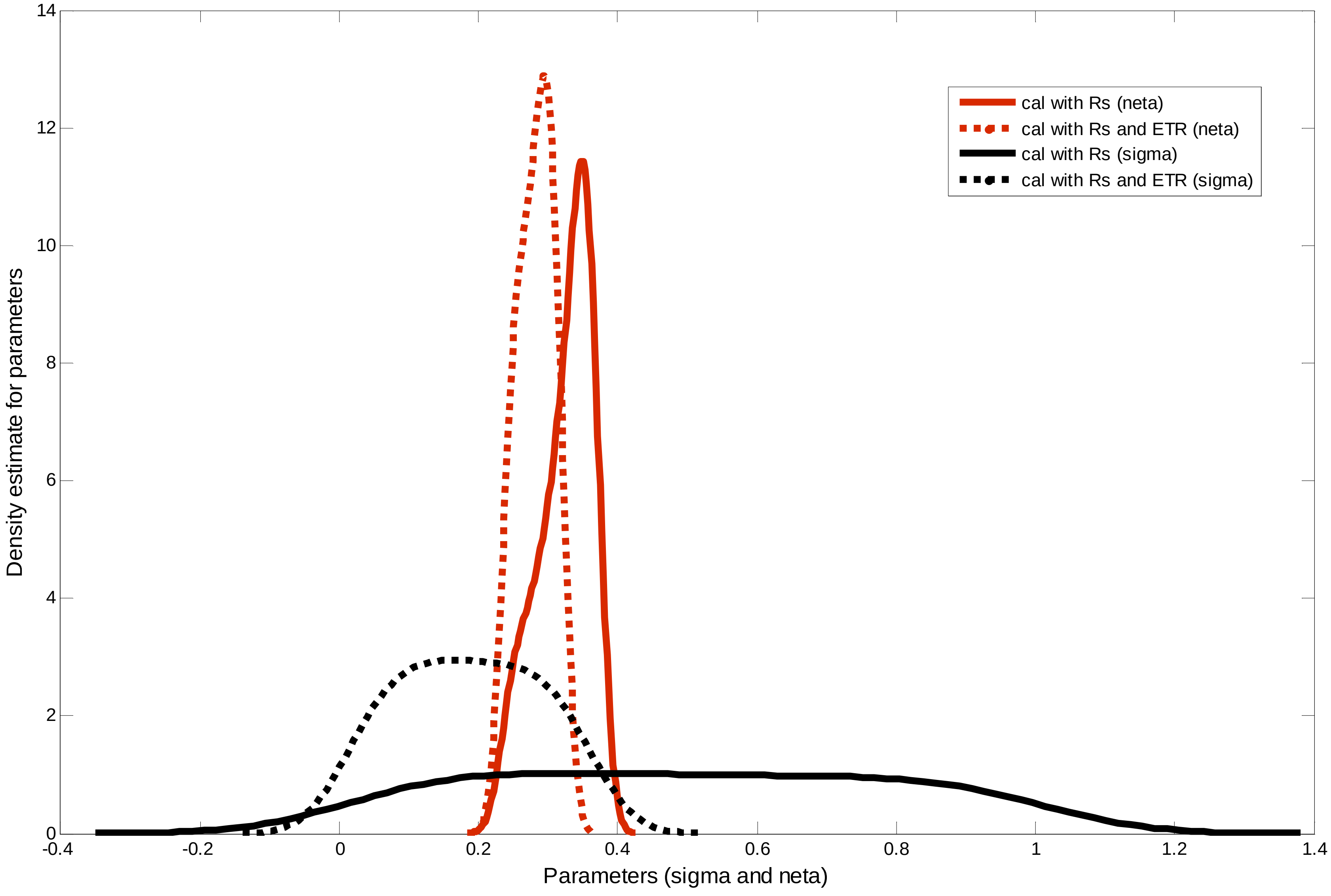
Kernel distribution of percolation



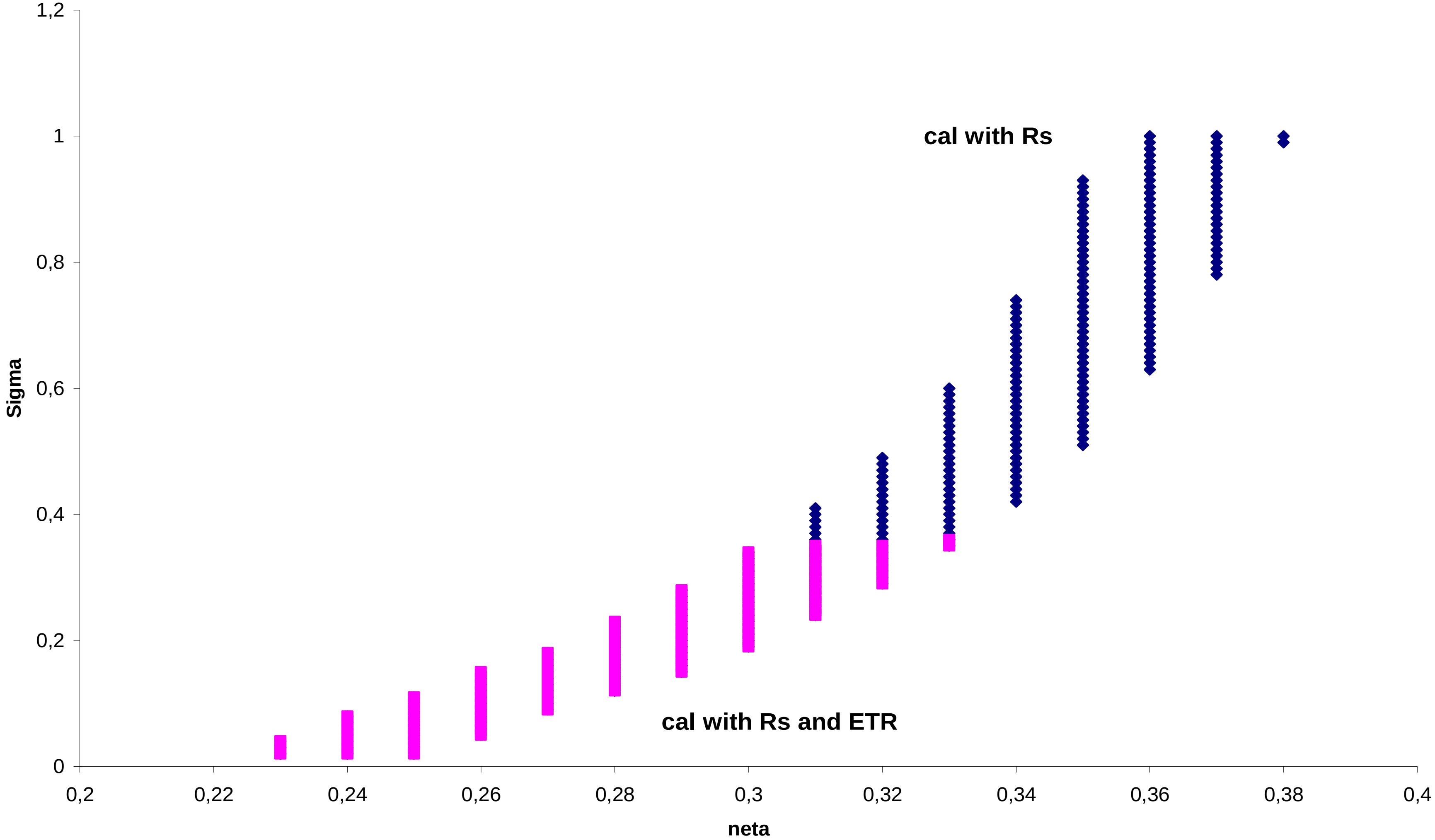
Kernel distribution of capillary rise



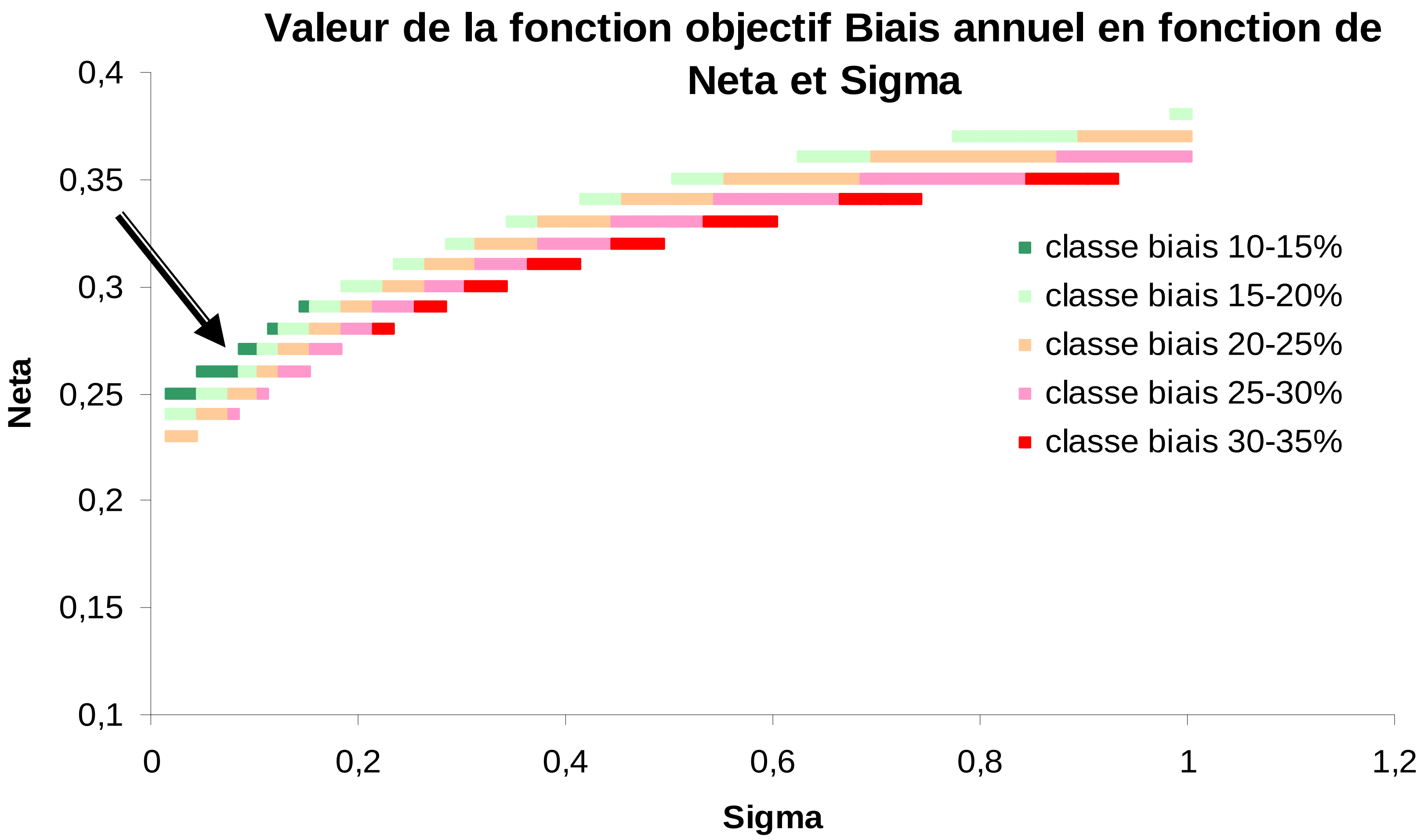
Kernel distribution of σ and η



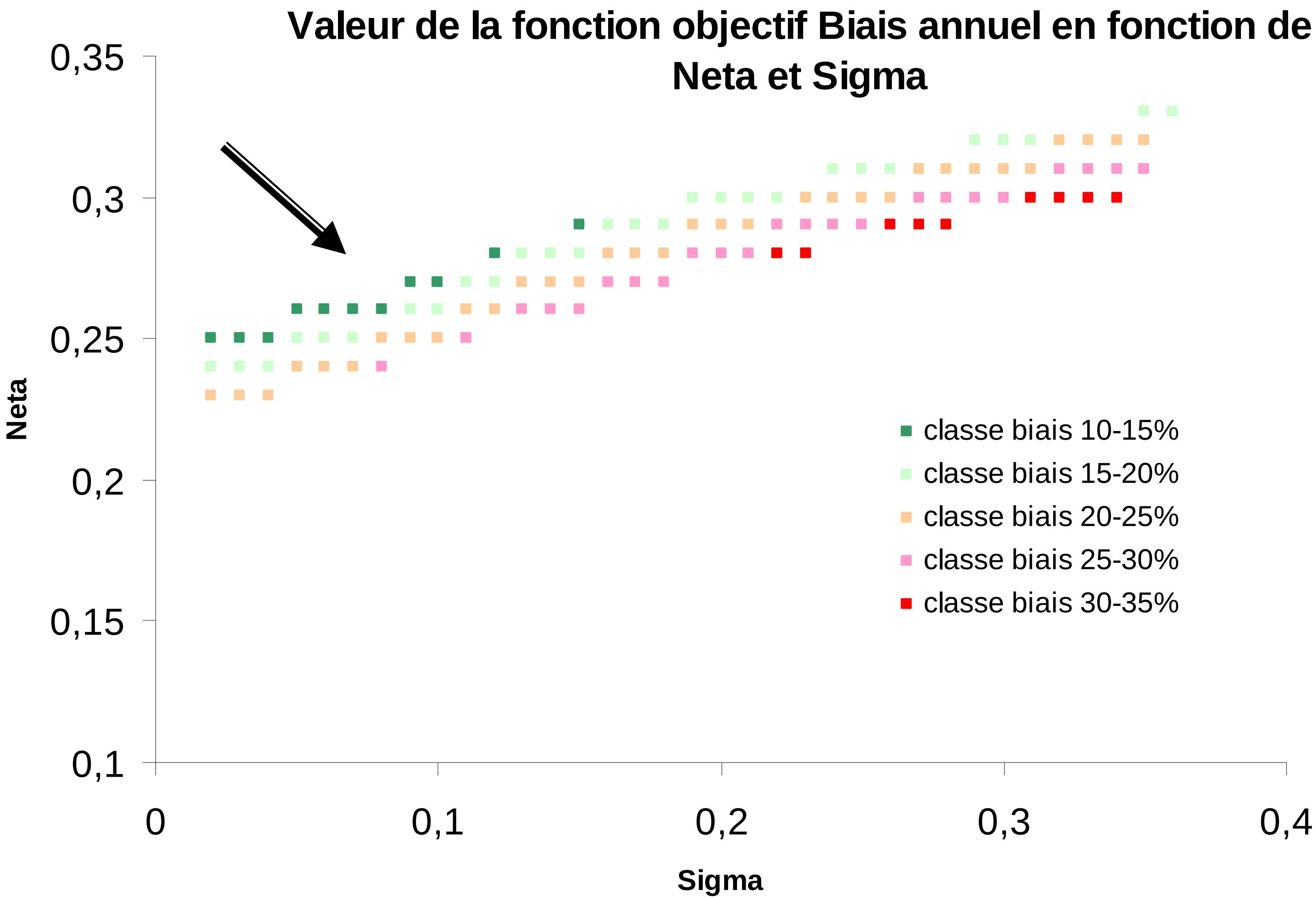
σ versus η through accepted solutions



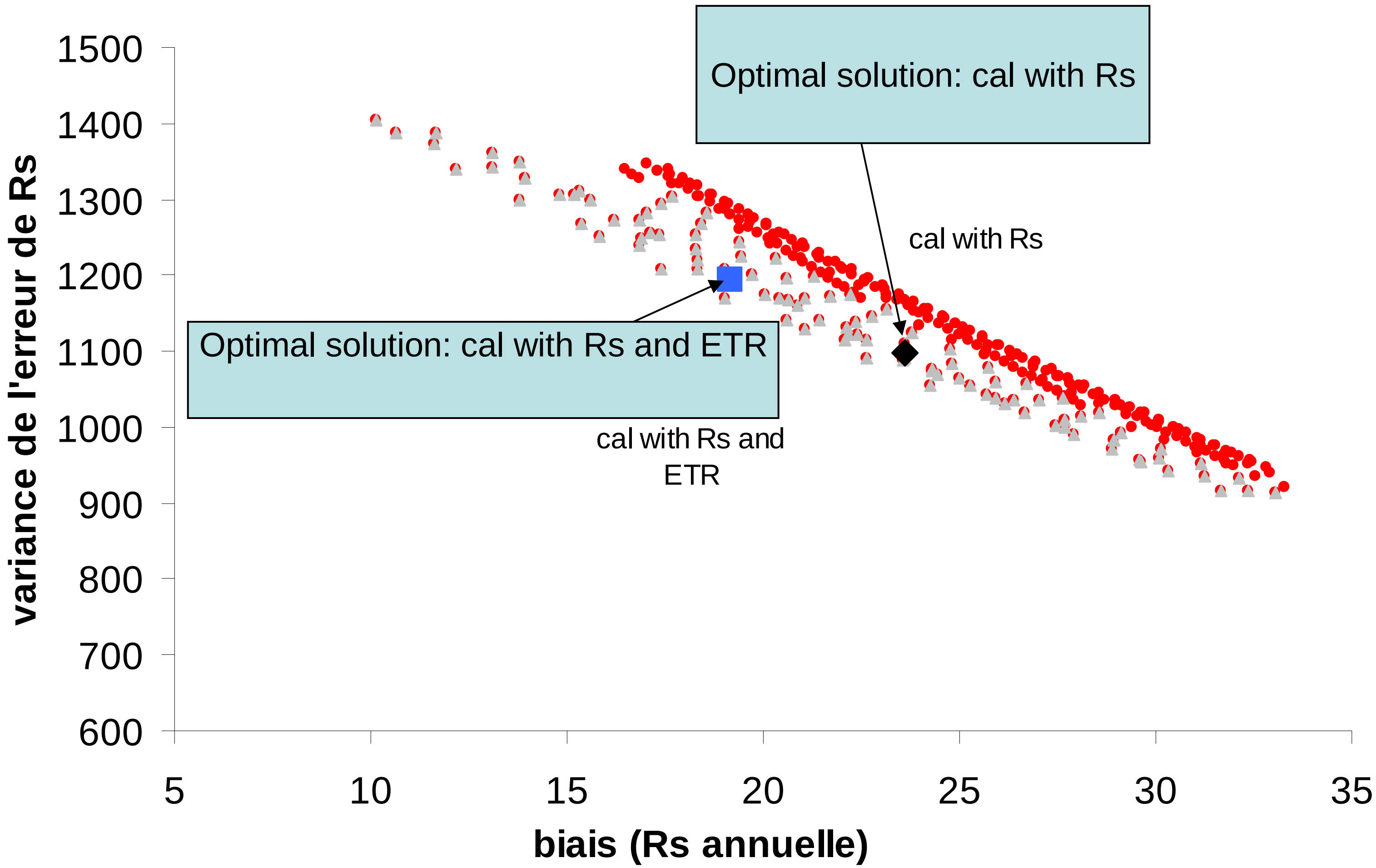
Sorted η and σ according to the local R_s as objective function



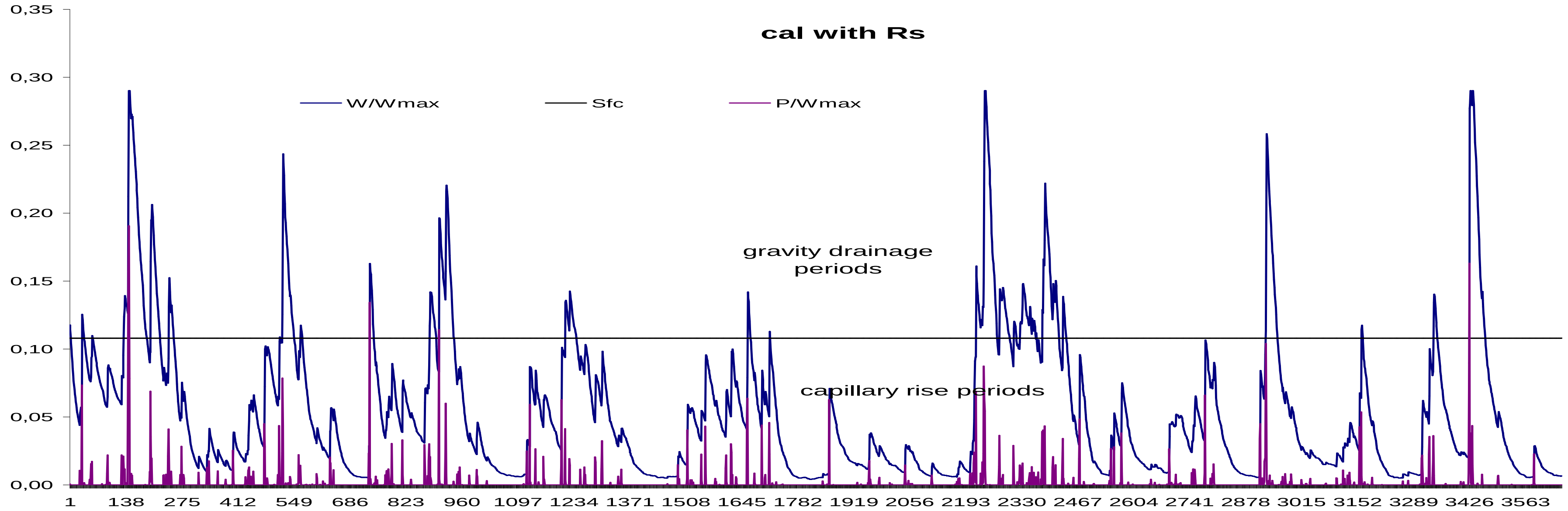
Sorted η and σ according to the local R_s and regional ETR as objective function

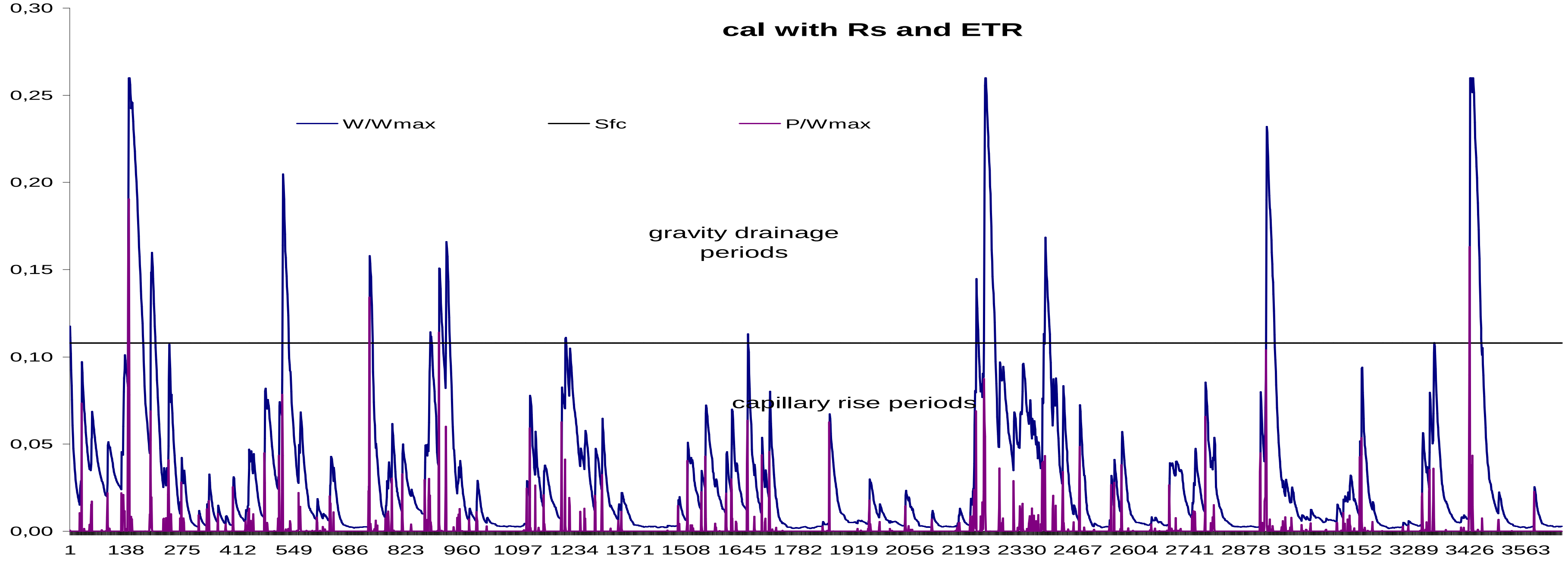


Selection of one optimal solution (median criteria value)

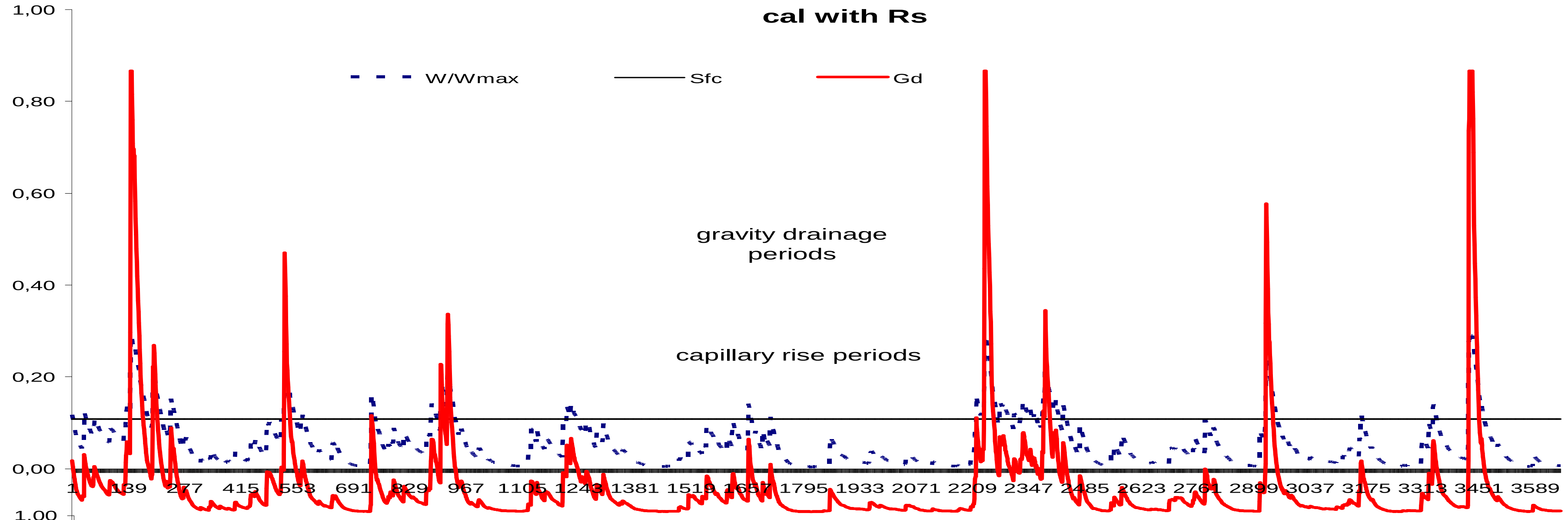


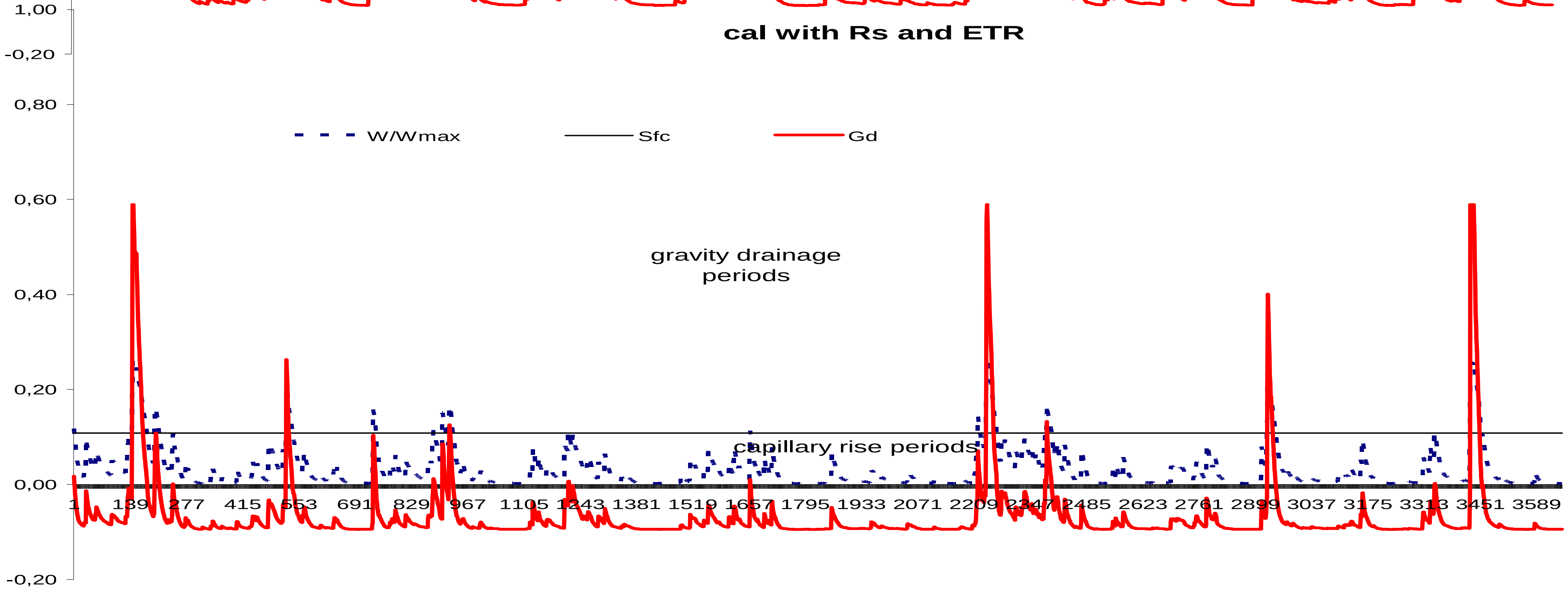
Effect of regional information on estimated water content



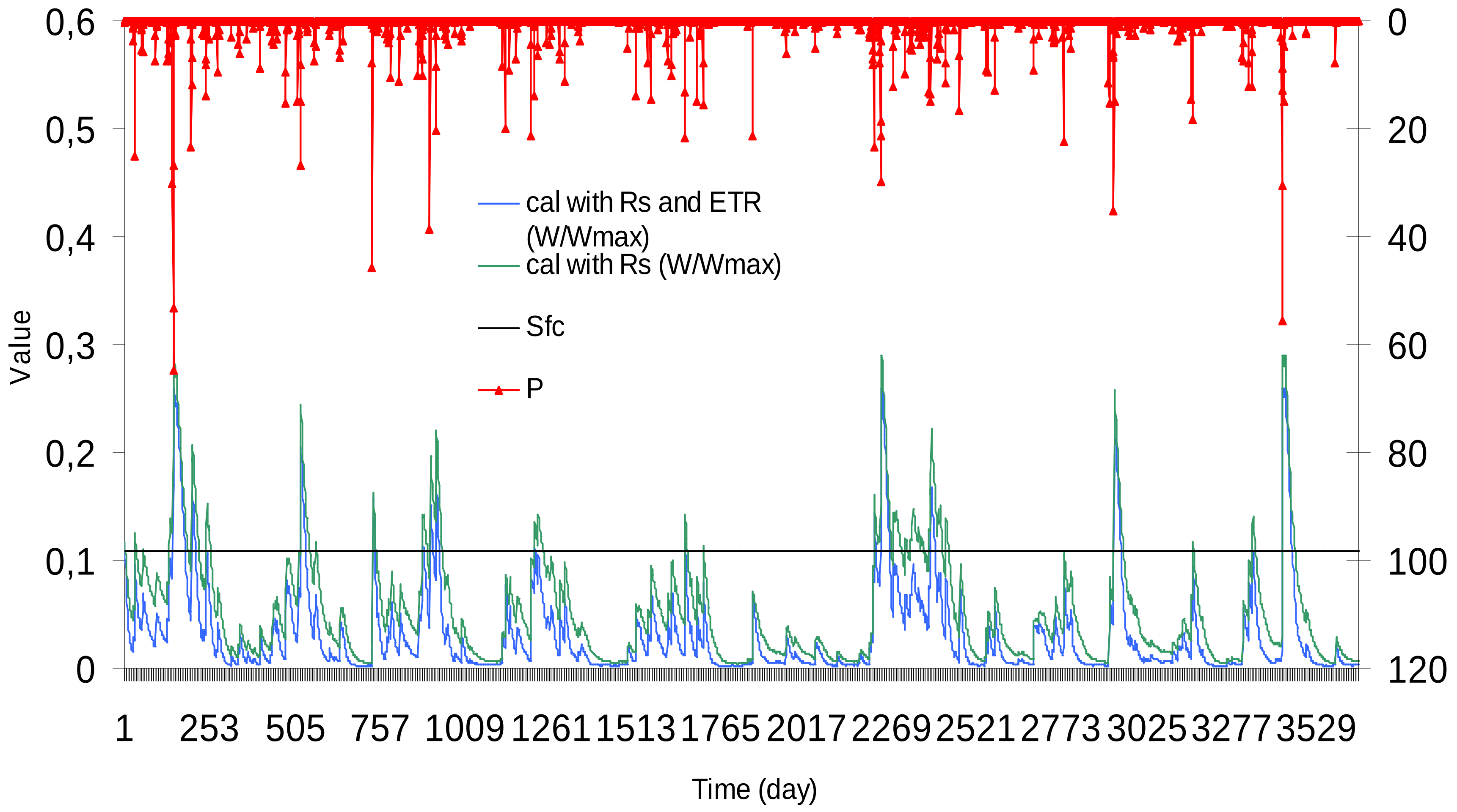


Effect on Water content, percolation capillary rise

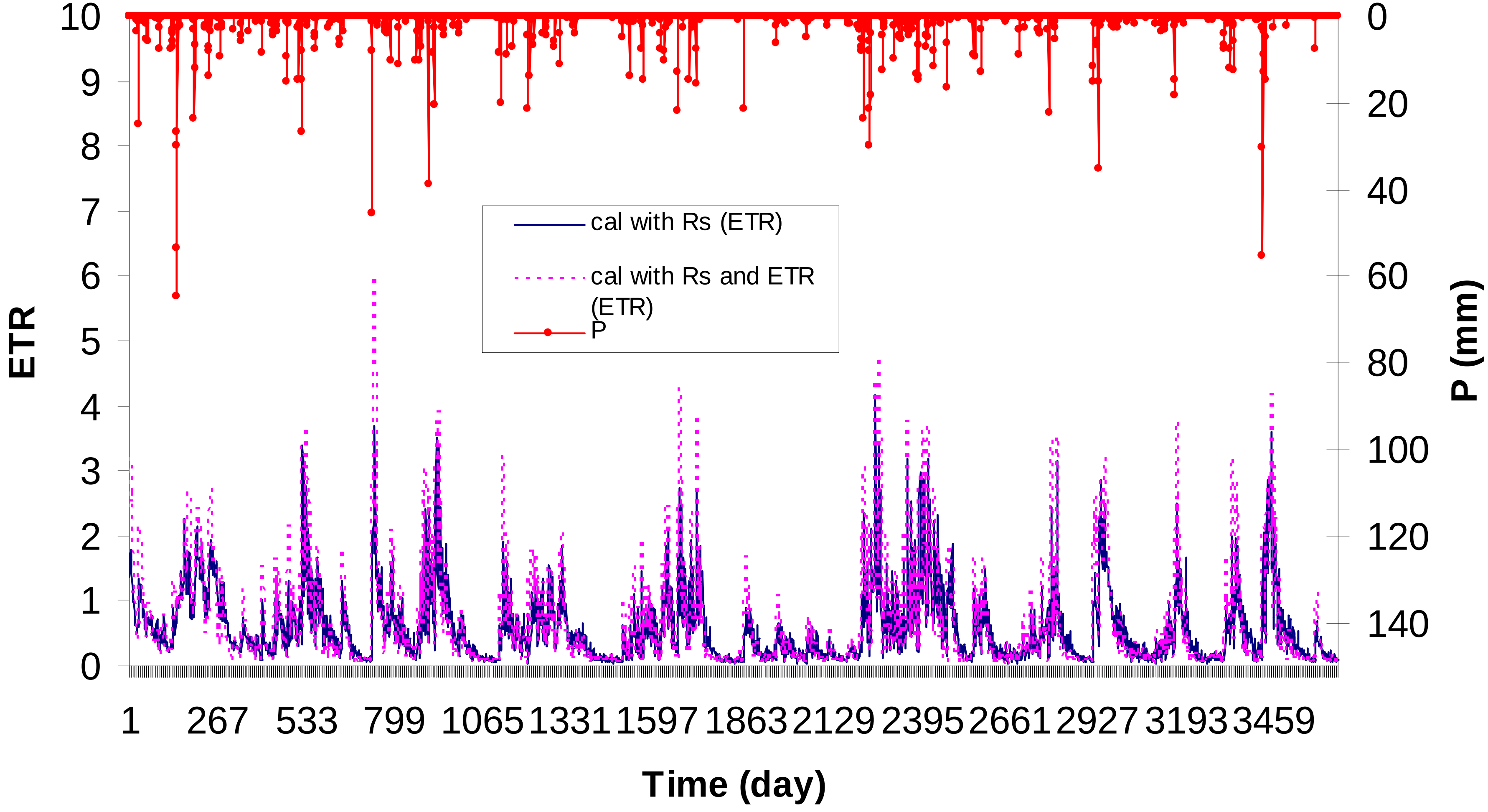




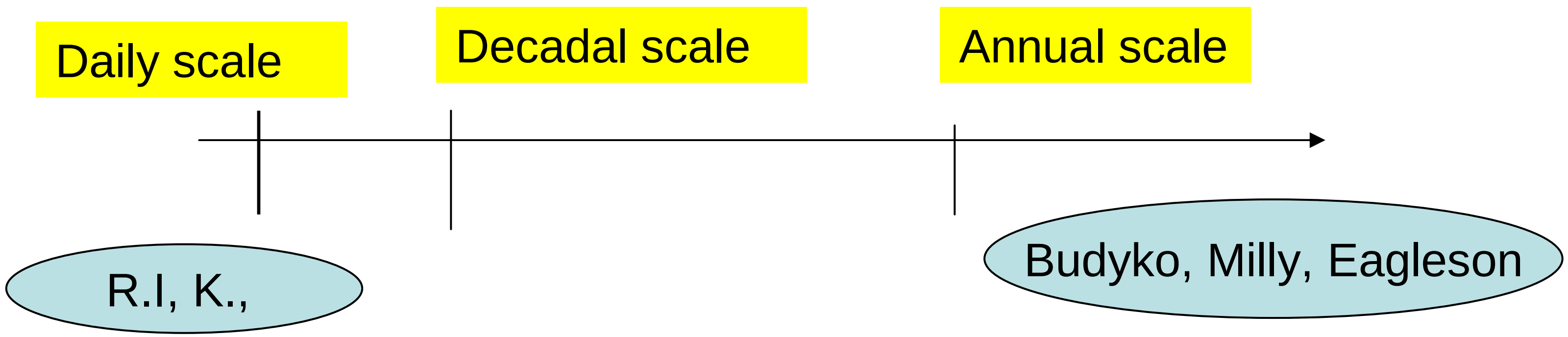
Effect on relative soil moisture



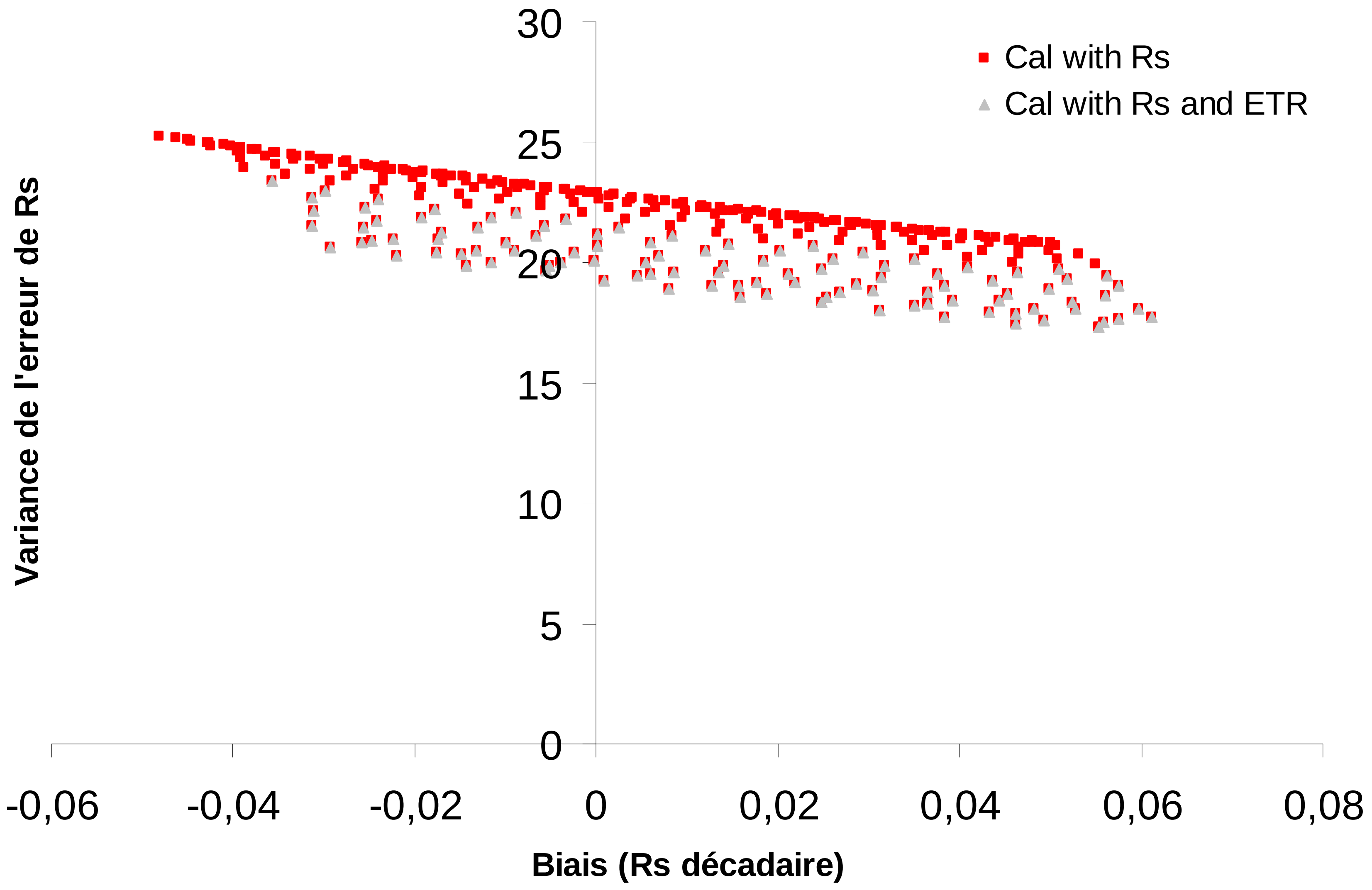
Effect on ETR



What is the performance on the decadal scale?



Representation of Bias and variance on the decadal scale



Water budget for the median solution

	Cal with RS	Cal with Rs and ETR
ETR (mm/year)	206	215,
Wmoy (mm/year)	0,052	0,030
Rs (mm/year)	16,72	16,65
Rc (mm/year)	22	28,
Per (mm/year)	7,	3,6

Conclusions

- Due to uncertainty about pedo transfer parameters as well as uncertainty about vegetation response to water stress, a lot of uncertainty is attached to soil moisture content prediction
- Kernel function is a way to quantify this uncertainty and to transfer it to other soil moisture related variables (median solution)
- Collection of data on vegetation response (LAI,NDVI) (ground and remote sensing) may contribute to decrease this uncertainty