



# Water budget monitoring of irrigated perimeters in semi-arid areas using high resolution NDVI image time series.

## Application for the assessment of groundwater extraction

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# Water budget monitoring of crops using high resolution NDVI satellite image time series

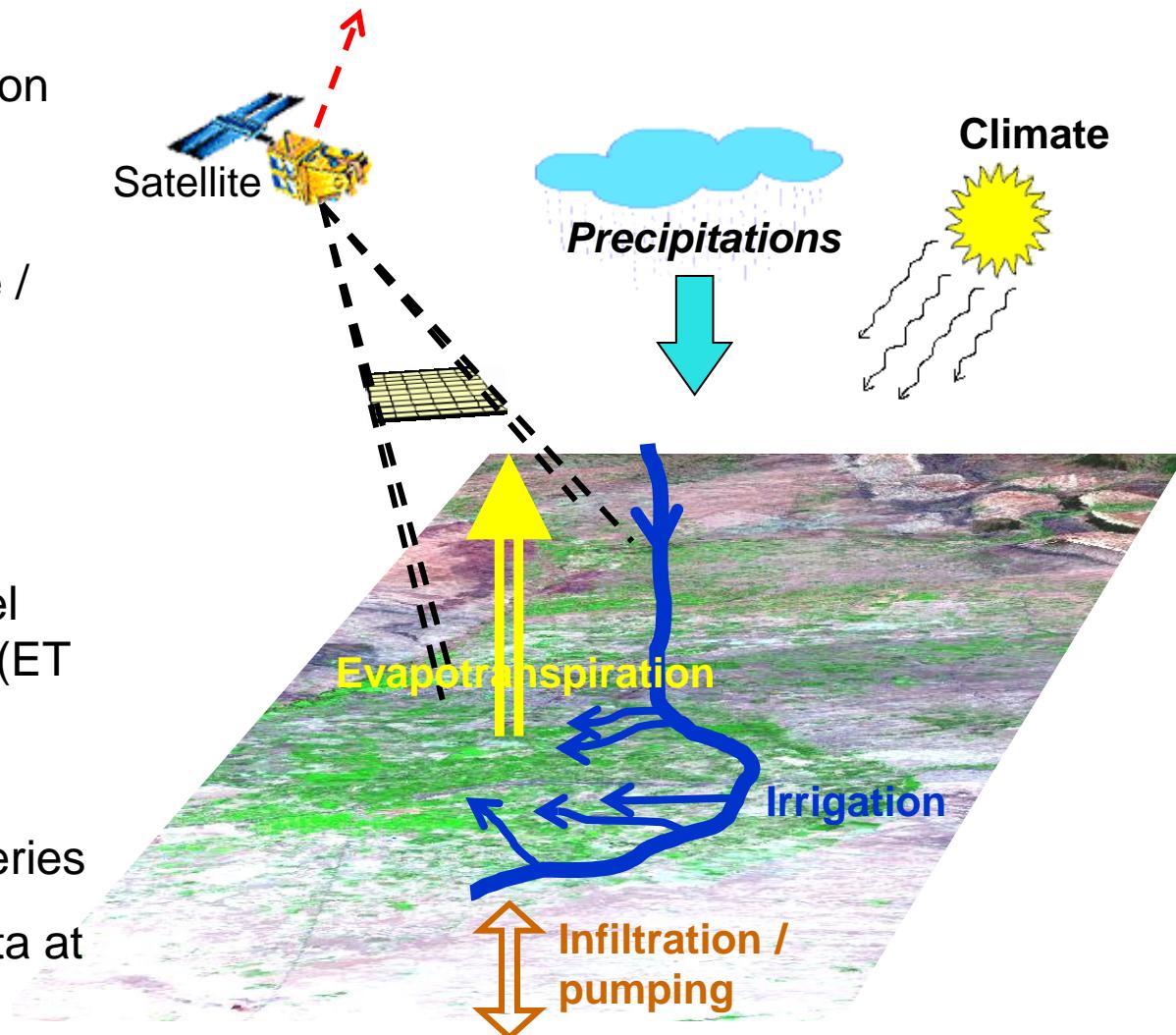
## Objective

Quantification of water fluxes for a better management

⇒ Estimating crop consumption and irrigation volumes.

⇒ Estimating fluxes between surface and aquifer (recharge / extraction).

- Land cover
- Vegetation development



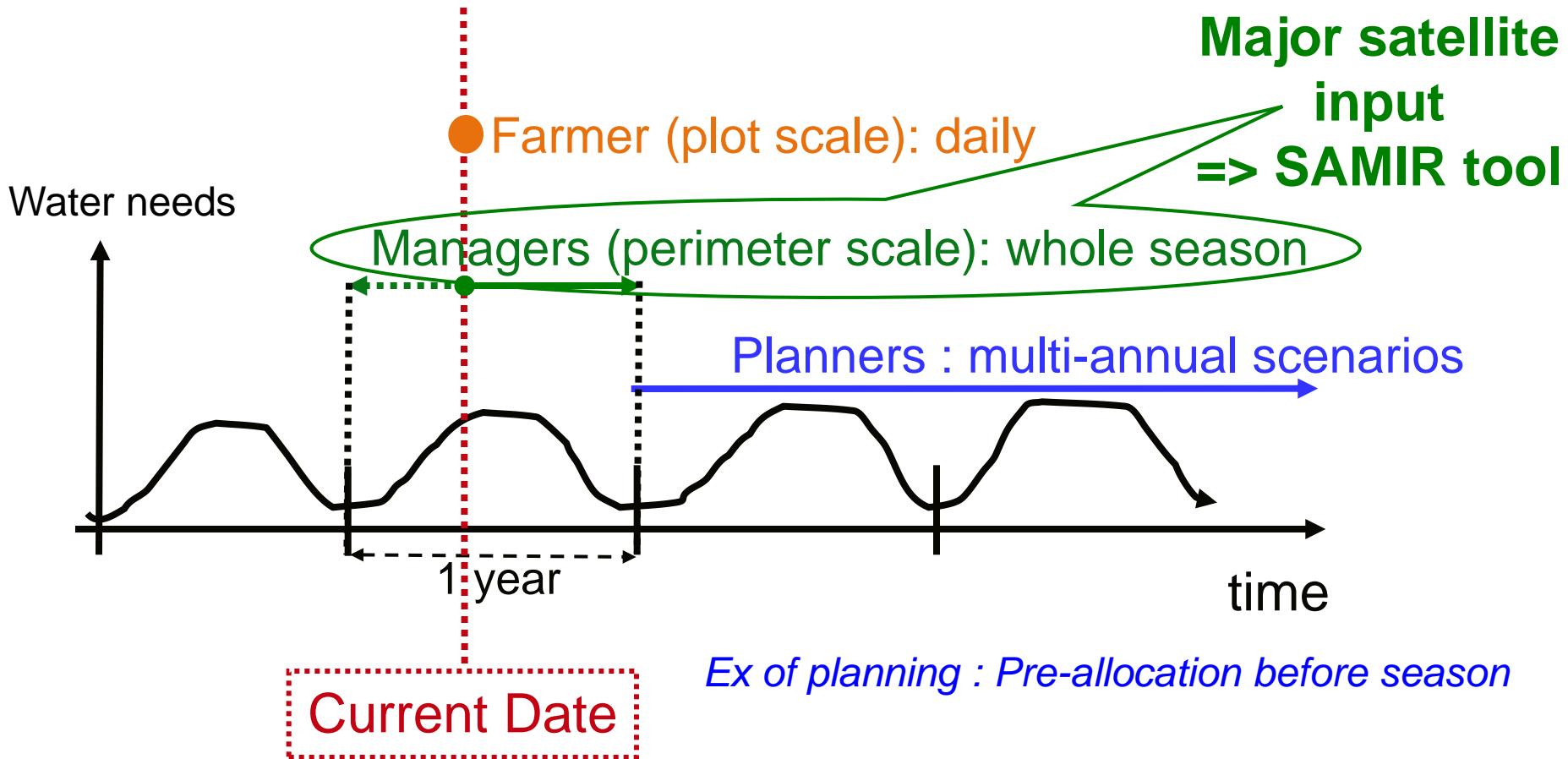
## Working steps

1- Calibrating an evapotranspiration (ET) model using ground measurements (ET flux data)

2- Spatialize ET and irrigation using SPOT HR NDVI time series

3- Validate using irrigation data at perimeter scale

# Irrigation: 3 types of End Users with specific information requirements



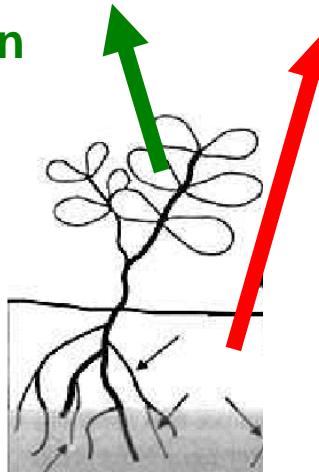
# Evapotranspiration using the FAO method dual coefficient approach

$$ET = ( Kcb * Ks + Ke ) * ( ET_0 )$$

« climatic »  
evaporative  
demand

Transpiration

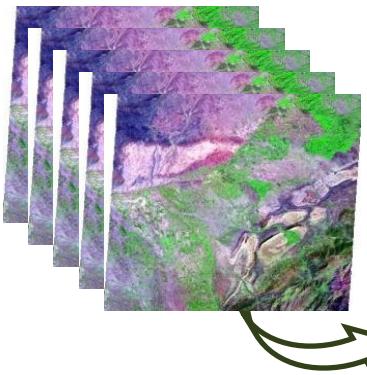
$Kcb = f(\text{vegetation development})$



Evaporation

$Ke = f(\text{top-soil moisture and bare soil fraction})$

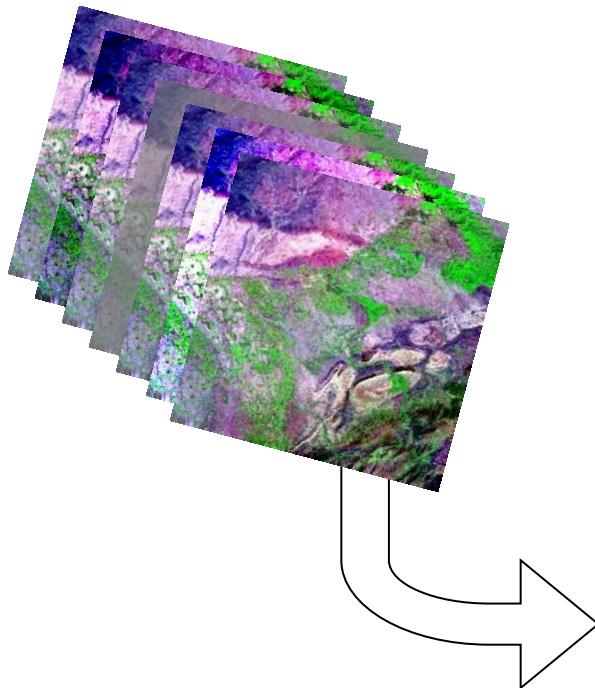
Sentinel-2  
time series



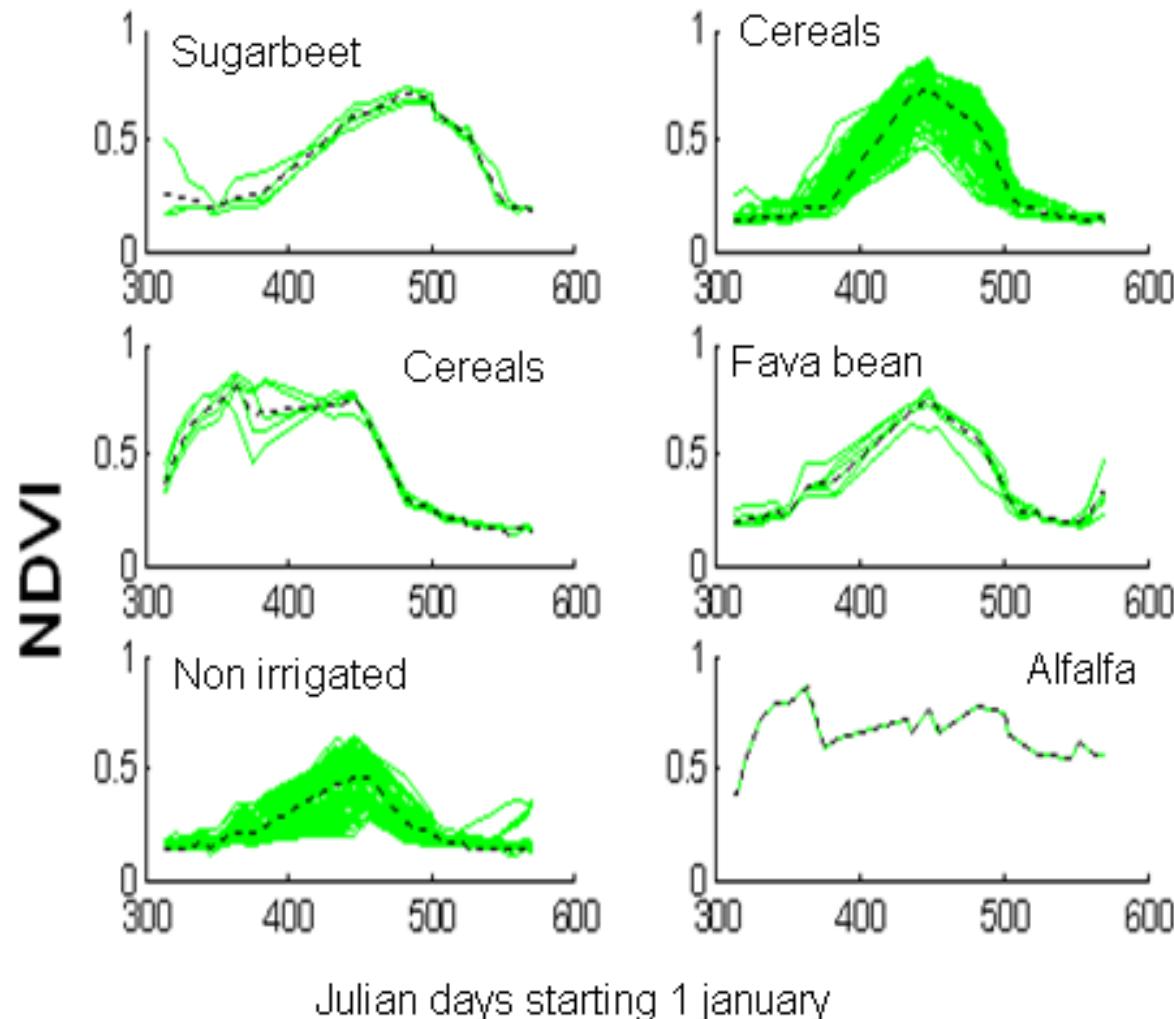
$Ks = f(\text{root-soil moisture})$

**Satellite :  $Kcb = a * \text{NDVI} + b$**

⇒ Crop development is monitored using  
Image Time series



NDVI time profiles of pixels



# The SAMIR tool

## “Satellite Monitoring of Irrigation”

**Calcul du bilan hydrique**

The diagram shows a plant canopy with arrows indicating various processes: a purple arrow pointing up from the soil surface labeled 'evapotranspiración' (R<sub>s</sub>), a blue arrow pointing down from the sky labeled 'lluvia' (precipitation), a blue arrow pointing down from the canopy labeled 'riego' (irrigation), a green arrow pointing up from the canopy labeled 'transpiración', a green arrow pointing up from the soil surface labeled 'evaporación', and a grey area at the bottom labeled 'zona radicular' (root zone).

**(1) ENTREES**

ET0 :  Spatialisé  Uniforme D:\Simon\_divers\SAMIR\IDL-DEMONSTRATEUR\DATA\ET0\Stations\Stations\_interpol\_0203\_jour\_test

Précipitation :  Spatialisé  Uniforme D:\Simon\_divers\SAMIR\IDL-DEMONSTRATEUR\SORTIES\pluies\aison\0203\_jour\_test

Occupation du sol : D:\Simon\_divers\SAMIR\IDL-DEMONSTRATEUR\DATA\OS\NDVI\_Serie\_Sat\OS\_ndvi0203\_R3

Sol :  Spatialisé  Uniforme

Kcb :  NDVI  Stat D:\Simon\_divers\SAMIR\IDL-DEMONSTRATEUR\SORTIES\Kc\kcb\_R3\_interp

FC :  NDVI  Stat D:\Simon\_divers\SAMIR\IDL-DEMONSTRATEUR\SORTIES\Kc\fc\_R3\_interp

**(2) IRRIGATION**

Déclenchement : RAW : Si un certain vide de l'Humidité Facilement Accessible est décelé (%)

Valeur de déclenchement : 100 Nom du fichier : D:\Simon\_divers\SAMIR\IDL-DEMONSTRATEUR\SORTIES\irrigation\R3\_secteurs\_irrig.

Quantité : RAW : Recharger un certain pourcentage de l'Humidité Facilement Accessible (%)

Valeur de quantité : 100 Allocation totale d'eau pour la saison (mm) : 300 Nombre maximum de tours d'irrigation : 5

Lame d'eau minimale par tour (mm) : 30 Lame d'eau maximale par tour (mm) : 60

**(3) SORTIES**

Capacité d'absorption d'eau évapotranspirée par l'atmosphère, limite supérieure de Kc (Kcmax) : 1.15

Chemin d'accès pour les fichiers de sortie : D:\Simon\_divers\SAMIR\IDL-DEMONSTRATEUR\SORTIES\bilan

Période de calcul du 01/09/2002 au 31/08/2003

Etat hydrique du sol |  Etc |  Irrigation |  Drainage profond

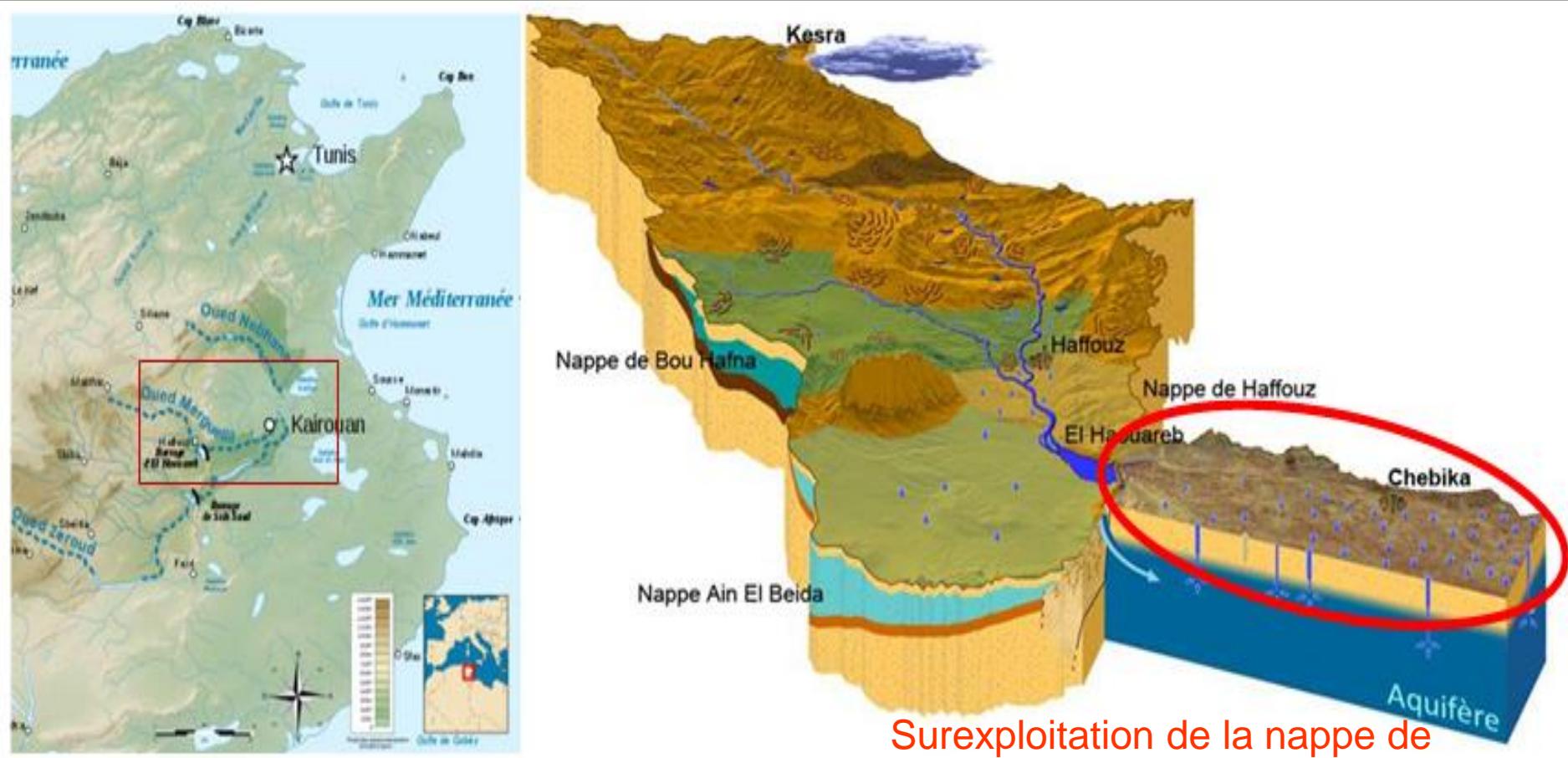
**CALCULER** **HELP** **CANCEL**

# The Kairouan plain study site

Lower part of the Merguellil watershed

Semi arid climate with limited water resources

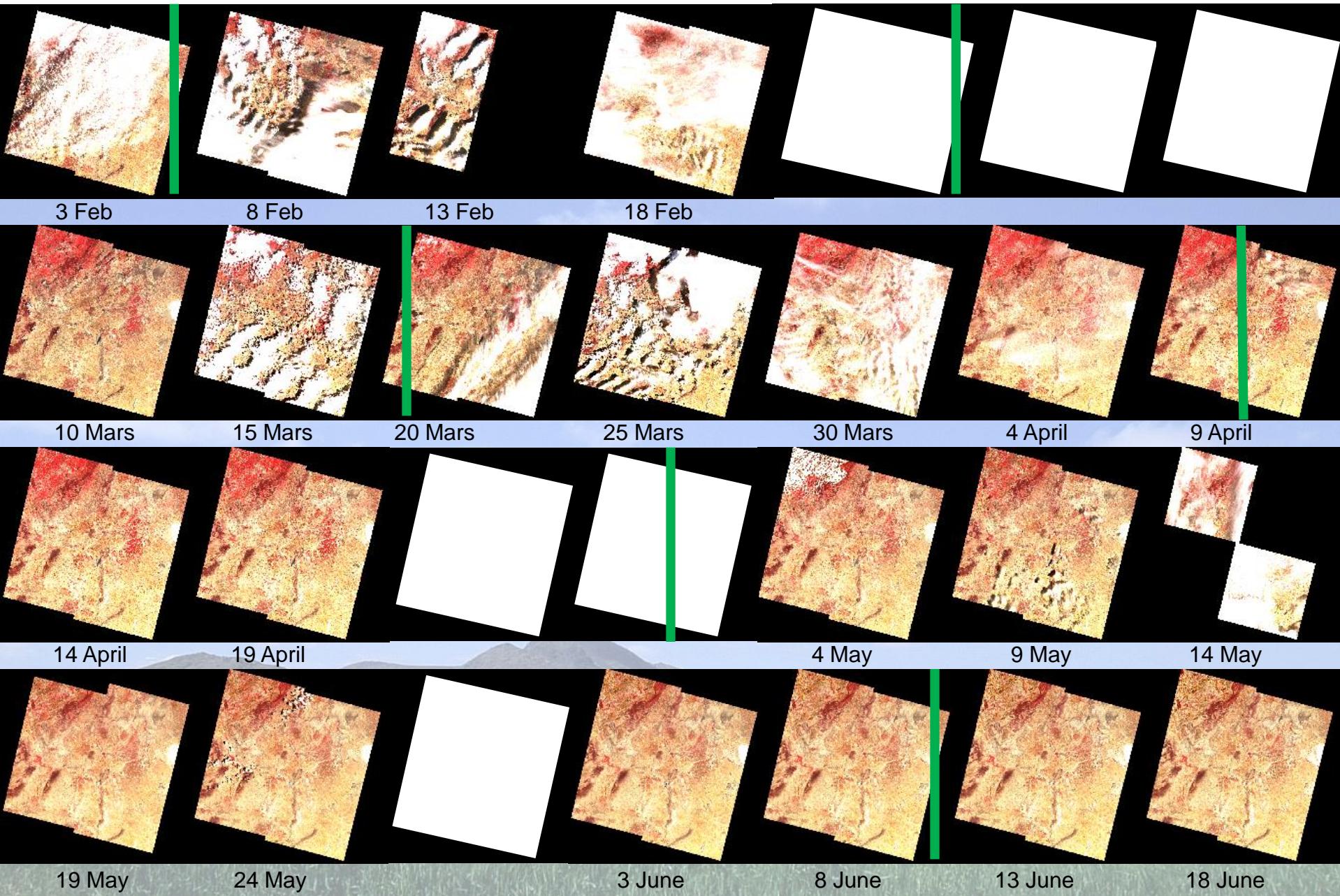
- Average temperature : 19.2 °C
- Precipitation 300mm/year with high spatial and temporal variability



Surexploitation de la nappe de Kairouan due à l'irrigation (-0,5 m/an).

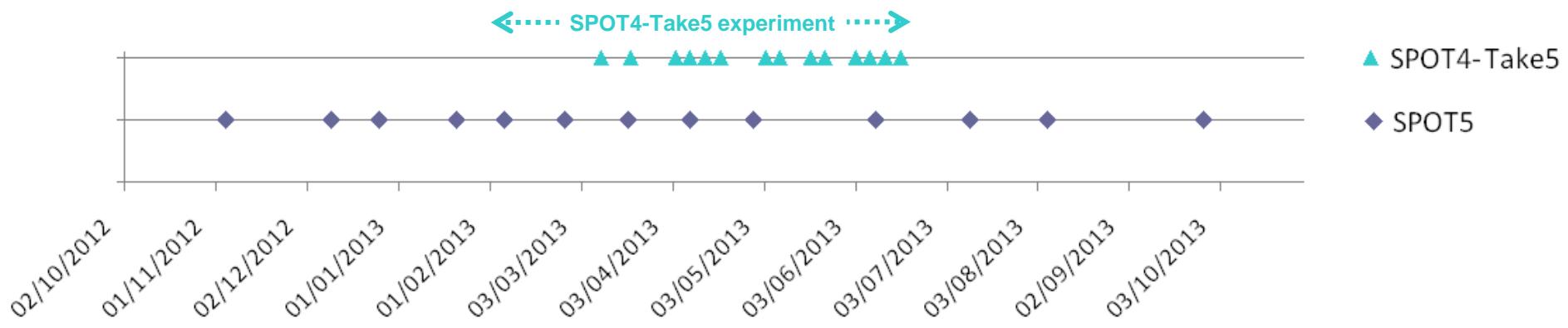
# SPOT4-Take5 experiment

Kairouan site (Merguellil, Tunisia) green bars = SPOT5 acquisitions (ISIS)



# SPOT4-Take5 experiment

## Image acquisition



# Images preprocessing

## Phase 1 – geometric and radiometric processing

- SPOT4-Take5 ready to use ! 

- SPOT5 1A ordered through ISIS (CNES)

1- Orthorectification ENVI + SRTM 90m

2- Radiometric correction using 6S model

- + on site photometer measurements

- + web data for missing dates (H<sub>2</sub>O, O<sub>3</sub> only...)



## Phase 2 – Time series consistency analysis using pseudo invariant features

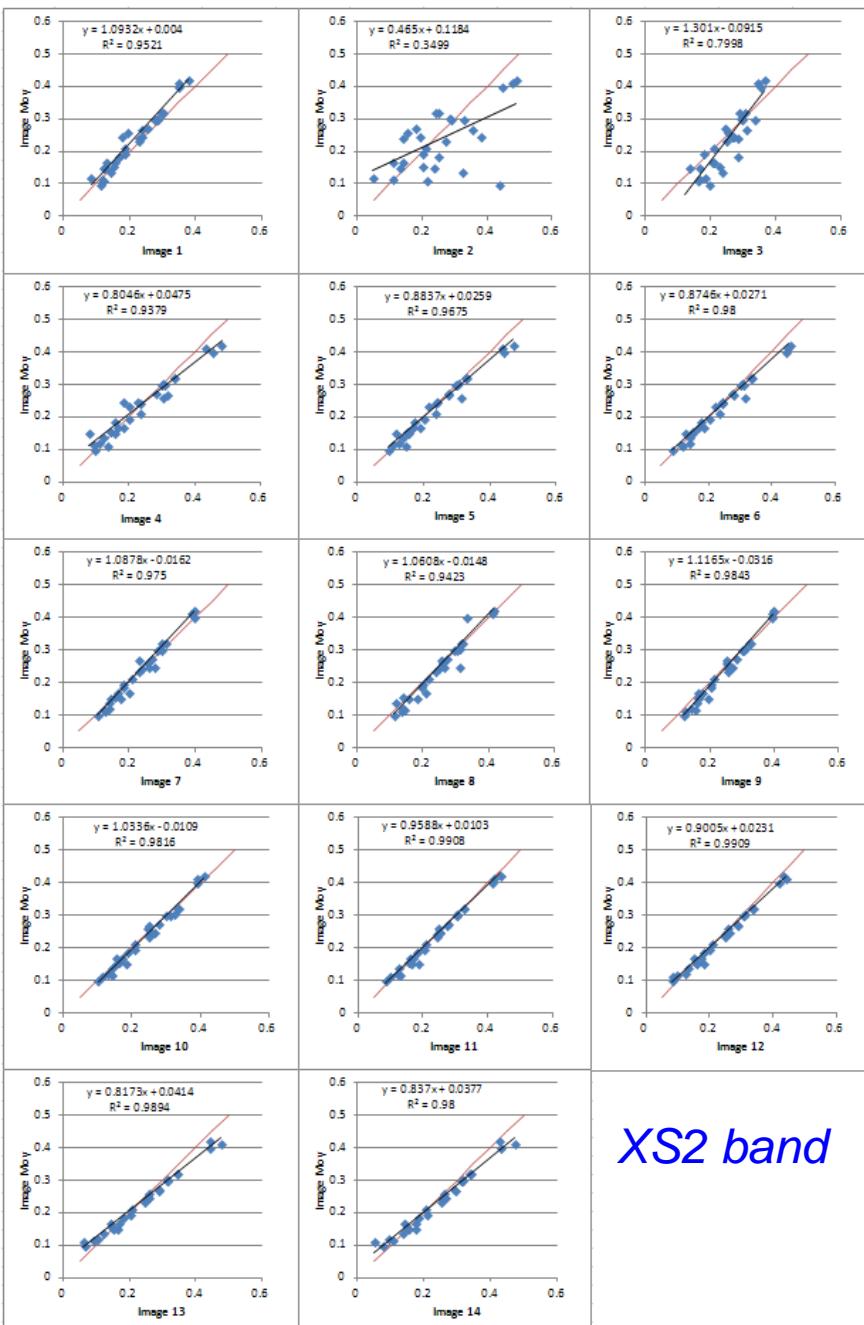
In arid areas pseudo-invariant areas can be easily found.

30 sites were delineated using two methods:

A- Areas of lower standard deviation computed on the time series of soil reflectance images.

B- Visual detection in comparing two color composite at very different dates.

# Radiometric check of SPOT4-Take5

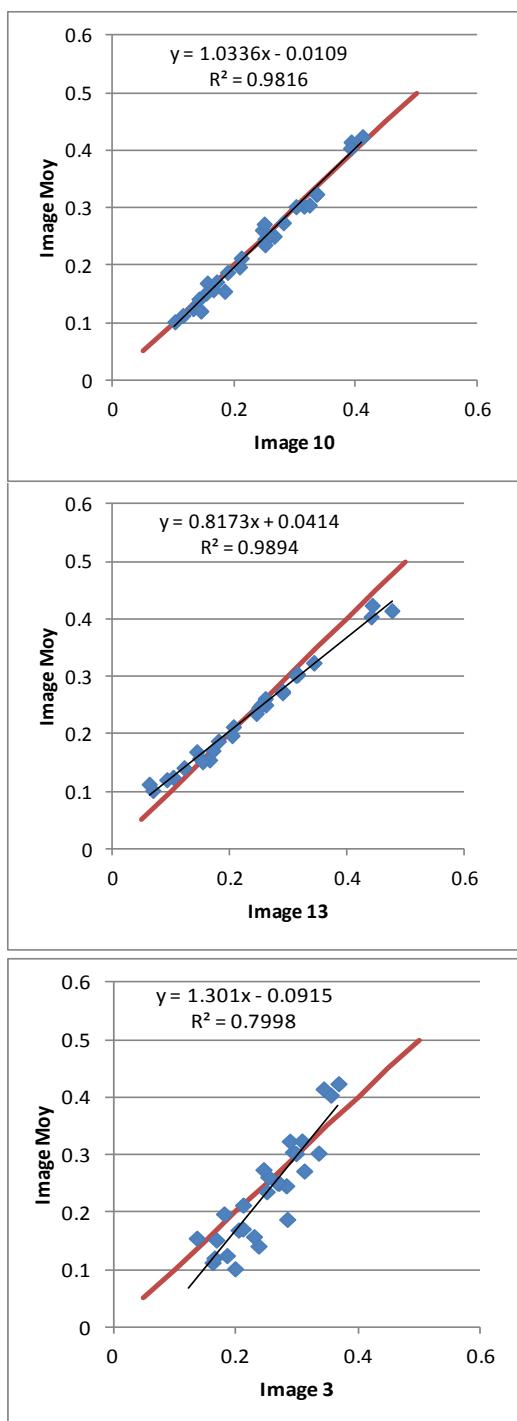


XS2 band

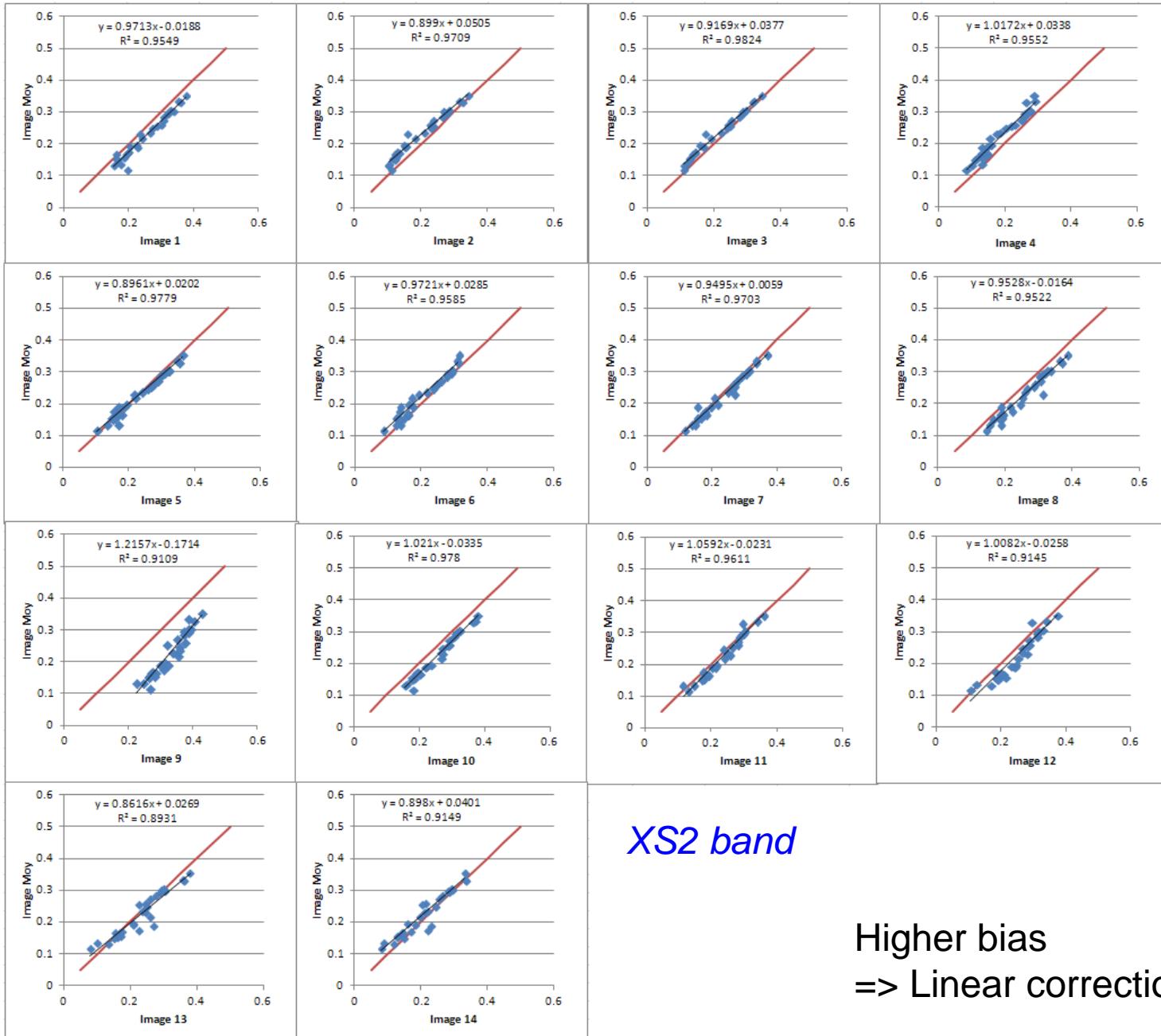
Ok !

Slight bias, but significant impact on NDVI  
⇒ Linear correction applied

Haze  
=> Elimination of the date



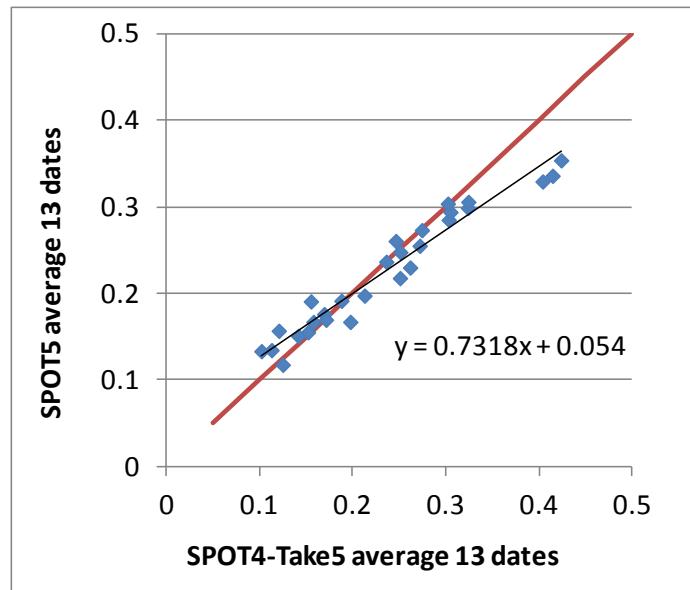
# Radiometric check of SPOT5



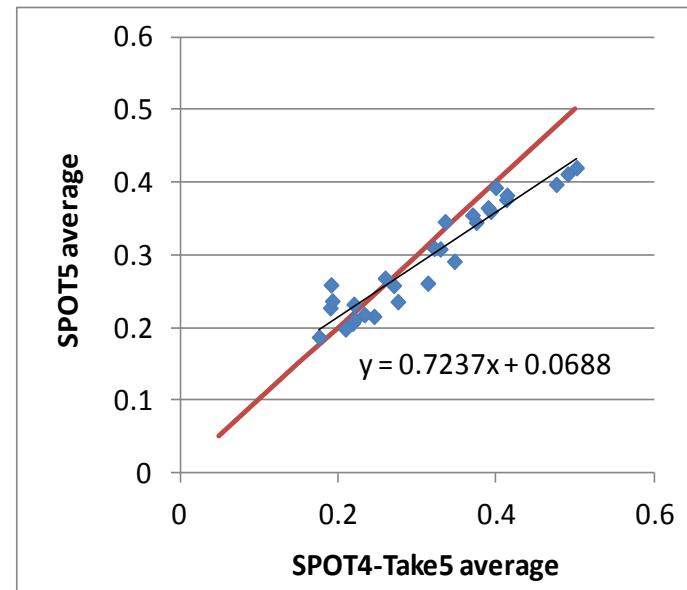
XS2 band

Higher bias  
=> Linear correction

# Comparison between SPOT5 and SPOT4-Take5 series



XS2



XS3

Discrepancy between the two data sets

Strong impact on maximum NDVI values:

SPOT4-Take5

0.9 (ok)

SPOT5

0.7 (underestimated)

⇒ Correction of the SPOT5 series (biased) to match SPOT4-Take5 radiometry

# Ground data

Meteo (ET0)



Evapotranspiration flux measurements (ETR)

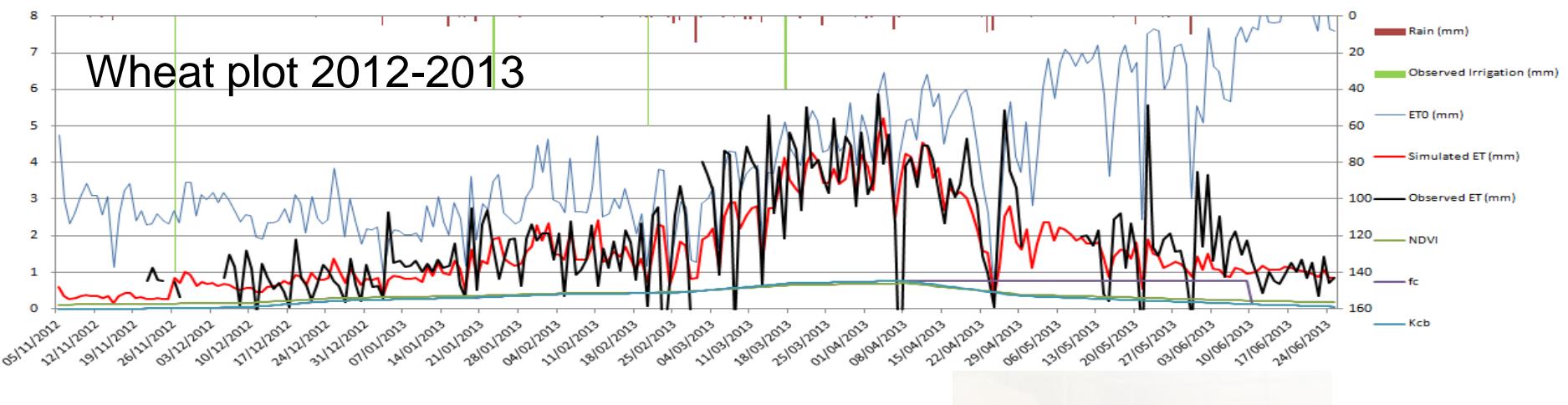
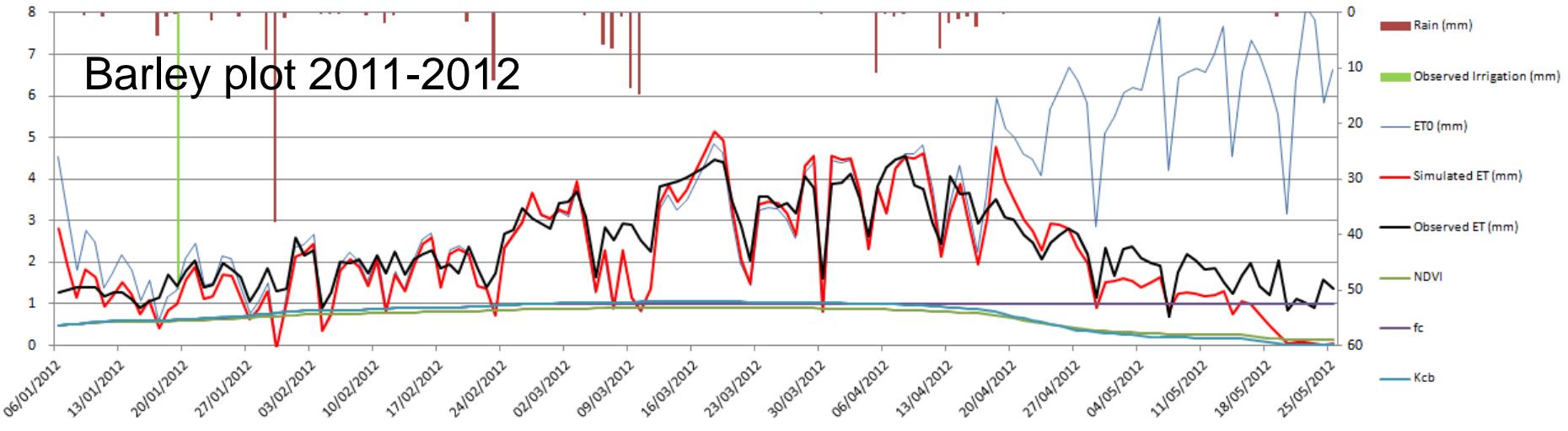
Irrigated barley 2012



Irrigated wheat 2013



# Calibration of the SAMIR model using the two flux plots



# Model parameters

	Parameter	Description	Source
Vegetation parameters	a_fc	Slope of the $fc=a*NDVI+b$	Biblio
	a_Kcb	<b>Slope of Kcb = a*NDVI+b</b>	Calibrated
	NDVIsolnu	bare soil NDVI ( $Kcb = fc = 0$ )	Image
	Duree_plateau	Fc plateau during senescence stage	Biblio
Soil parameters	Wcc - Wpf [0-1]	Soil water holding capacity	Ground observations
	REW (mm)	Readily evaporable water	Calibrated
	Diff E (mm/jour)	Diffusion coef between root and evaporation layer	Calibrated
	RU initiale (%)	Initial soil water content	Ground observations
	Ze (mm)	DEpth evaporation layer	Biblio (FAO56)
	Zr max (mm)	Maximum root depth	Calibrated
	p	Fraction of easily available water (transpiration)	Biblio (FAO56)

# Landcover map

- Trees (Olive trees)                          irrigated / rainfed
- Winter cereals (wheat)                      irrigated / rainfed
- Vegetables (from march to october)        irrigated

Légende :

- Routes nationales
- Zones urbaines
- Barrages
- Sols nus
- Sebkhas et zones humides
- Reliefs
- Lits d'oueds (souvent à sec)
- Légumes de primeurs
- Légumes d'hiver
- Légumes d'été
- Céréales en secs
- Céréales en irriguées
- Arboricultures irriguées
- Oliviers secs



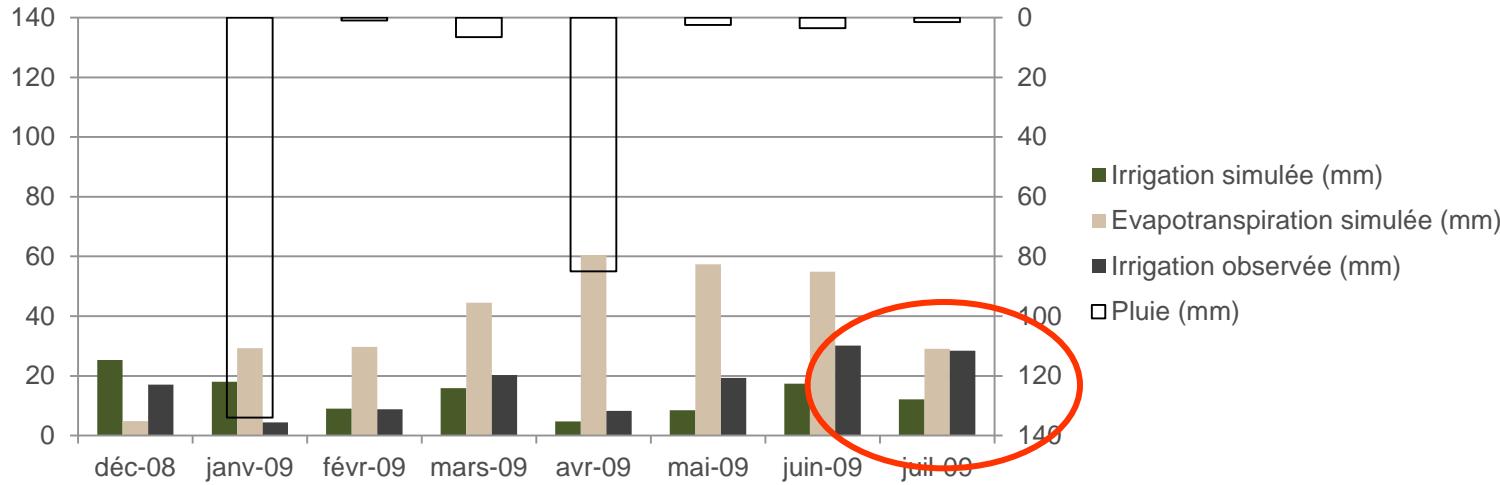
# Irrigations

Actual irrigations at plot level cannot be obtained, they are **simulated**  
→ Objective: to reproduce the average practices of farmers.

Irrigation rules	Vegetables	Cereals	Trees
Fraction of wetted soil (%)	25	100	100
Level of readily available water (RAW) to trigger irrigation (%)	RAW < 75	RAW=0	RAW=0
Rate of filling of available water (%)	100	100	100
Threshold of Kcb to start irrigation (to avoid irrigating weeds)	0.05	0.05	0.05
Threshold to stop irrigation after vegetation peak (% of max Kcb reached)	75	95	0
Seasonal constrains			
Min depth for each irrigation event (mm)	0	20	0
Max depth for each irrigation event (mm)	0	50	100
Min days between two successive irrigations	0	7	7

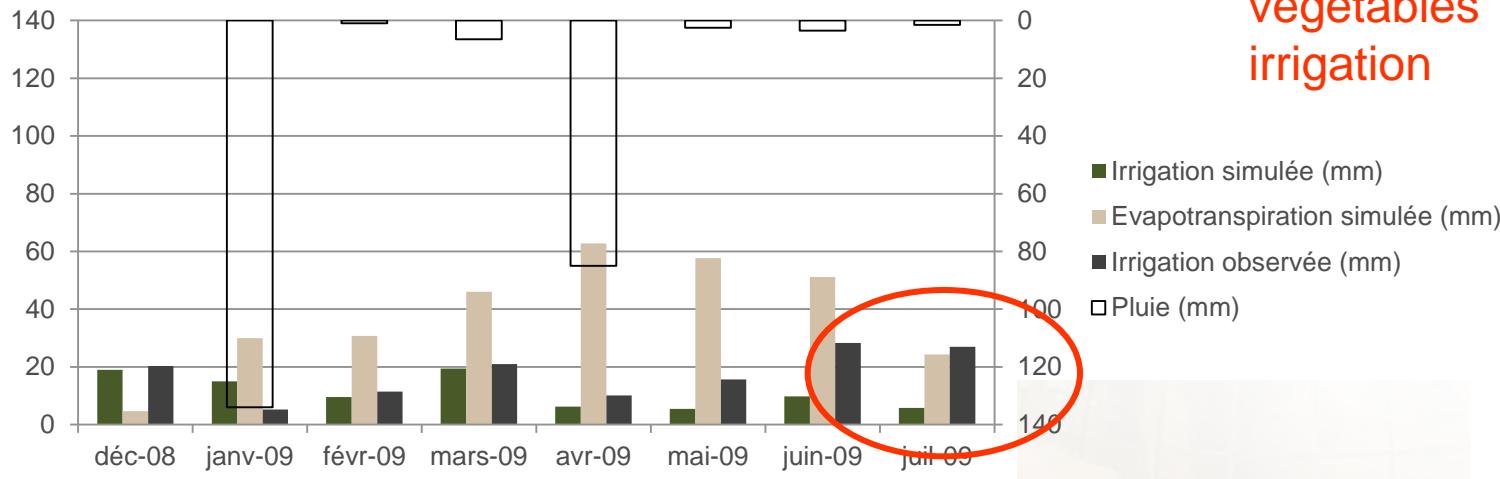
# Results - 2008/2009 season

GDA Ben Salem II



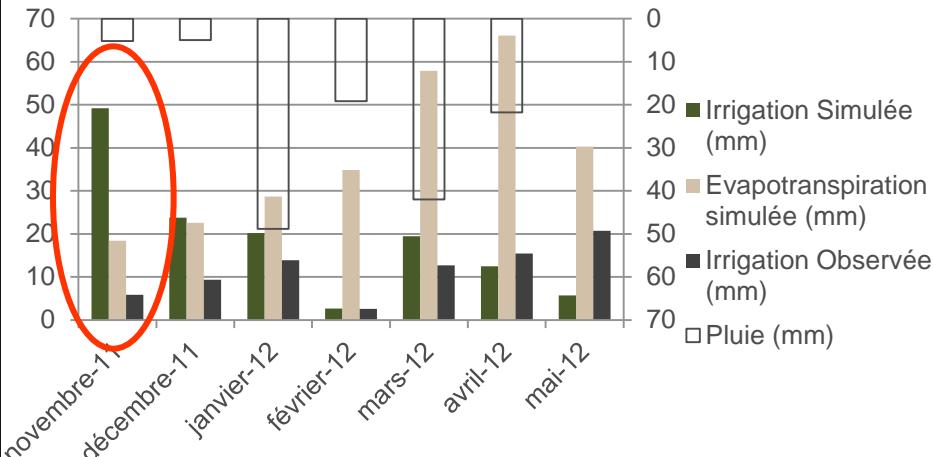
GDA Mlelsa

- Pb of  
vegetables  
irrigation

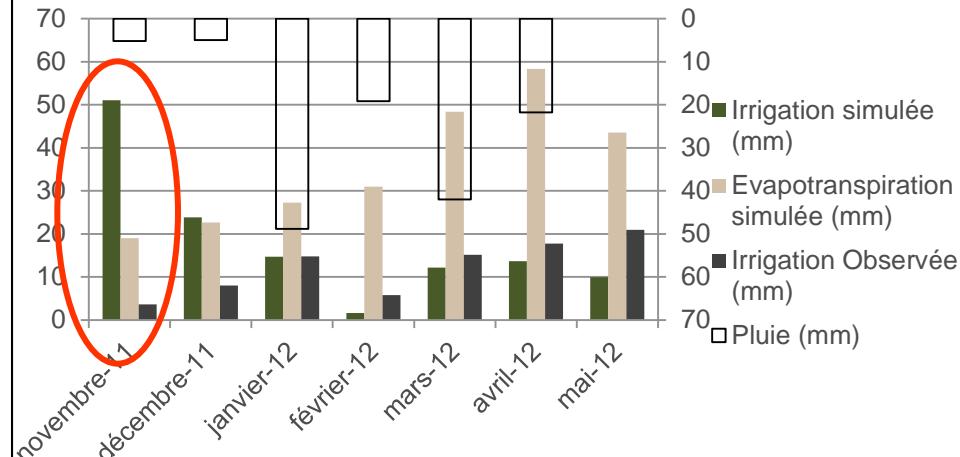


# Results - 2011/2012 season

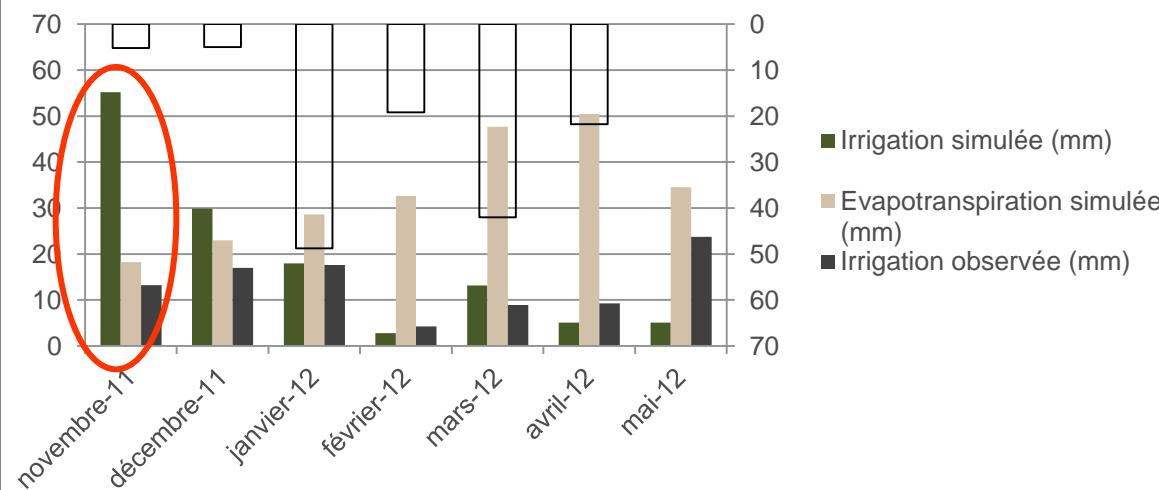
**GDA Ben Salem II**



**GDA Mlelsa**

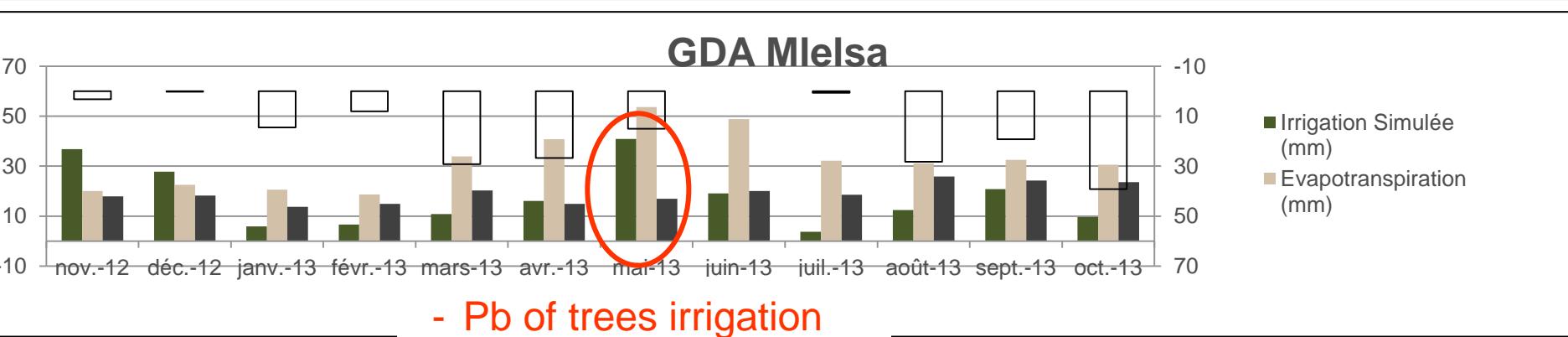
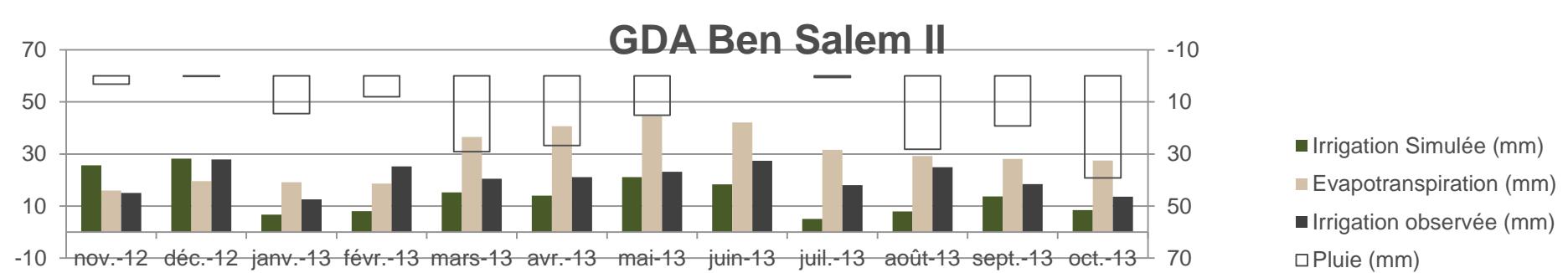


**GDA Karma II**

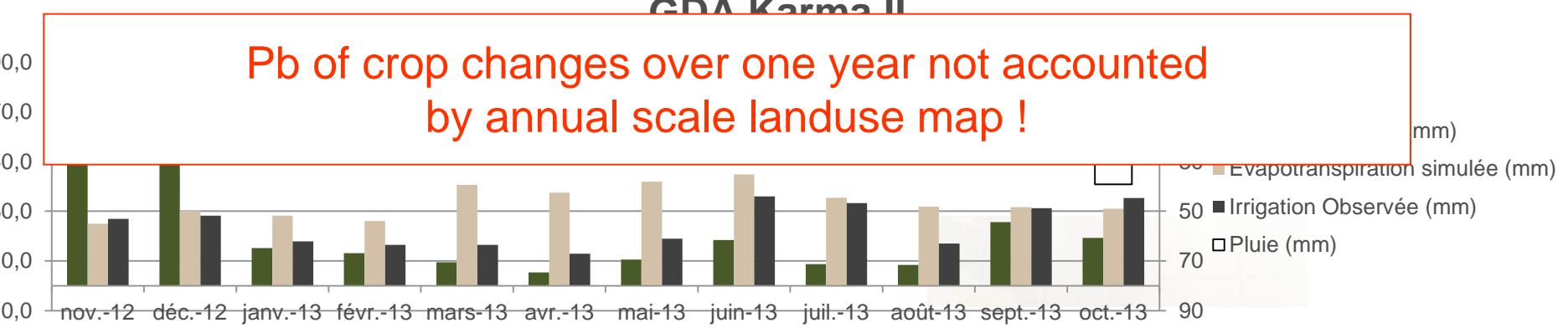


- End of previous crop (should not be irrigated)
- Pb of soil water content initialisation

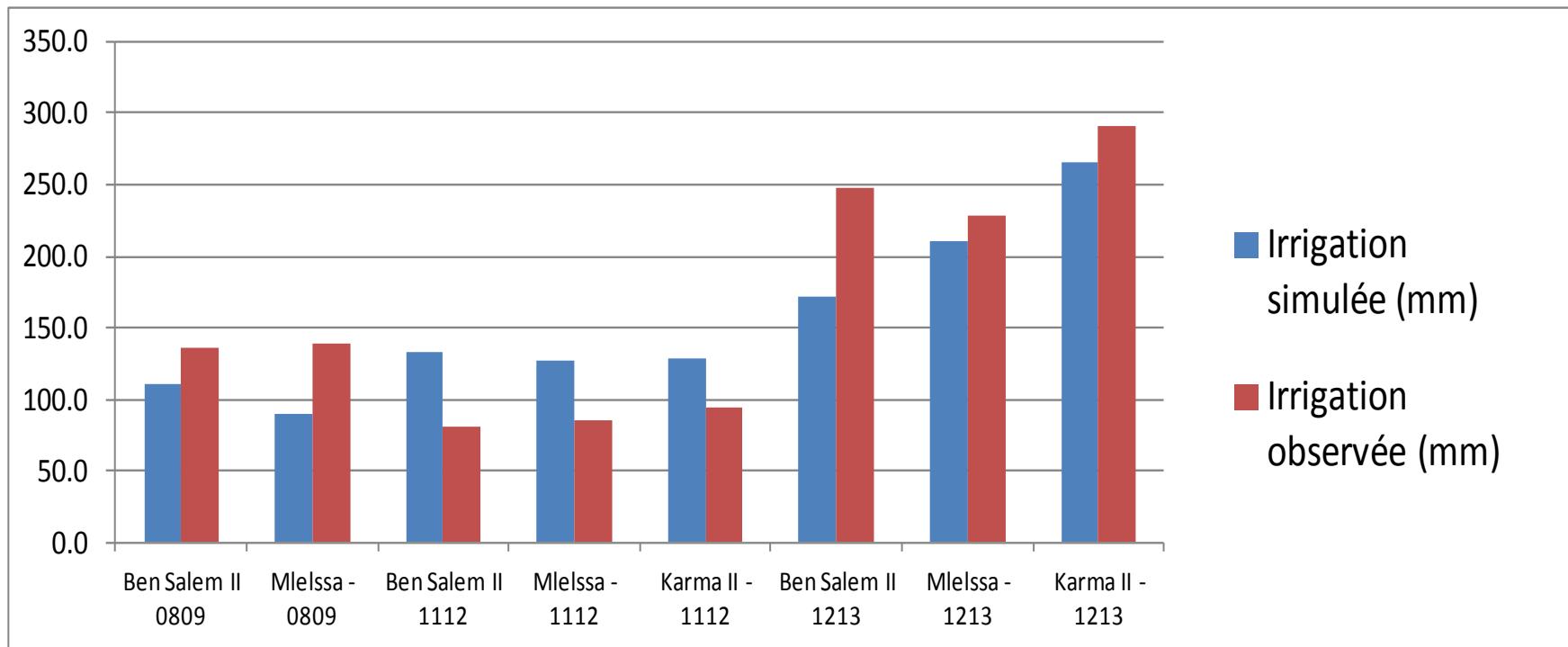
# Results - 2012/2013 season



Pb of crop changes over one year not accounted by annual scale landuse map !



# Results – Seasonal scale

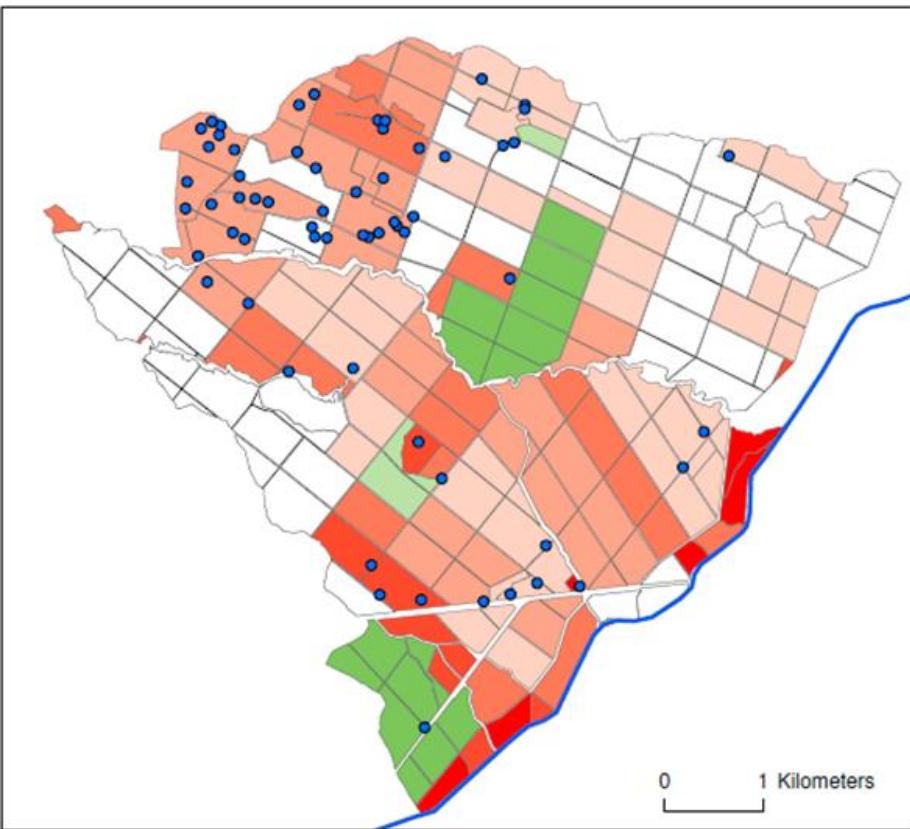


Average for the 8 “perimeter - year”

Simulated	155 mm
Observed	163 mm

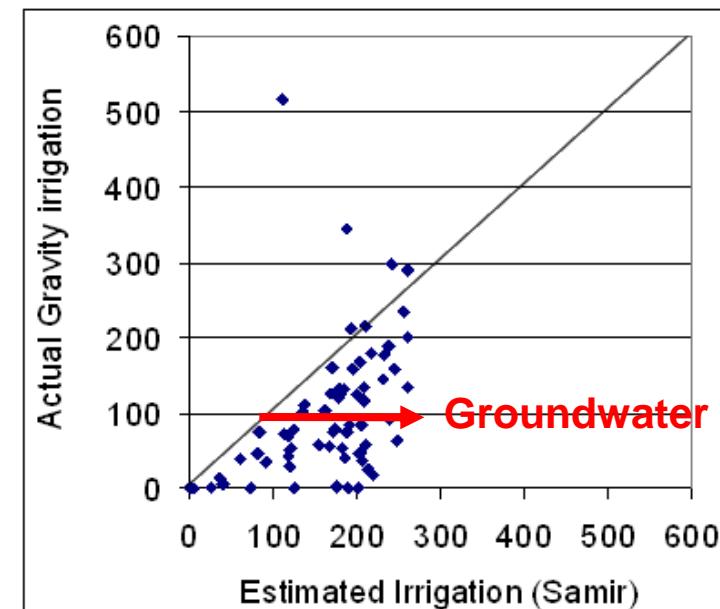
# Comparaison between irrigation estimates and official volumes.

## Detection of groundwater extraction



Difference between estimates and official irrigation depths are linked with wells locations

R3 irrigated sector  
**Haouz plain, Morocco**  
2005-2006 season



**FIN**