Mapping surface soil moisture over wheat crops in southern Mediterranean regions using the backscattering coefficient and the interferometric coherence derived from Sentinel-1

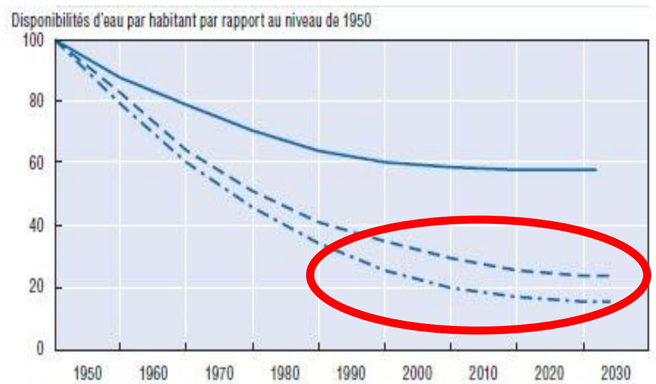
Nadia Ouaadi[a,b], Lionel Jarlan[b], Jamal Ezzahar[c,d], Mehrez Zribi[b], Saïd Khabba[a,d], Elhoussaine Bouras[e,b], Safa Bousbih[f], Pierre-Louis Frison[g]

[a]LMME,Cadi Ayyad University, Marrakech, Morocco.
[b]CESBIO, University of Toulouse, Toulouse, France.
[c]MTI, National School of Applied Sciences, Cadi Ayyad University, Safi, Morocco.
[d]CRSA, Mohammed VI Polytechnic University UM6P, Benguerir, Morocco.
[e]LP2M2E, Cadi Ayyad University, Marrakech, Morocco.
[f]National Institute of Agronomy of Tunis, Tunis, Tunisia.
[g]LaSTIG//MATWAS University of Paris-Est, Champs sur Marne, Paris, France.

EGU General Assembly 2020

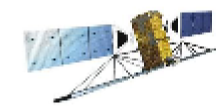
Monitoring of crop hydric conditions with remote sensing

South-Mediterranean:
Limited and irregular water resources
90%: Agriculture
75% Wheat



Source : Bridging Troubled Waters : Assessing the World Bank Water Resource Strategy, Banque mondiale, 2002.

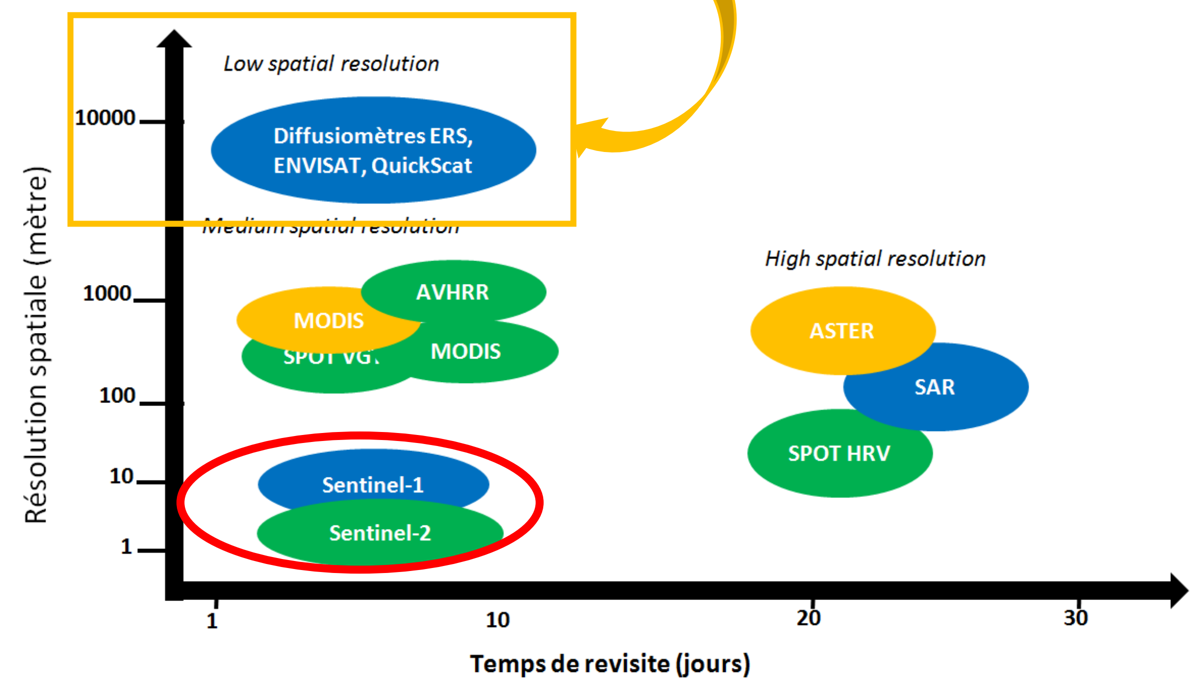
Surface soil moisture (SSM)



Microwaves

- Sensitivity to SSM
- Independent of weather conditions

SSM products



Sentinel-1 / Data compatible with plot scale

Soil moisture retrieval / mixed response soil-vegeation at C-band / use of optical data

Optical data under cloudy conditions ? SSM estimation using radar only ?

Objective

Surface soil moisture estimation using C–band radar data only

Approach

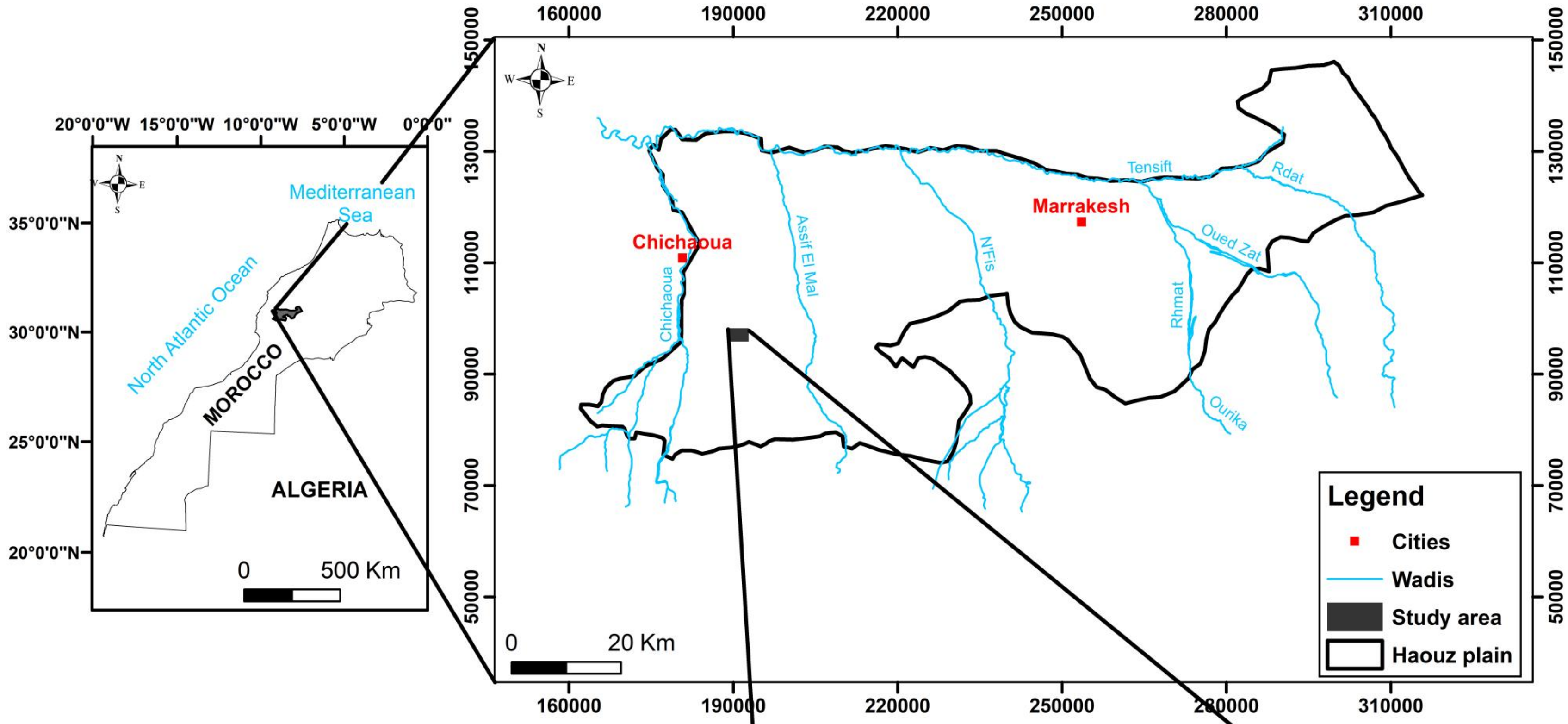
1. In situ and satellite data
2. Data analysis
3. Radar signal understanding/ Modeling
4. New approach for SSM estimation

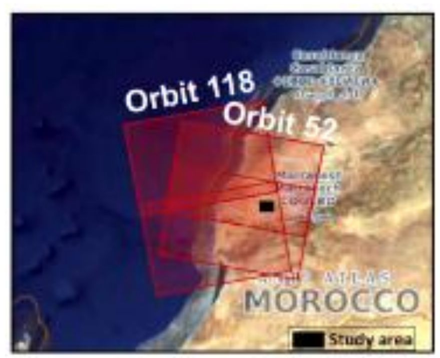
1. In situ and satellite data
2. Data analysis
3. Radar signal understanding/ Modeling
4. New approach for SSM estimation

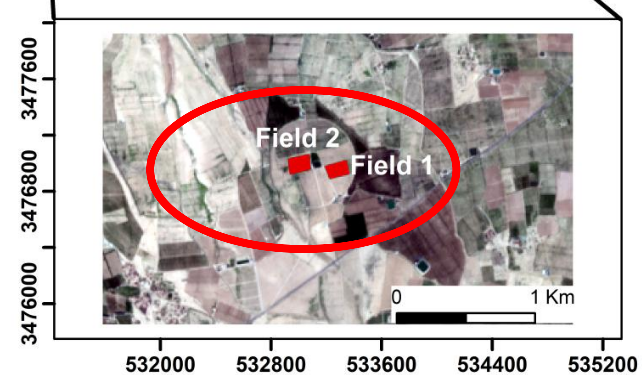
Study area

Main Study Area : Chichaoua (Morocco) / monitoring period: 2016-2018

- Semi-arid climate (Rainfall: 242 mm / ET0 : 1600 mm)
- Winter wheat / drip irrigation
- Crop season: Nov to May







Field measurements

Experimental data

Automatic measurements and measurement campaigns :

TDR sensors

Thetaprobe

Pin profiler

Soil measurements

- Soil moisture
- Surface roughness

Wheat measurements

- Biomass
- Vegetation water content
- LAI
- Canopy height
- Cover fraction

Meteorological data

- Rainfall
- Temperature

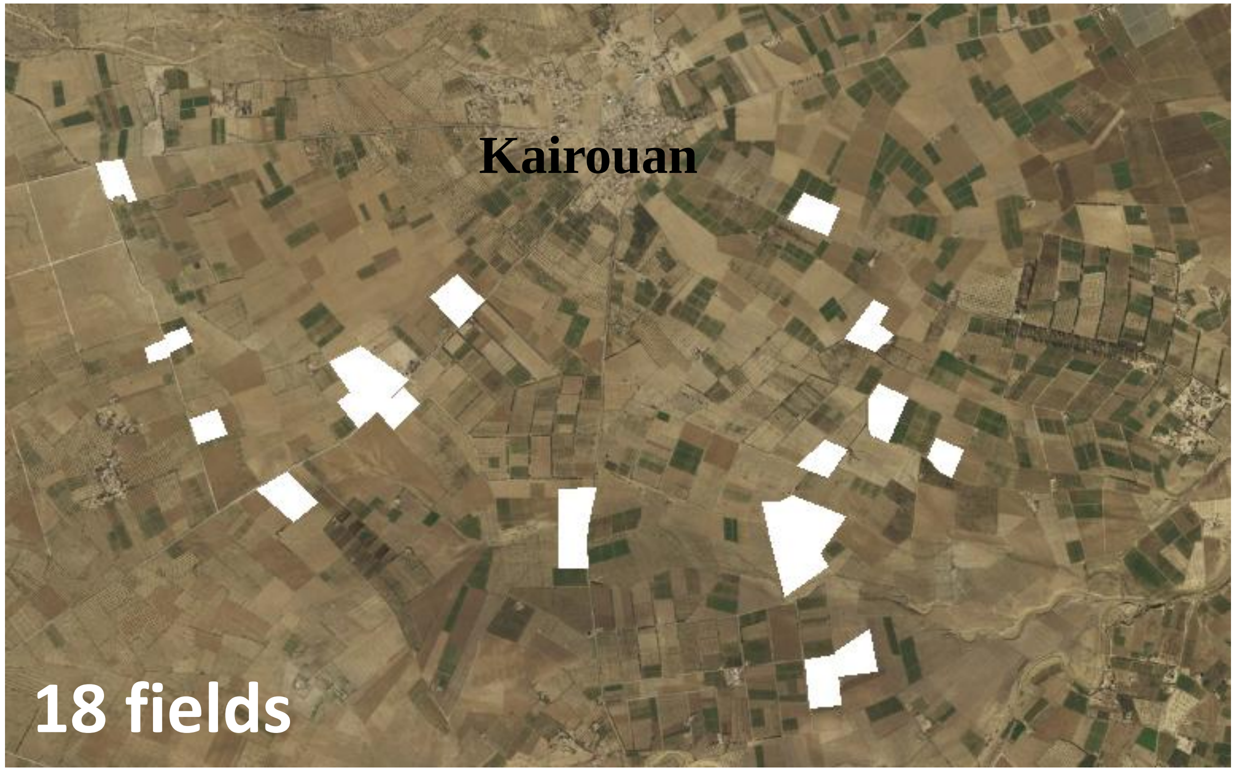
Weather station

Soil moisture/ Validation database

Field 3 (Chichaoua)
65 Km west of Marrakech
Morocco
Agricultural season : 2018-2019

13 irrigated plots
7 rainfed fields
445 measurements

Kairouan Plain
Tunisia
Agricultural season : 2016-2017

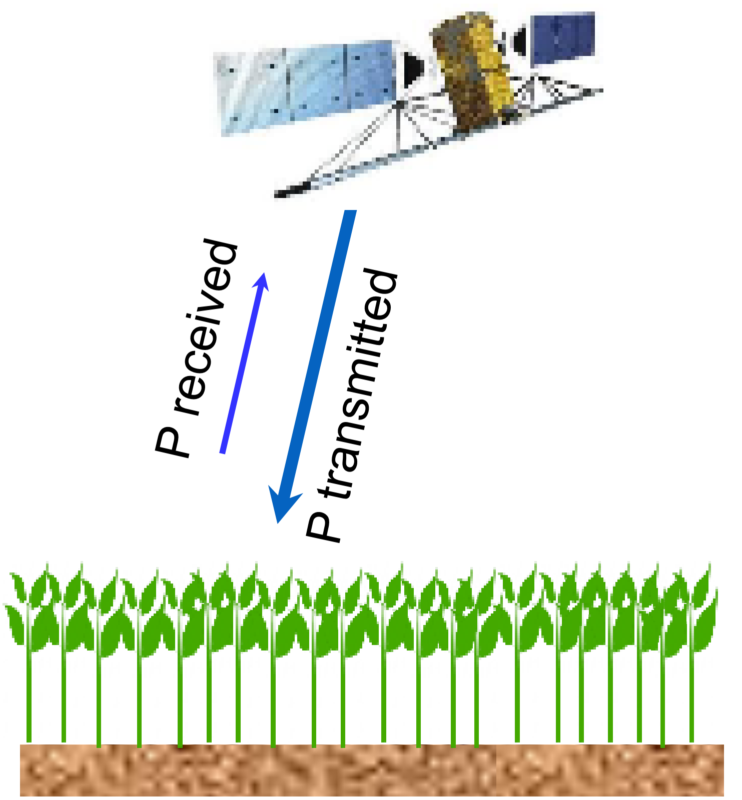


Sidi Rahal
40 km east of Marrakech city
Morocco
Agricultural season : 2016-2017 & 2017-2018

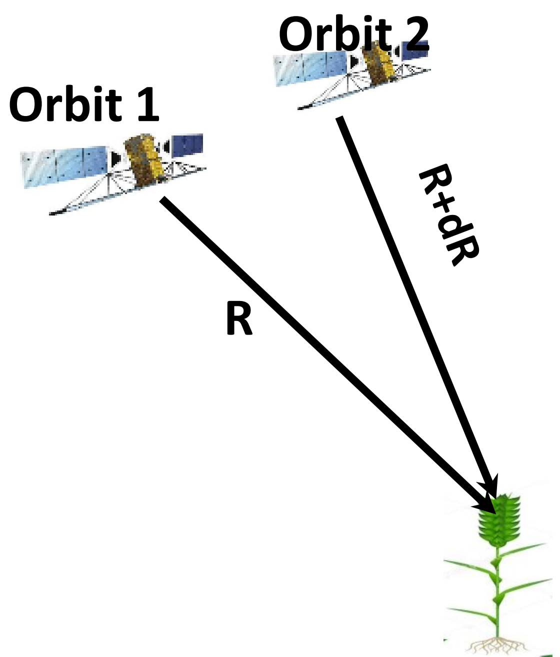
Backscattering coefficient

The backscatter coefficient is the backscattered intensity from the target:

$$\sigma^0 = \frac{\text{P received}}{\text{P transmitted}}$$



It contains information on the target (soil moisture, biomass, surface roughness ...)



Interferometric coherence

→The variance of the interferometric phase

→ It characterizes the stability of the scatterers

→Decreases when changes of scatterers geometrical and dielectrical properties (position, orientation, moisture content)

Processing of sentinel-1 data

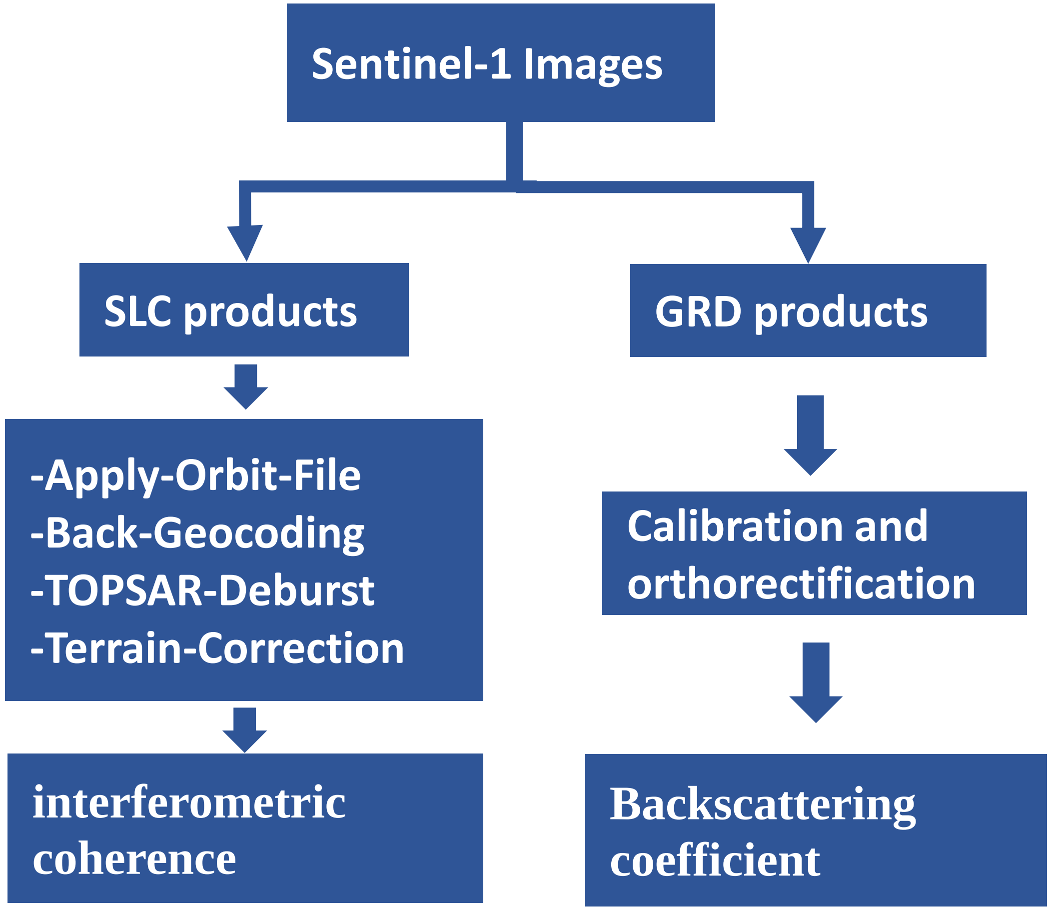
Sentinel-1 products : SLC (coherence) and GRD (backscattering coefficient)

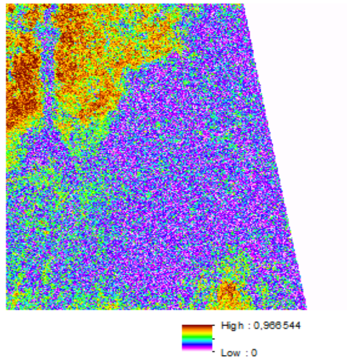
On the calibration sites

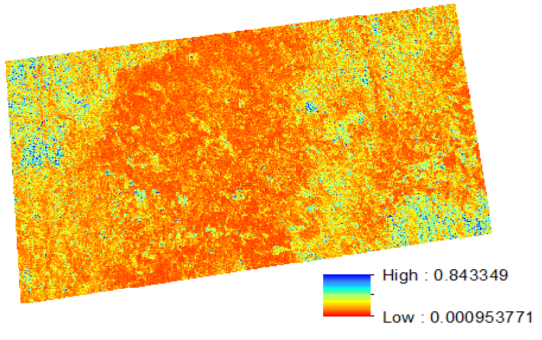
- Two relative orbits: 52 (35.2°) and 118 (45.6°)
- Two polarizations :VV et VH
- October 1, 2016 → Jully 31, 2018
- Total number of images on the two plots : **207 GRD and 219 SLC.**

On the validation sites

Site	Season	Relative Orbit	Overpass time	Product	Number of images
Field 3	2018-2019	118 & 52 (45,6° & 35,2°)	18:30 & 06:30	GRD	**65**
				SLC	**65**
Sidi Rahal	2016-2017 & 2017-2018	154 (40°)	06:28	GRD	**71**
				SLC	**70**
Kairouan	2016-2017	88 & 95 (~40°)	17:20 & 05:21	GRD	**65**
				SLC	**65**







1 In situ and satellite data

2 Data analysis

3 Radar signal understanding/ Modeling

4 New approach for SSM estimation

Time series analysis

Backscattering

Seasonal evolution of the signal (Minimum at heading (Picard et al. ,2003))

VV: Dominated by rapid changes in soil moisture.

VH: stronger after heading due to volume diffusion +High sensitivity to biomass.

The polarization ratio

•More stable over time

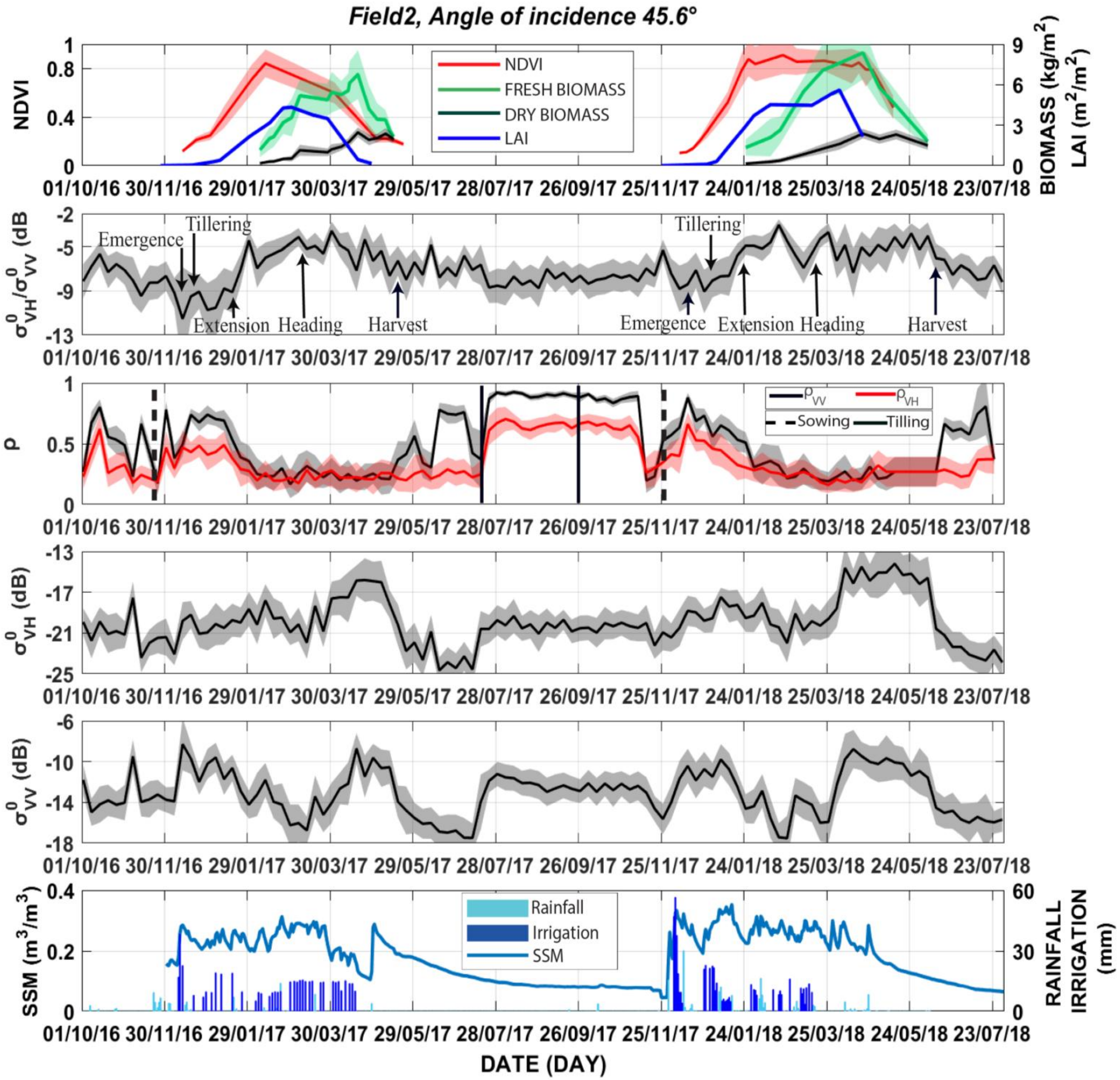
•Follows the temporal evolution of the biomass: both increase from emergence to heading, then begin to decrease.(Veloso et al., 2017)

Interferometric coherence:

•High values (0.9) during summer

• Post-emergence decrease with vegetation development(reaches 0.15)

• Low sensitivity to soil moisture variation (not shown)



Data analysis/Coherence-vegetation relationships

Relationship between Coherence and AGB

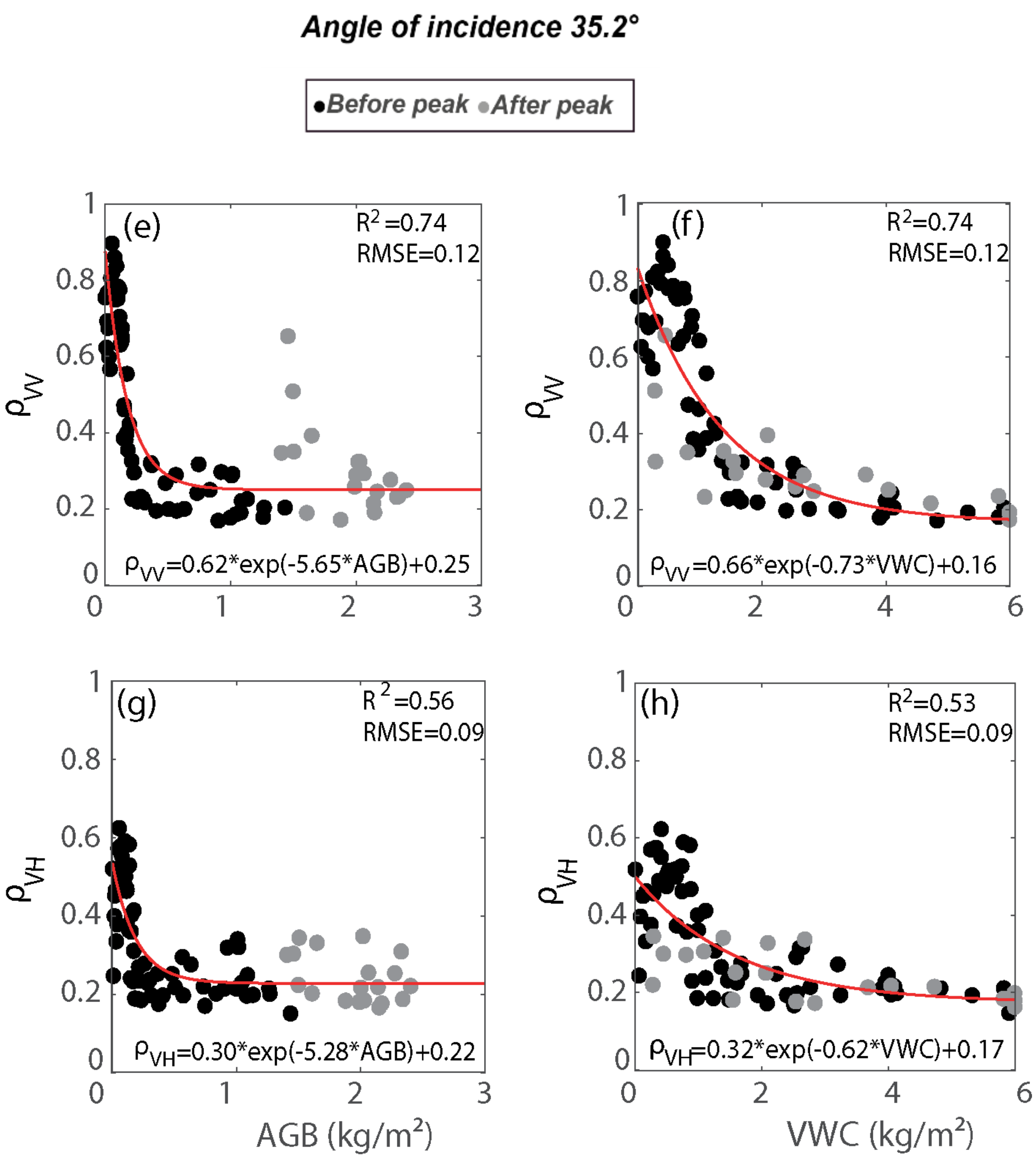
•Significant exponential relationships obtained for all cases using data of the whole season.

•Best correlations obtained between coherence and ABG

•Best results obtained using coherence at VV polarization.

•Relationship saturates at ABG value of about 0,9 kg / m².

•Similar results obtained at 45,6 °



1. In situ and satellite data
2. Data analysis
3. **Radar signal understanding/ Modeling**
4. New approach for SSM estimation

Backscatter modeling

Water Cloud-Oh Model Modeling of the C-band radar signal

•Vegetation model : Water Cloud Model

•Soil model : Oh Model

$$\sigma^0_{canopy} = \sigma^0_{veget} + e^{-2BV_1/COS\theta}\sigma^0_{soil}$$

$$\sigma^0_{veget} = AV_1 \cos\theta(1 - e^{-2BV_1/COS\theta})$$

θ : Incidence angle

V1 : Vegetation descriptor

VWC: (Attema and Ulaby, 1978; Wang et al., 2018)

LAI : (Bai et al., 2017; Kumar et al., 2014; Prevot et al., 1993)

NDVI: (Baghdadi et al., 2017; Bousbih et al., 2017; El Hajj et al., 2016)

AGB: (Hosseini and McNairn, 2017)

…

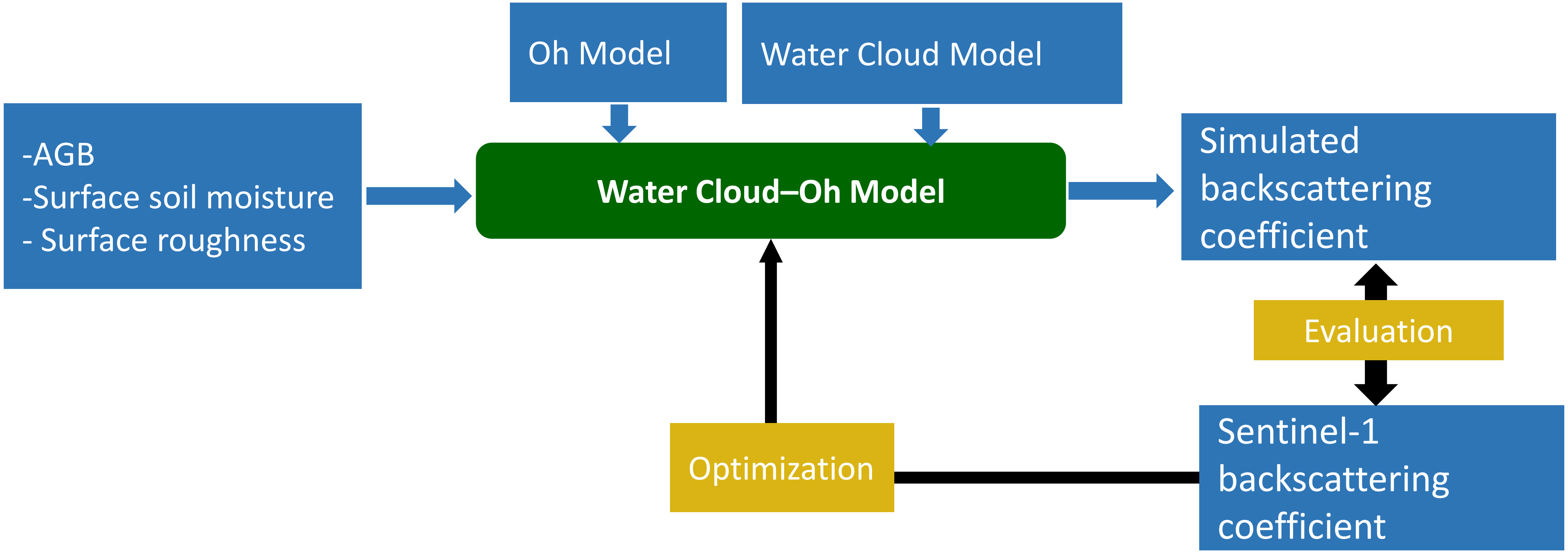
A&B : the parameters of the model, depend on the canopy type, the sensor frequency, the polarization and the incidence angle.

Backscatter modeling/ Calibration

Methodology

Calibration and validation of the coupled model

Vegetation descriptor: Above ground biomass



Calibration: minimize the RMSE between the simulated and observed backscattering coefficient of the first season

Validation: second season.

	45,6°		35,2°	
	VV	VH	VV	VH
R	0.73	0.47	0.76	0.24
RMSE	1.54	1.66	1.44	1.92
Bias	-0.17	0.25	-0.31	0.27

Backscatter modeling/ Simulation results

Simulation results

Seasonal evolution / OK

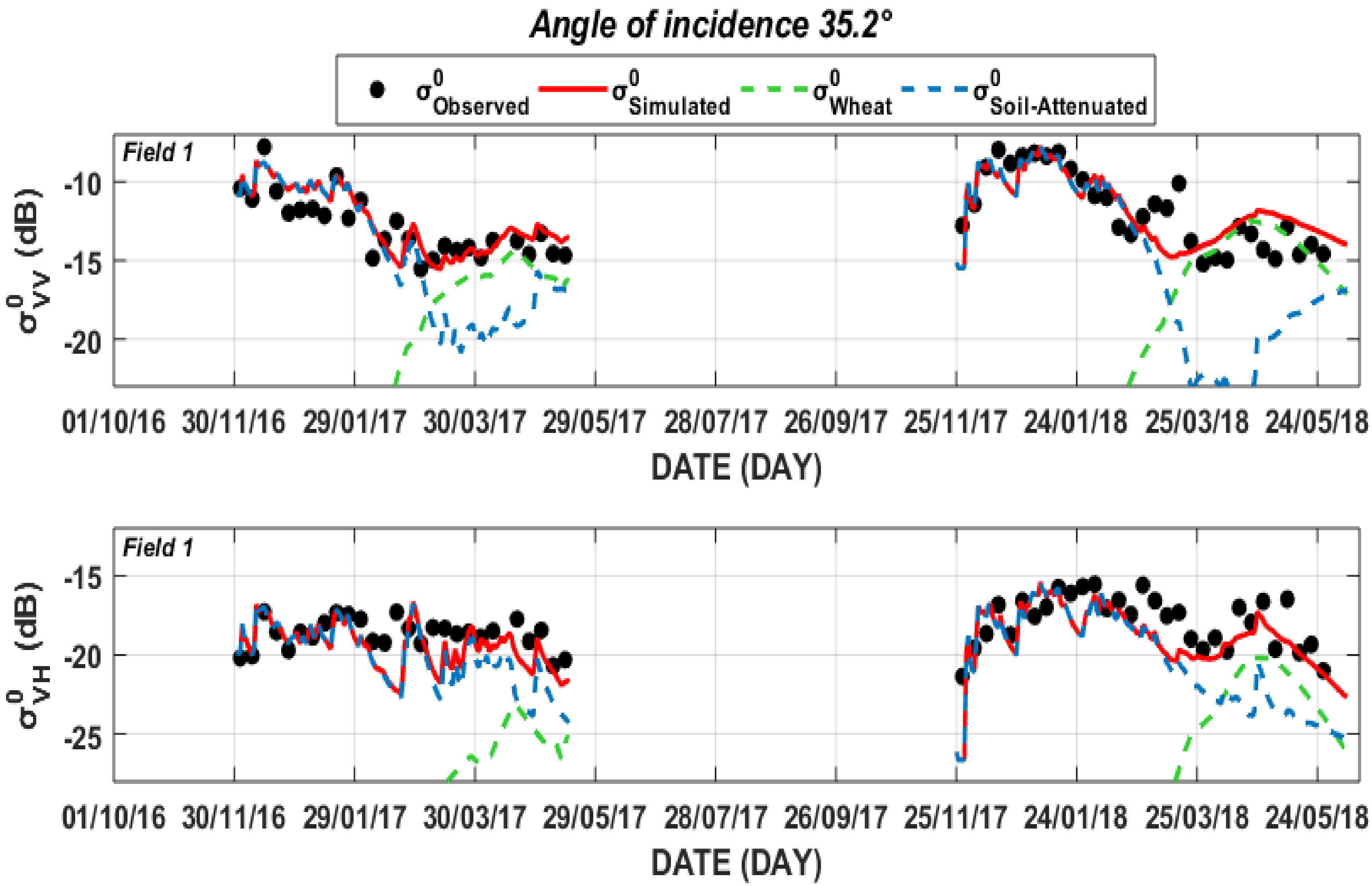
soil dominates / beginning of the season

volume backscattering increases with the development of the vegetation

soil is gradually attenuated by the canopy.

attenuation stronger for VV (Picard et al., 2003)

Disagreement observed in March / stem-soil interaction neglected in the model



1 In situ and satellite data

2 Data analysis

3 Radar signal understanding/ Modeling

4 New approach for SSM estimation

Inversion procedure

NDVI, LAI, cover fraction : derived from optical data : weather conditions? + Daytime?

Can we avoid the use of optical data?

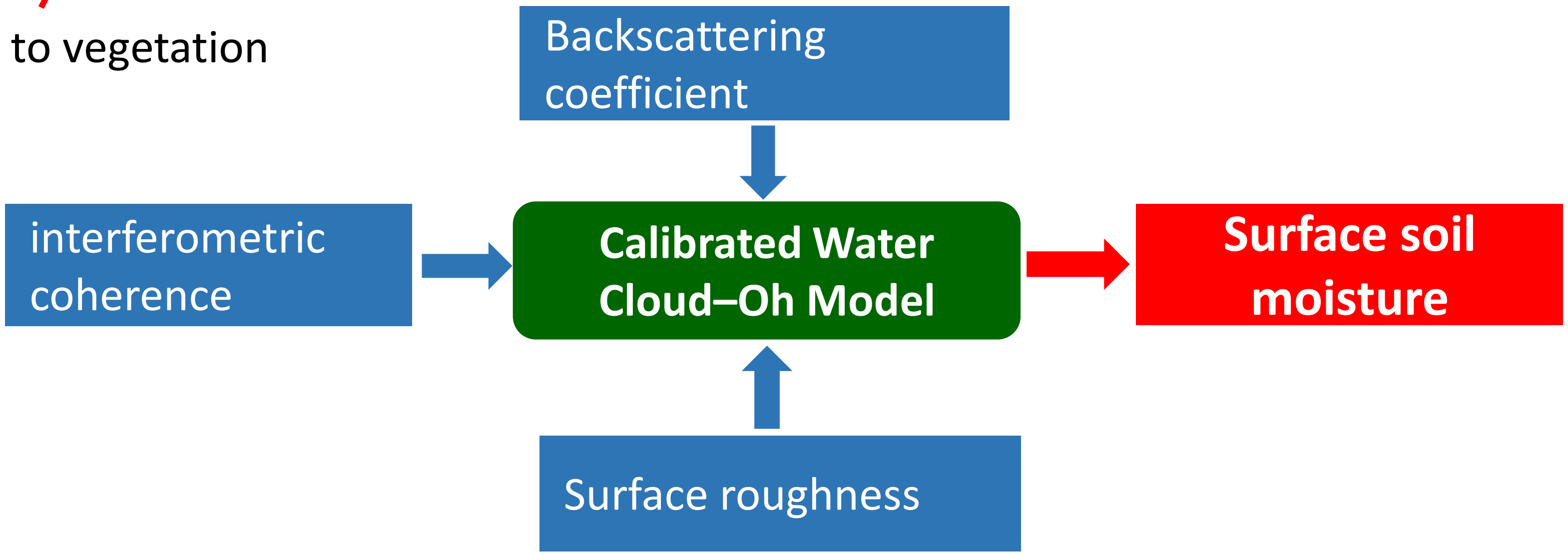
Coherence-AGB relationship

Implementation of the calibrated WCM-Oh model in a soil moisture inversion approach using only radar data :

Combining two independent and complementary information: the backscattering coefficient and the interferometric coherence.

sensitivity to soil moisture

Sensitivity to vegetation



Inversion results/ SSM estimation

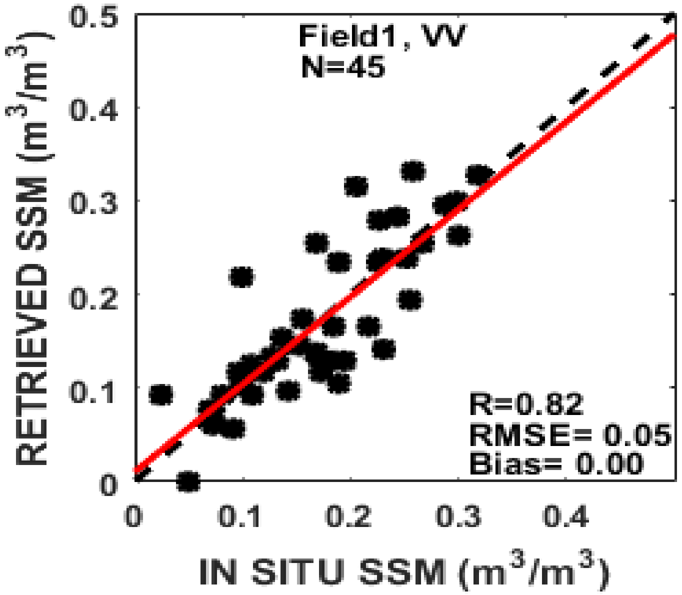
Study area: Field 1

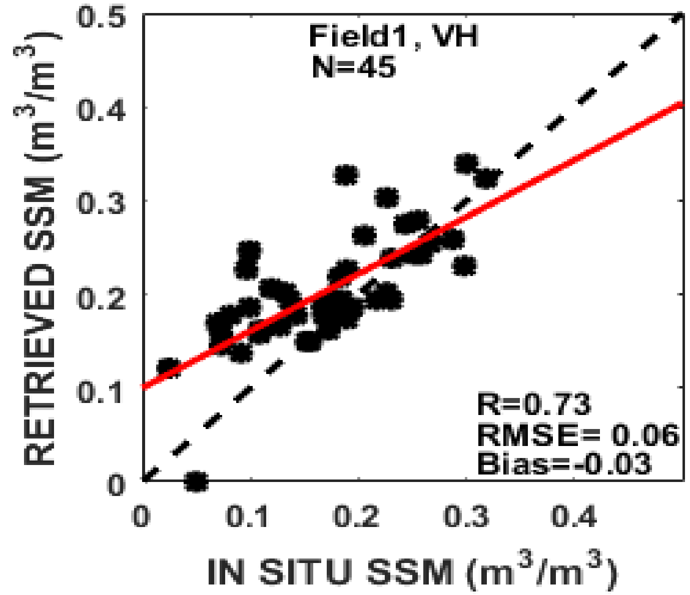
• Surface soil moisture is successfully retrieved using data of both orbits.

•Results at VV are better than VH : The effect of vegetation on the signal is higher at VH.

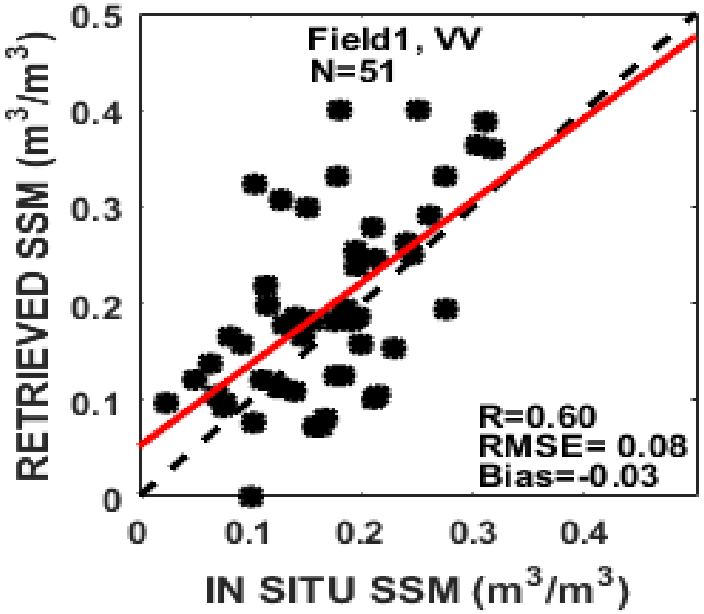
•Similarly, the high contribution of vegetation at higher incidence angles explain the observed differences between 35,2° and 45,6 ° results

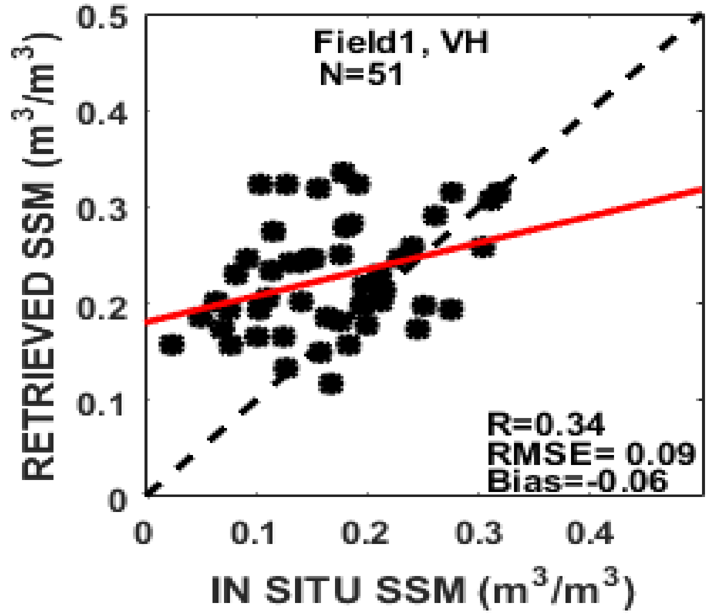
35.2° of incidence angle





45.6° of incidence angle





Inversion results/ SSM estimation

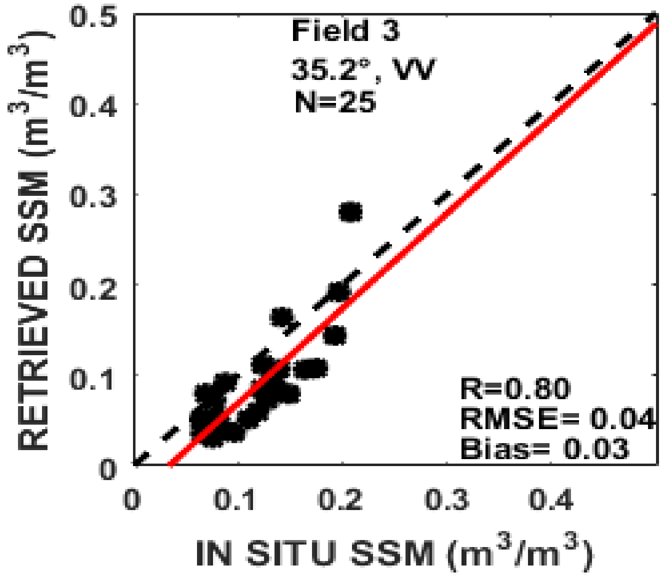
Validation sites: Morocco

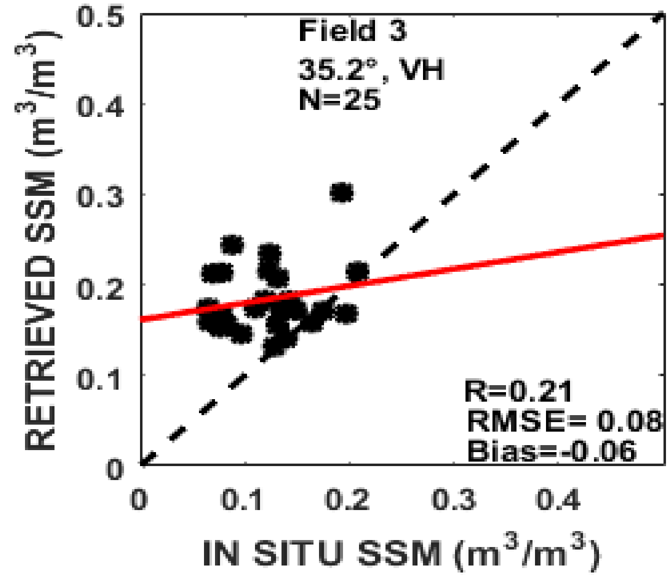
- Field 3 is an irrigated wheat plot
- Sidi Rahal is a rainfed wheat plot

- The results are satisfying
- The statistics are of the same order of magnitude as those obtained on the study site

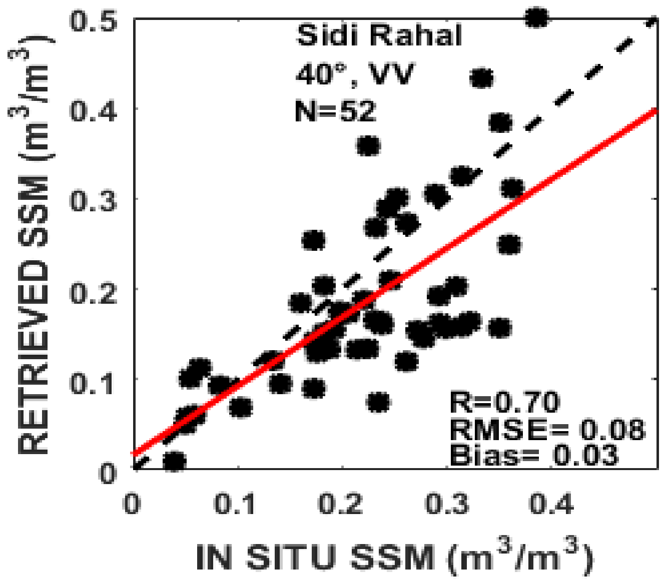
- A higher value of the R is obtained on Field 3 compared to Sidi Rahal: higher angle of incidence at the second site.

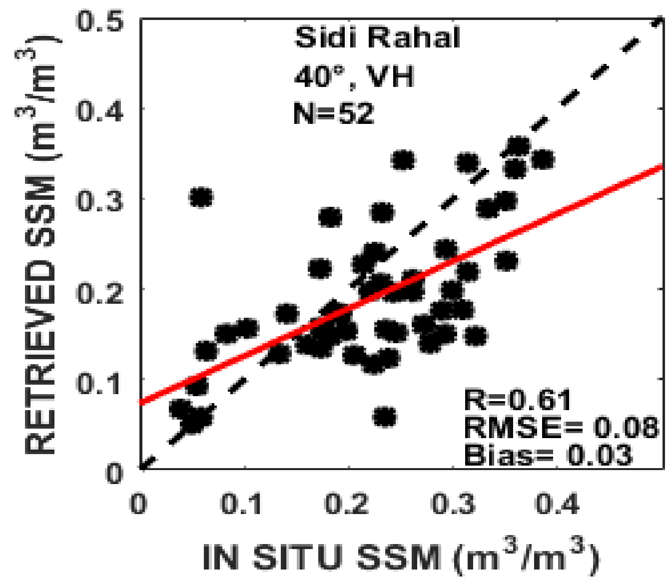
35.2° of incidence angle





40° of incidence angle





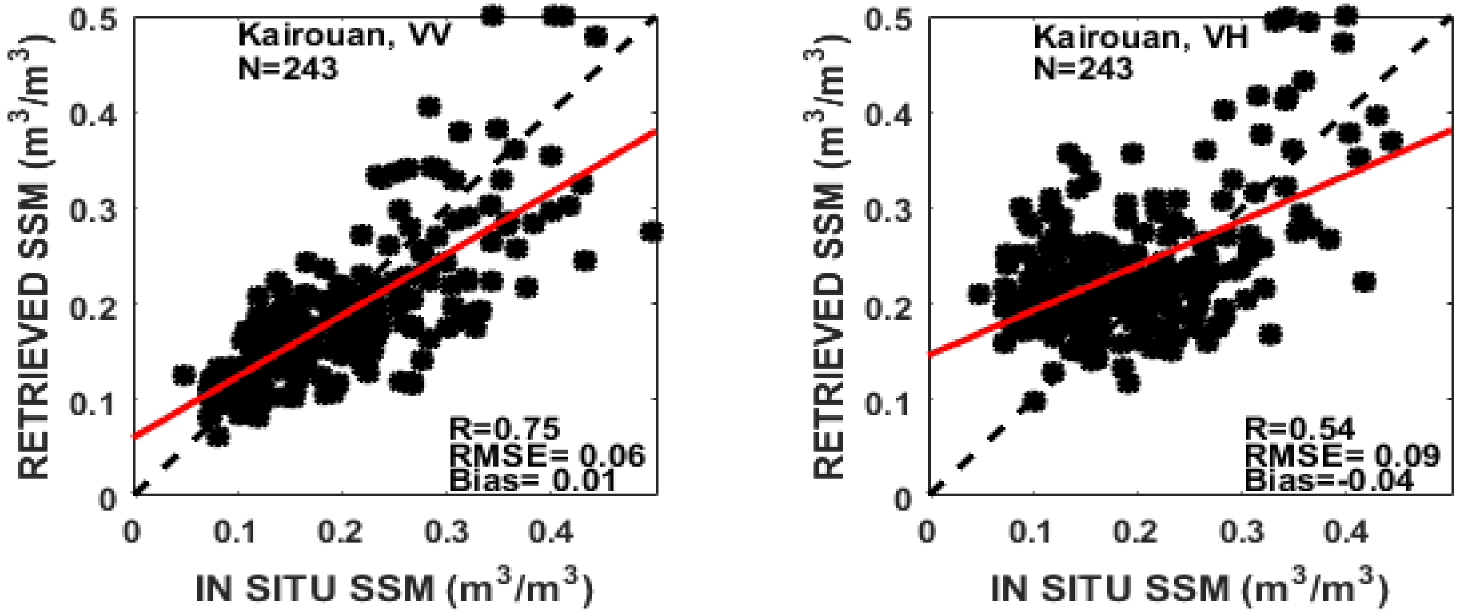
Inversion results/ SSM estimation

Validation on 18 plots: irrigated and rainfed in Tunisia, gives a higher R and a lower RMSE and bias.

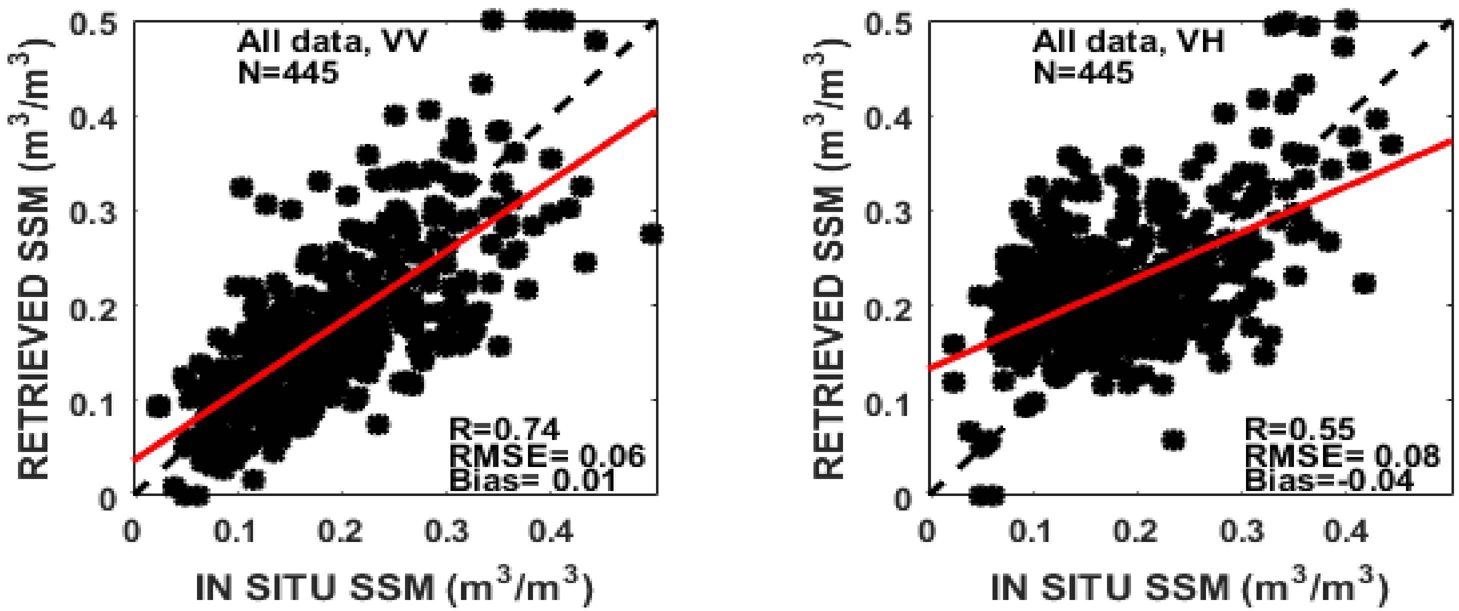
The limited loss of performance at all validation sites demonstrates the robustness of the new proposed approach.

The last two figures show the results of the whole database: all orbits and all sites (Moroccan and Tunisian)

Validation sites: Tunisia



All data



Inversion results/ SSM estimation

Sensitivity test

VV:

•Results comparable at the beginning of the season

•Decrease of R with the development of vegetation except the proposed approach

•Degradation:

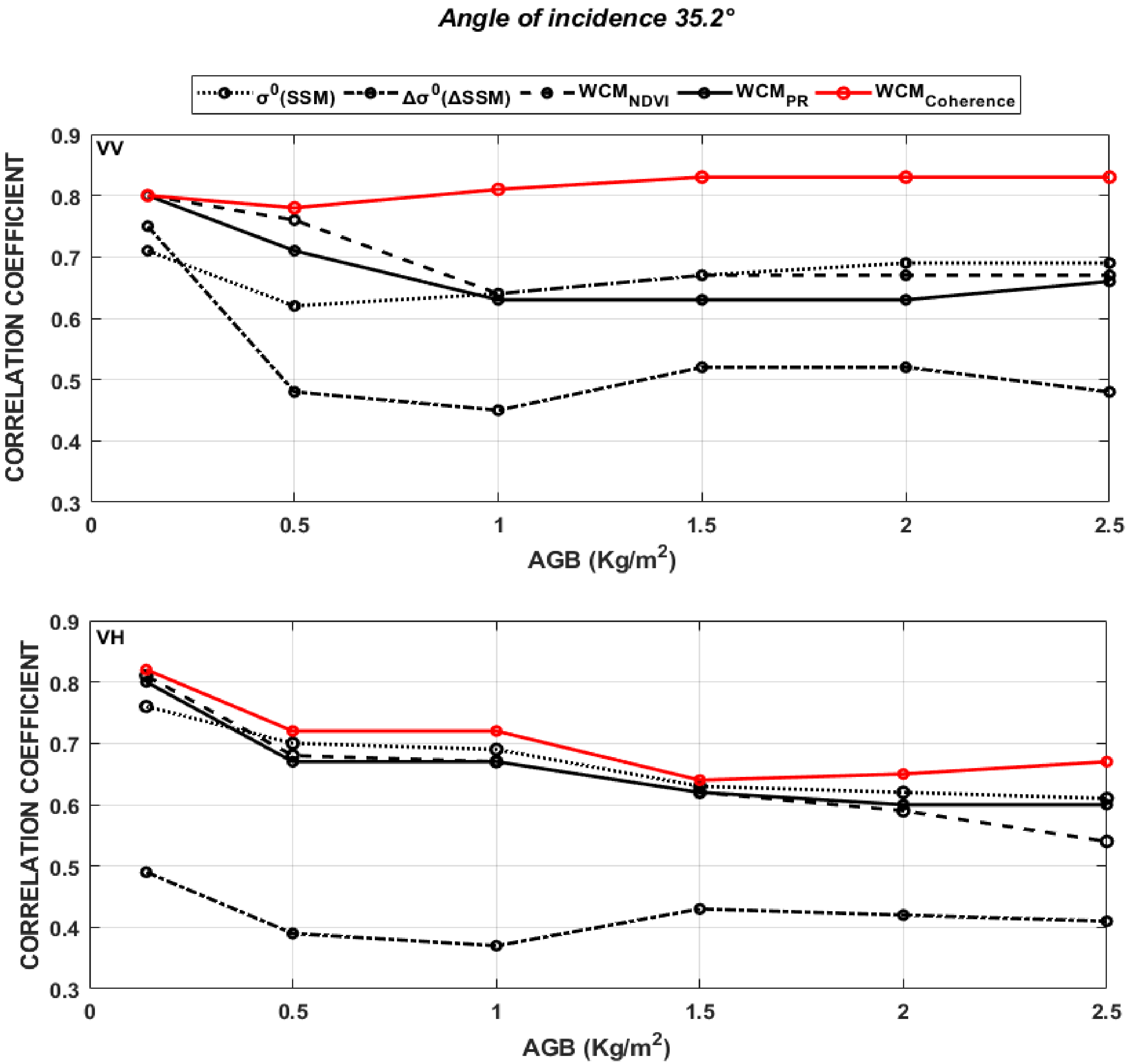
→ 13%, 40%, 20%, 21% & 2.5%

•Improvement by the proposed approach:

→ 17%, 42%, 19.3% & 20.5%.

VH

•Comparable results up to AGB=2 kg/m²
(except one)



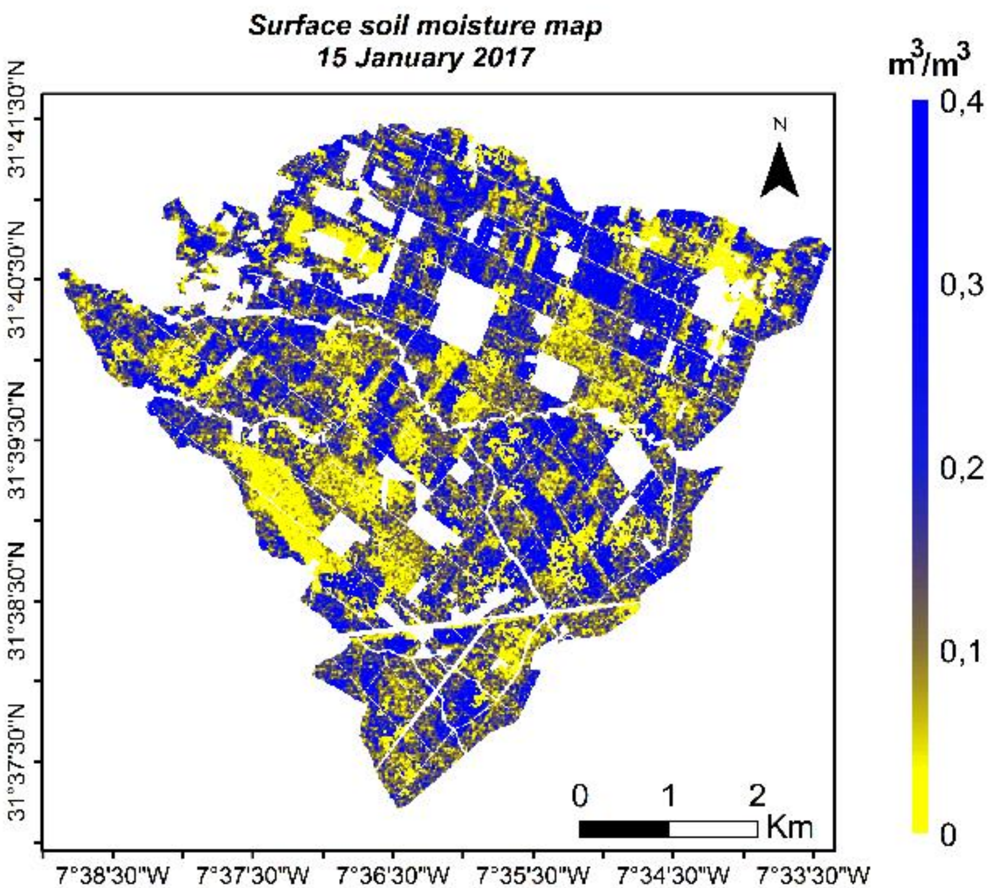
Surface soil moisture mapping

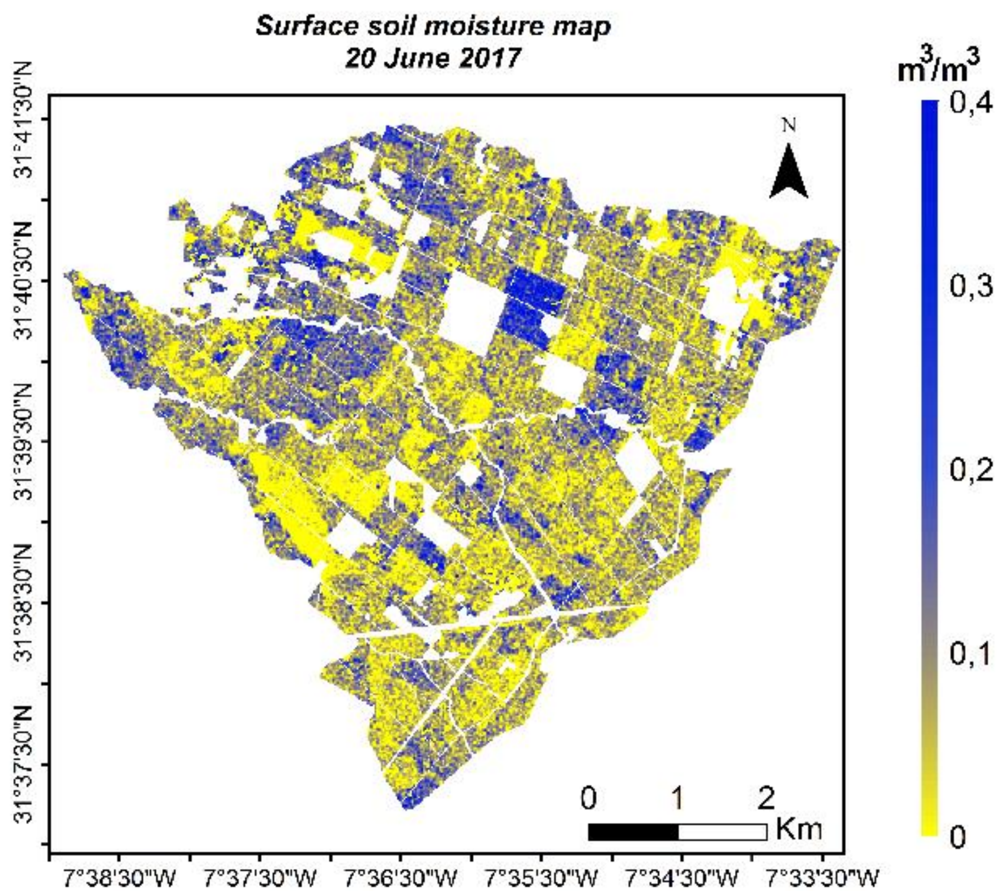
Surface soil moisture mapping using the new proposed approach

The approach is used to map SSM on an irrigated perimeter in Morocco dominated by wheat. In January the plots are irrigated while after June 15 most of the plots are harvested.

SSM is estimated at the Sentinel-1 pixel scale.

The approach allows the monitoring of the SSM variation within each plot





Conclusion and perspectives

Conclusions

- The surface soil moisture can be estimated using radar data only, for the whole growing season on wheat plots
- Better results obtained with interferometric coherence than polarization ratio.
- Extensive validation on rainfed and irrigated plots
- The approach improve surface soil moisture estimation with ~20% compared to commonly used methods.

Perspectives

- Extend the approach to other types of crops and for other climatic conditions.
- Uses of SSM products: Data assimilation in a water budget model for the prediction of evapotranspiration.

Thank you!

Mapping surface soil moisture over wheat crops in southern Mediterranean regions using the backscattering coefficient and the interferometric coherence derived from Sentinel-1

Nadia Ouaadi[a,b], Lionel Jarlan[b], Jamal Ezzahar[c,d], Mehrez Zribi[b], Saïd Khabba[a,d], Elhoussaine Bouras[e,b], Safa Bousbih[f], Pierre-Louis Frison[g]

[a]LMME,Cadi Ayyad University, Marrakech, Morocco.
[b]CESBIO, University of Toulouse, Toulouse, France.
[c]MTI, National School of Applied Sciences, Cadi Ayyad University, Safi, Morocco.
[d]CRSA, Mohammed VI Polytechnic University UM6P, Benguerir, Morocco.
[e]LP2M2E, Cadi Ayyad University, Marrakech, Morocco.
[f]National Institute of Agronomy of Tunis, Tunis, Tunisia.
[g]LaSTIG//MATWAS University of Paris-Est, Champs sur Marne, Paris, France.

EGU General Assembly 2020