



RGA : Comprendre, Anticiper, Prévenir

JST DU 06/03/2025

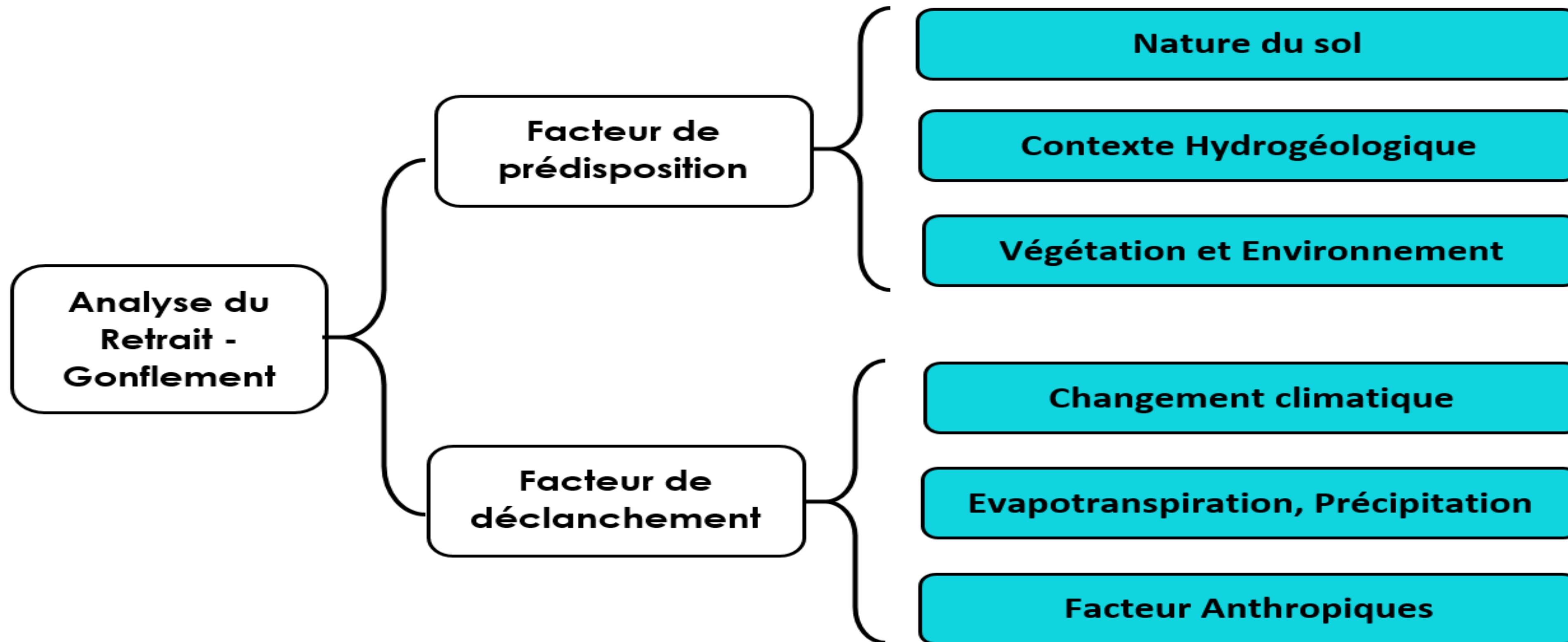
Expérimentation et modélisation numérique de retrait/gonflement des argiles

Hossein NOWAMOOZ

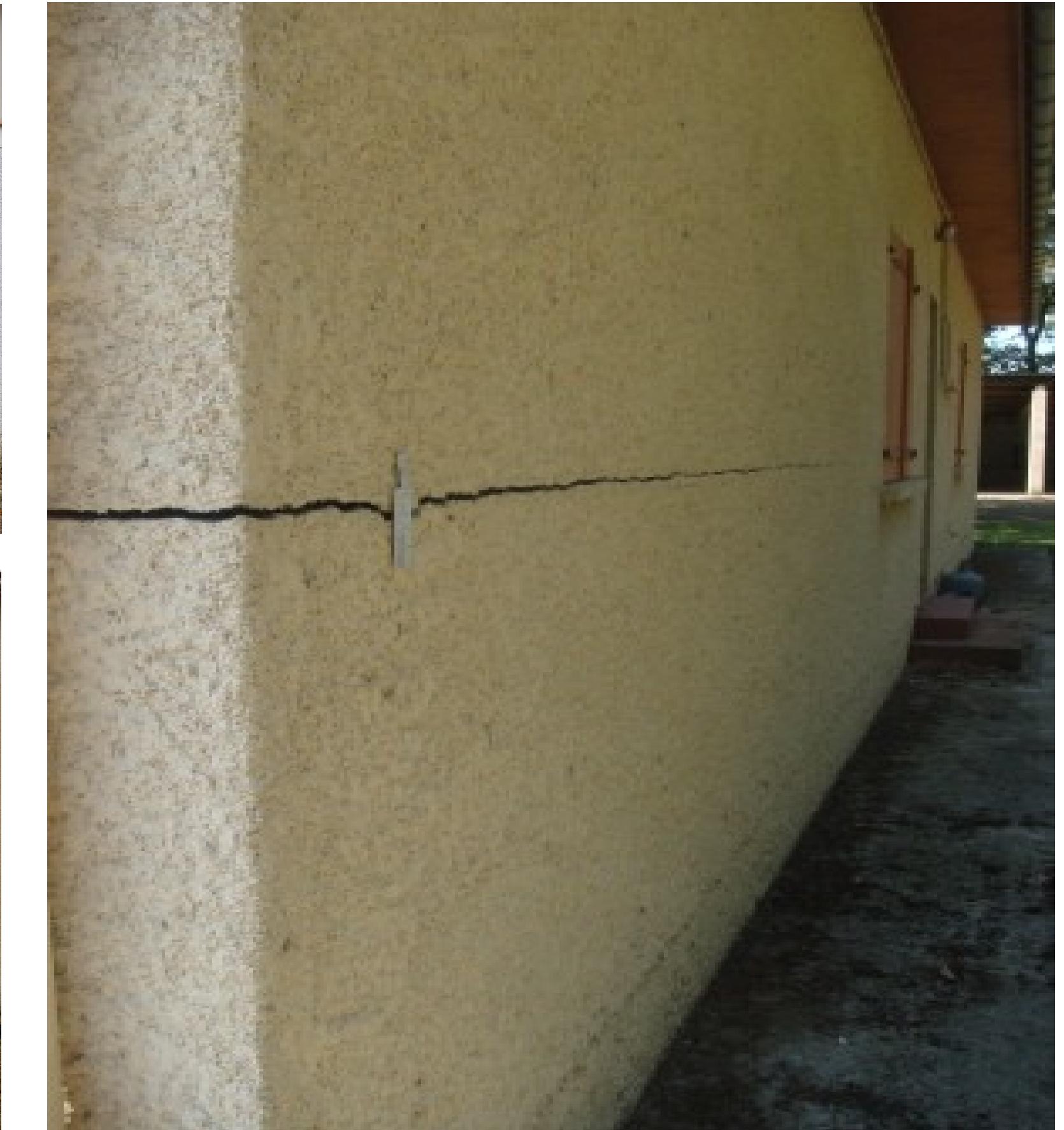
Hossein.nowamooz@insa-rennes.fr

Introduction

Facteurs de prédisposition et de déclenchement :



Couplage thermo-hydro-mécanique dans les argiles gonflantes

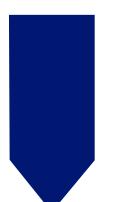


(www.determinant.fr)

Thèse de doctorat CIFRE de H. ASSADOLLAHI avec l'entreprise DETERMINANT.

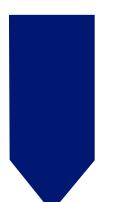
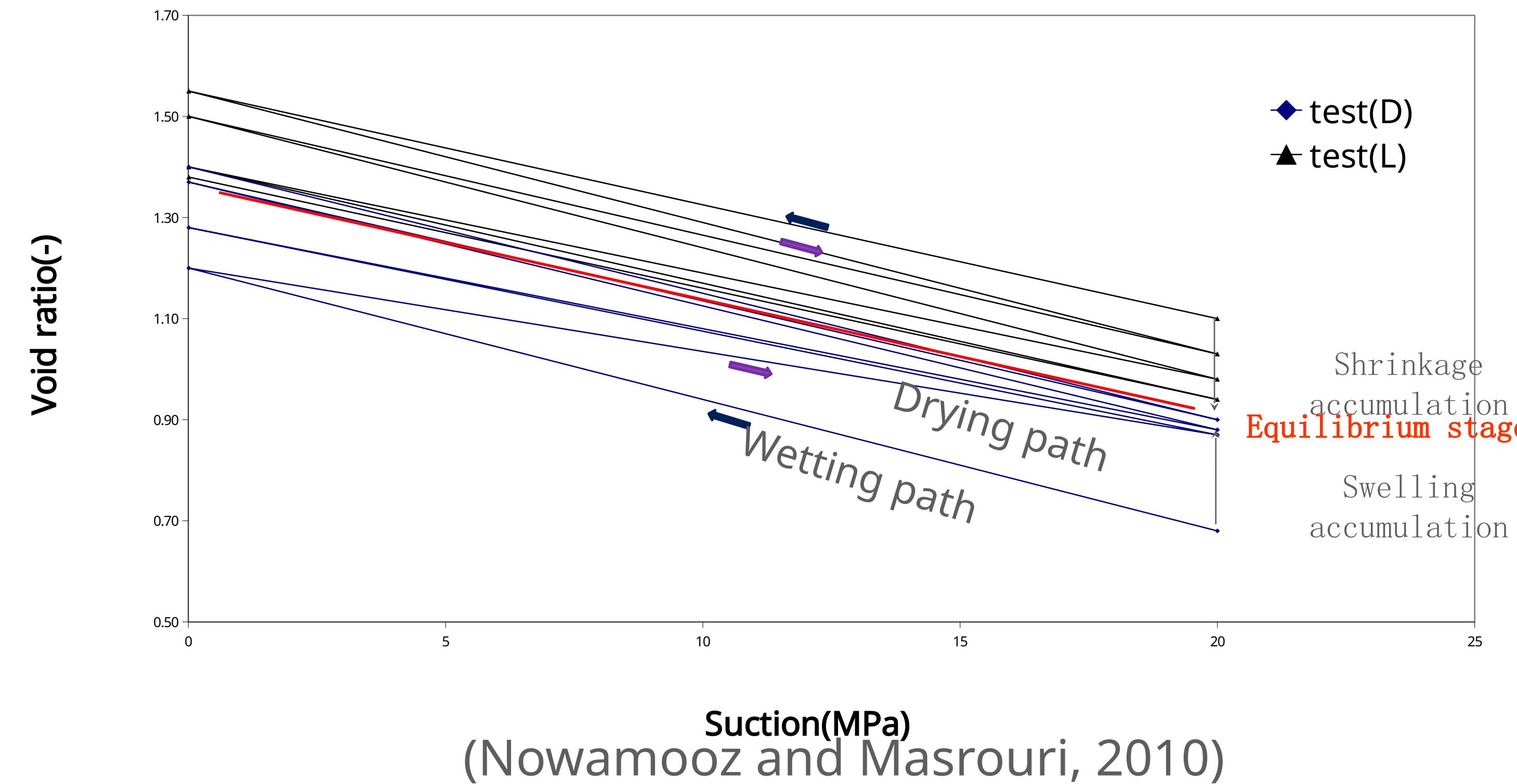
CFMS-06/03/2025

Expérimentation et modélisation numérique de retrait/gonflement des
argiles



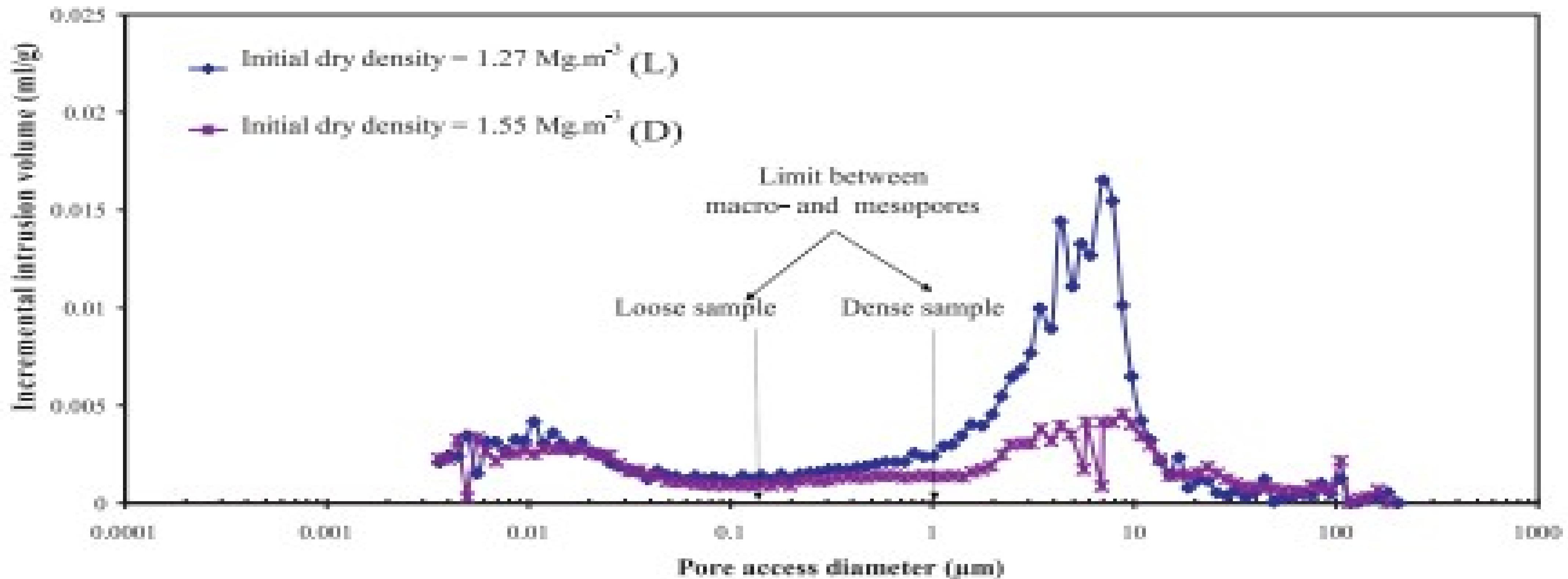
Introduction

- Matériaux: Mélange of 40% limon and 60% bentonite;
- Densités sèches initiales: 1,27(L) and 1,55(D) Mg/m³ ;
- Suction initiale de 20 MPa;
- Cycles de séchage et humidification entre 20 et 0 MPa.



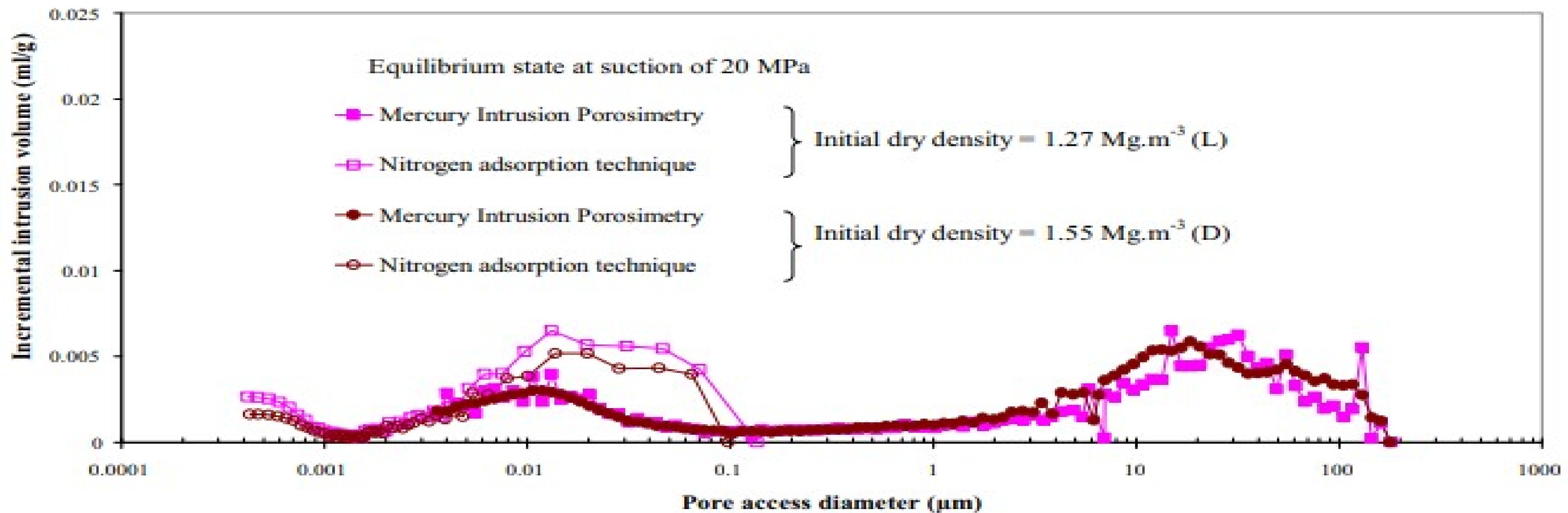
Introduction

- Structure interne initiale avant les cycles hydriques;
- Densités sèches initiales: 1,27(L) and 1,55(D) Mg/m³.



Introduction

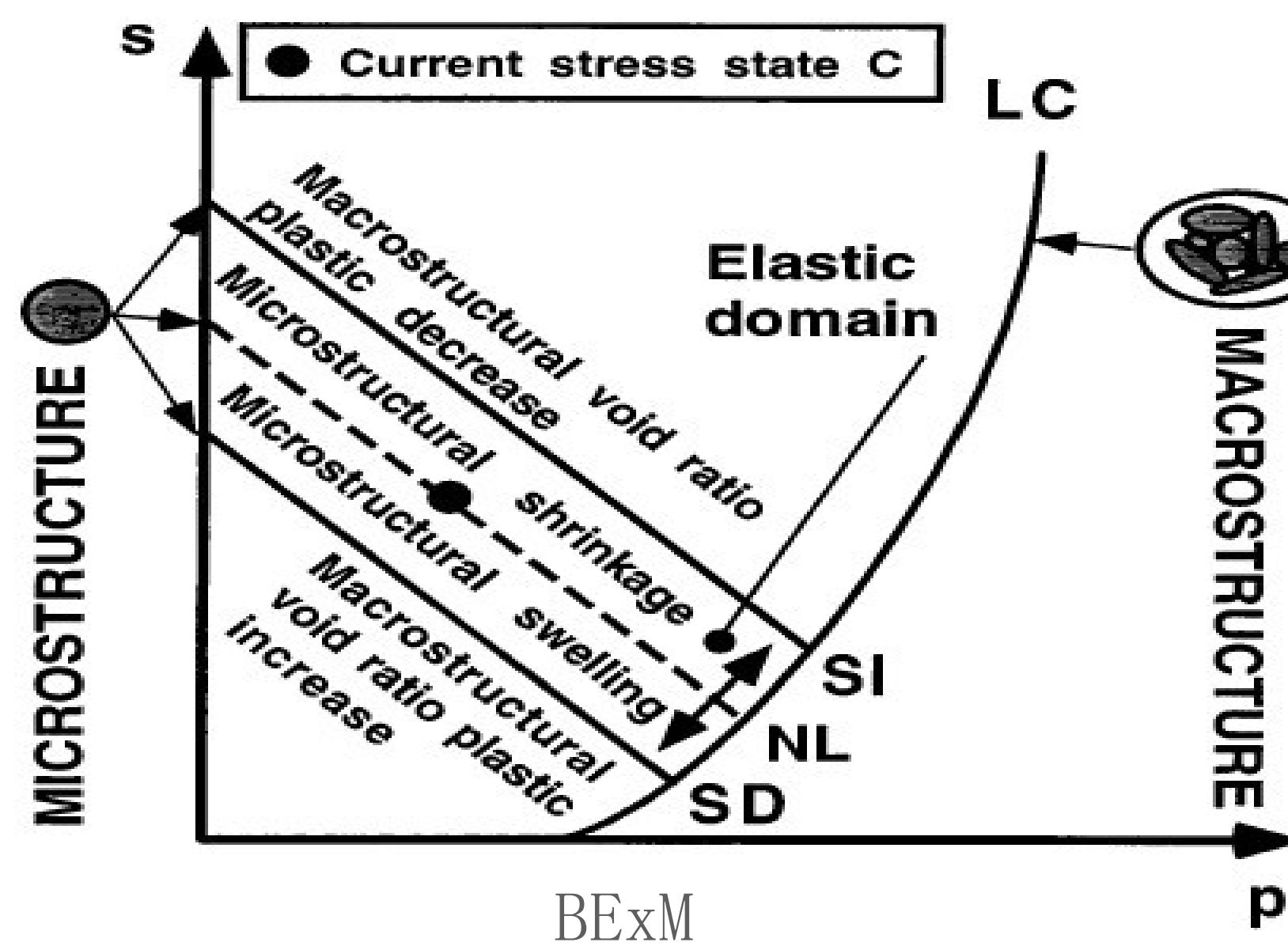
- Structure interne finale après les cycles hydriques successifs;
 - Densités sèches initiales: 1,27(L) and 1,55(D) Mg/m³.



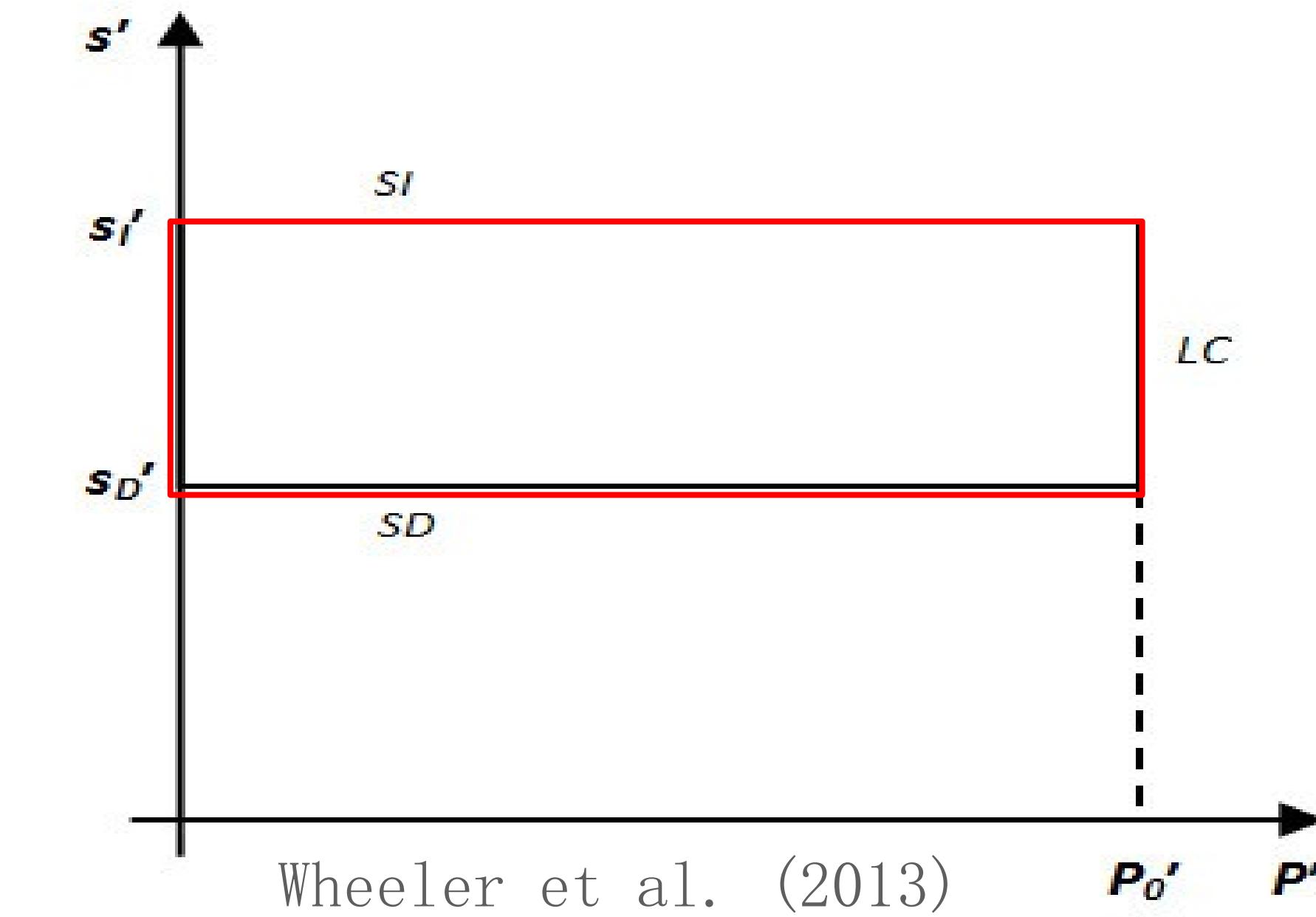
Introduction

Modèles théoriques pour les sols argileux gonflants

- Contrainte totale
- ✓ BExM (Alonso *et al.* 1999)

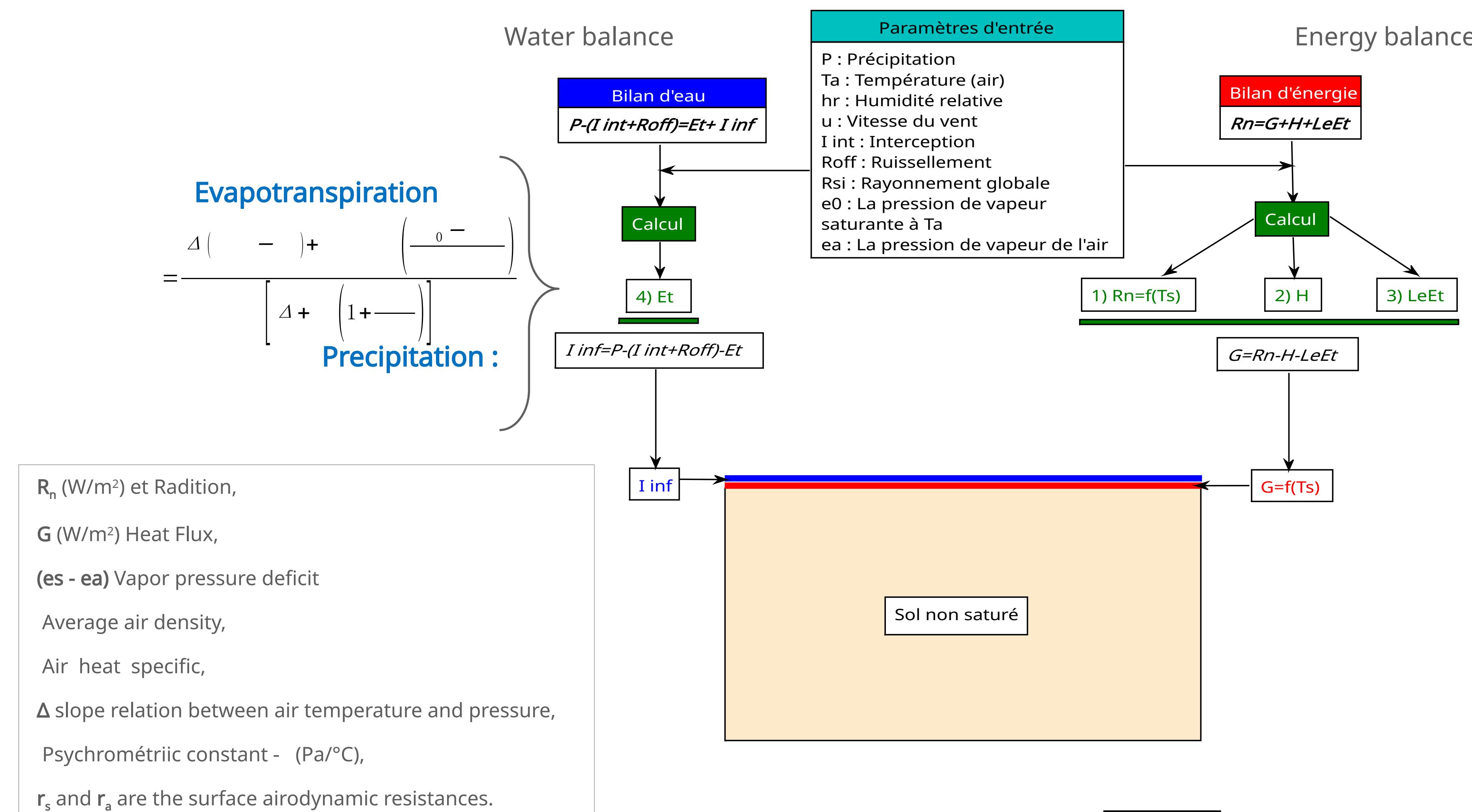


- Contrainte effective
- ✓ Wheeler et al., 2003



Sans interaction Sol-Végétation-Atmosphère (SVA).

Interaction Sol-Atmosphère :



Net Radiation Rn:

Heat flux in soil G:

Sensible heat flux (H):

$$= h \left(- \frac{-}{-} \right)$$

Latent heat flux (LeE):

$$= 1,26 \frac{\Delta}{\Delta +} \left(\frac{i_i}{i_i} - \frac{i_i}{i_i} \right) i$$

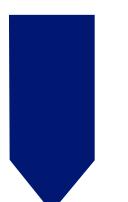
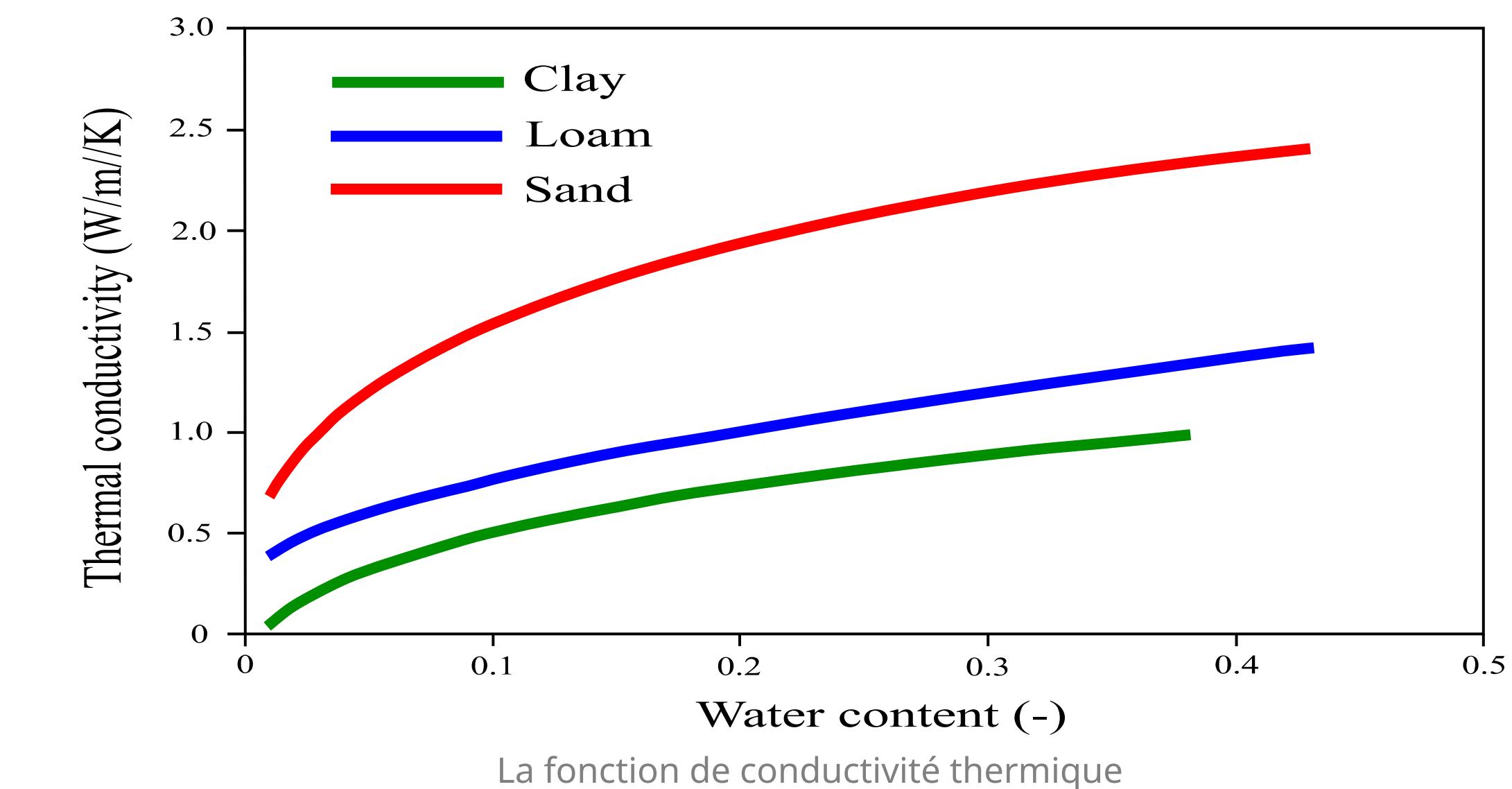
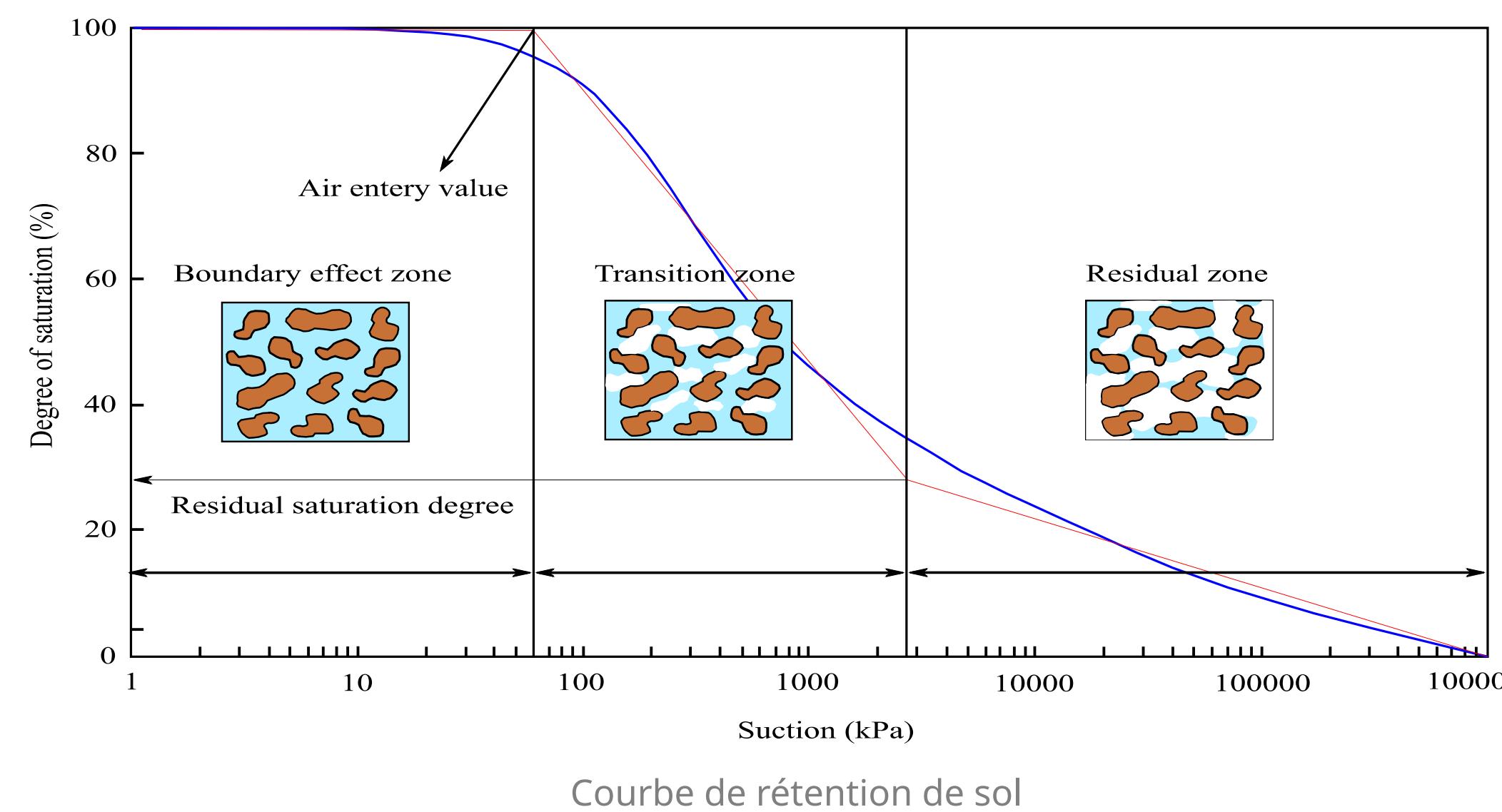
Couplage Hydro-Thermique :

$$\begin{aligned}
 & \text{---} = \left[\left(\frac{1}{1 + \left(\frac{h}{h_a} \right)^n } \right) \left(\frac{1}{1 + \left(\frac{h}{h_r} \right)^m } \right) - \left(\frac{1}{1 + \left(\frac{h}{h_a} \right)^n } \right) \right] \\
 & \left(\frac{1}{1 + \left(\frac{h}{h_a} \right)^n } \right) = \left[1 - \left(1 - \frac{1}{1 + \left(\frac{h}{h_a} \right)^n } \right)^2 \right] \\
 & (h) = \begin{cases} +\frac{1}{\left[1 + \left(\frac{h}{h_a} \right)^n \right]} & \wedge h < 0 \\ -\frac{1}{\left[1 + \left(\frac{h}{h_a} \right)^n \right]} & \wedge h \geq 0 \end{cases}
 \end{aligned}$$

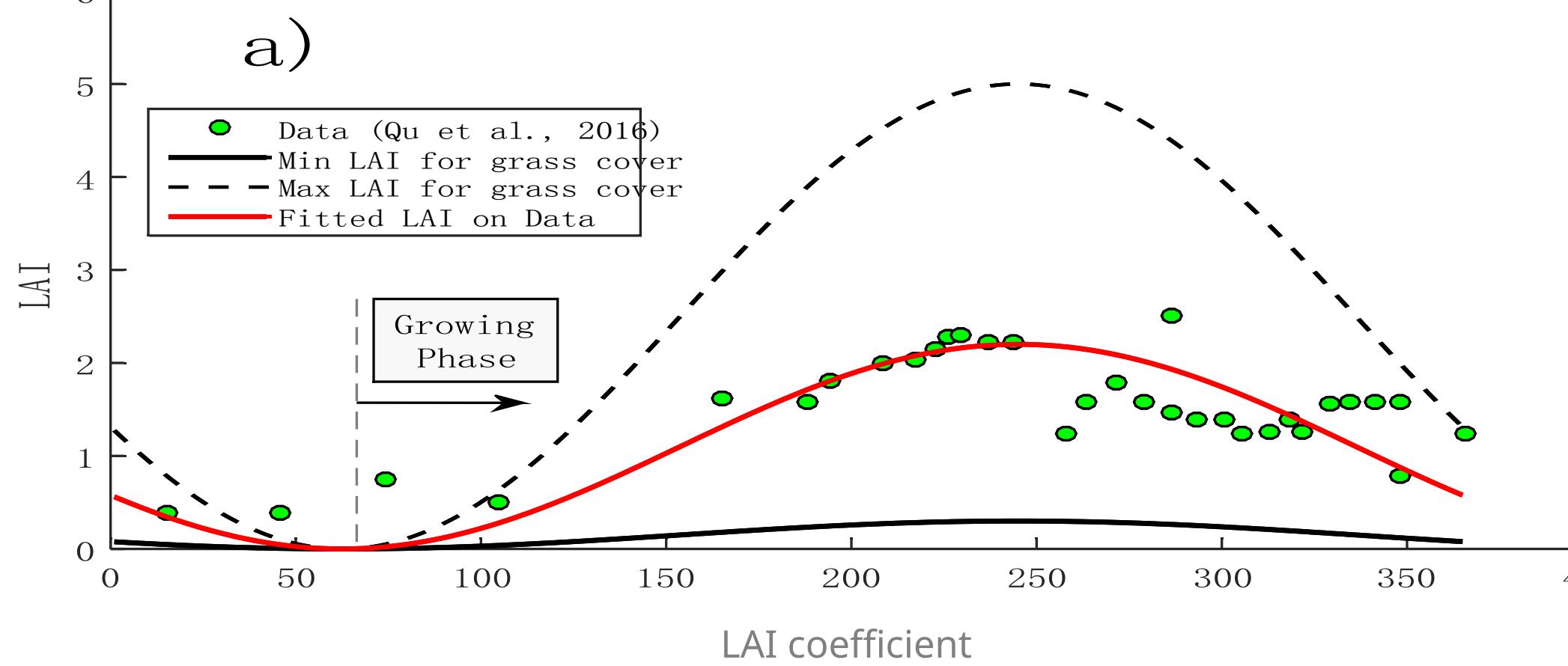
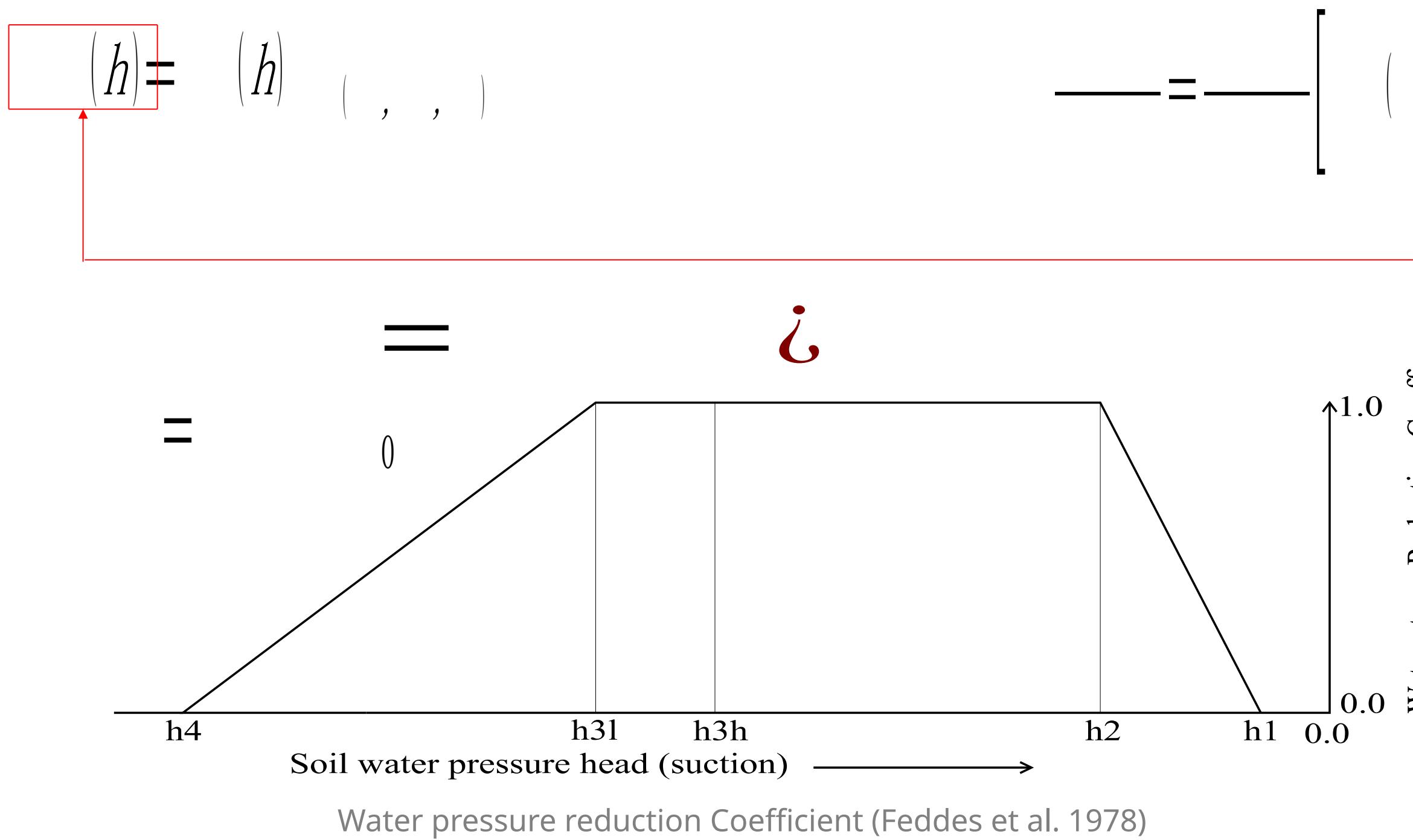
van Genuchten (1980) & Mualem (1976)

$$\begin{aligned}
 & \text{---} = \left(\frac{1}{1 + \left(\frac{h}{h_a} \right)^n } \right) \left(\frac{1}{1 + \left(\frac{h}{h_r} \right)^m } \right) - \left(\frac{1}{1 + \left(\frac{h}{h_a} \right)^n } \right) \\
 & \left(\frac{1}{1 + \left(\frac{h}{h_a} \right)^n } \right) = +0.0 + 0.0 \\
 & _0 \left(\frac{1}{1 + \left(\frac{h}{h_a} \right)^n } \right) = +1.0 + 0.2 + 0.3 + 0.5
 \end{aligned}$$

De Vries (1963) & Chung and Horton, (1987)

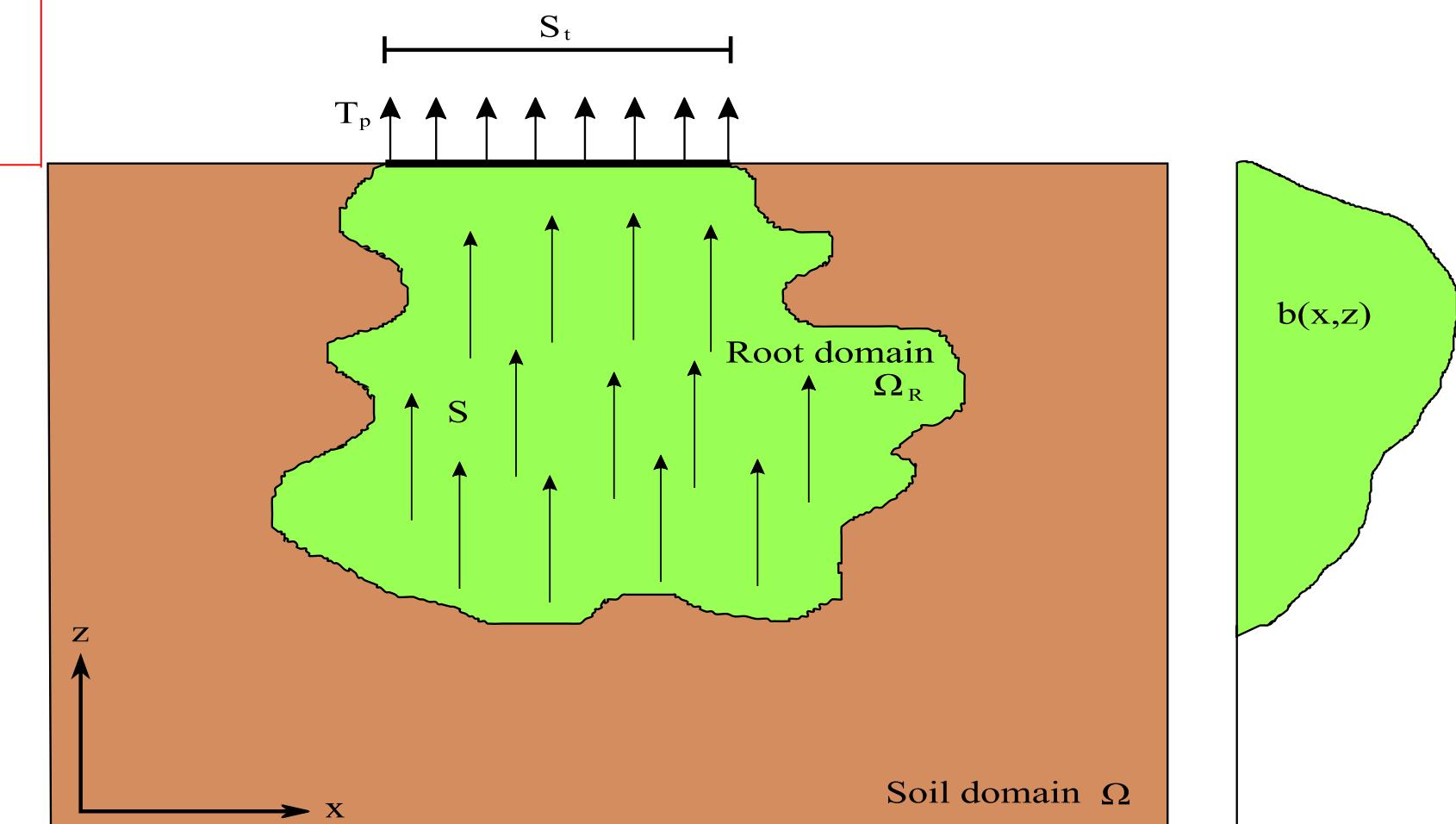


Végétation (Feddes et al. 1978) :

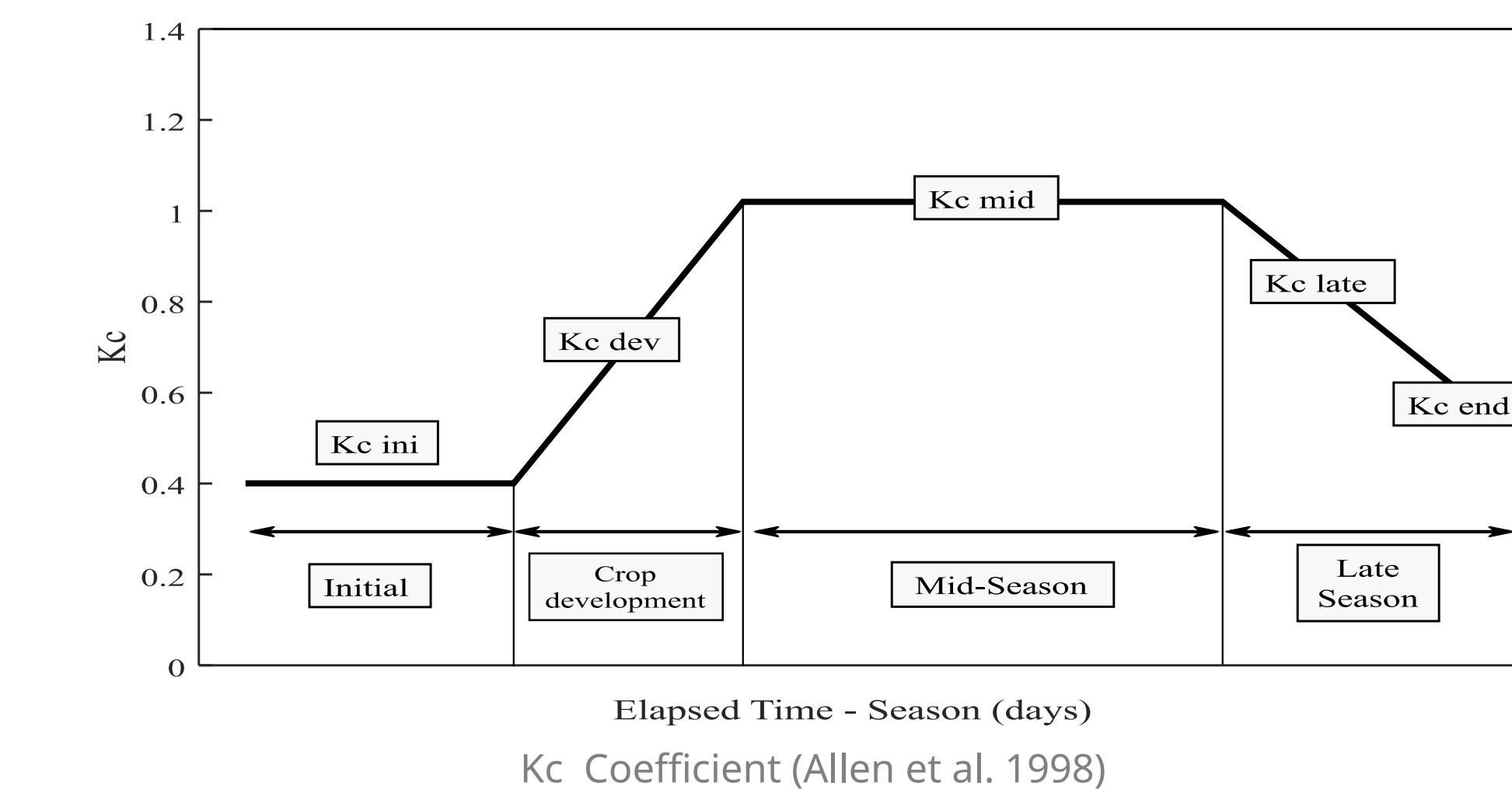


$$\boxed{(h)} = \boxed{(h)} \left(, , \right)$$

$$= \boxed{ } \left[\left(\quad \right) \left(\quad + 1 \right) \right] - \boxed{, }$$



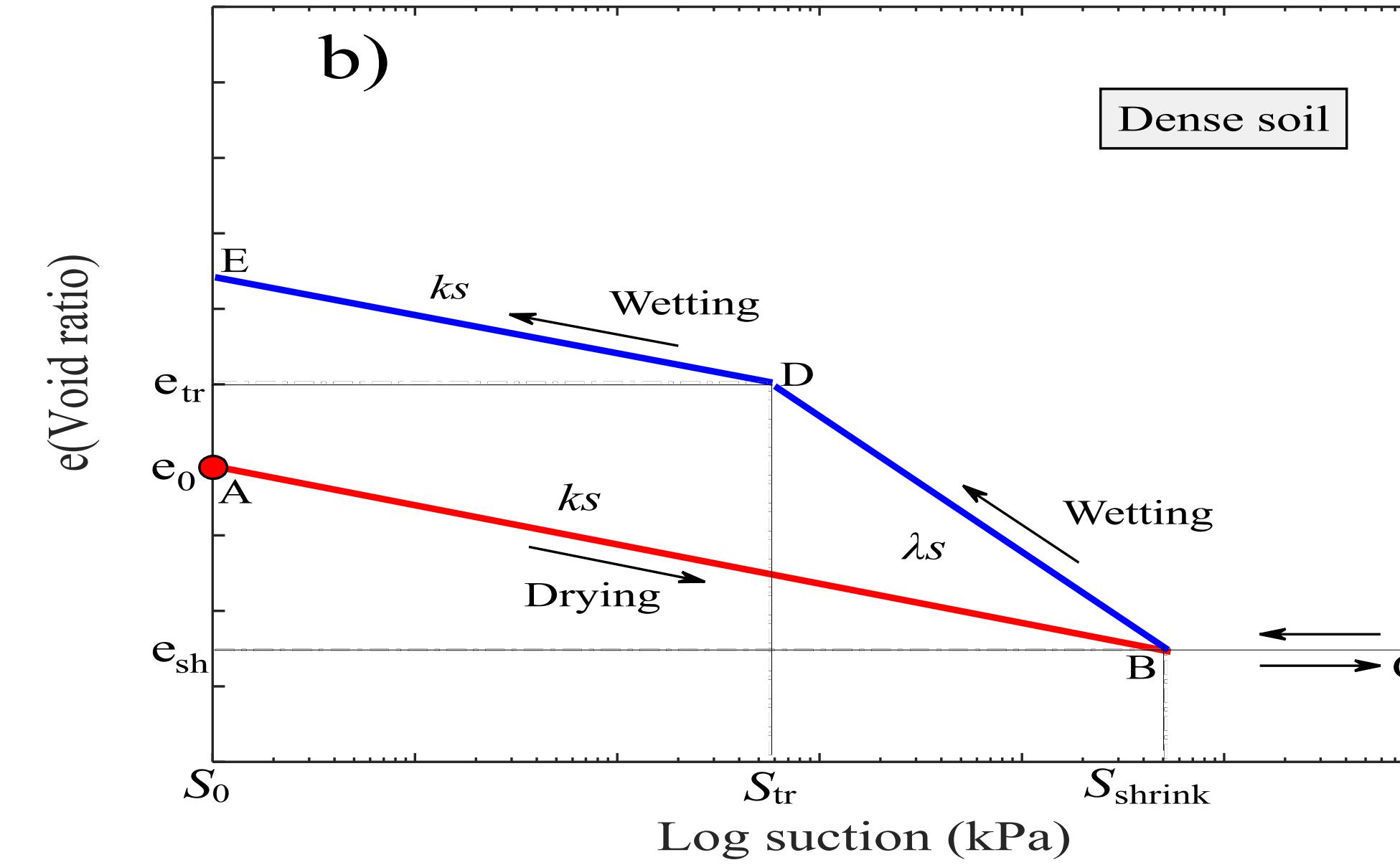
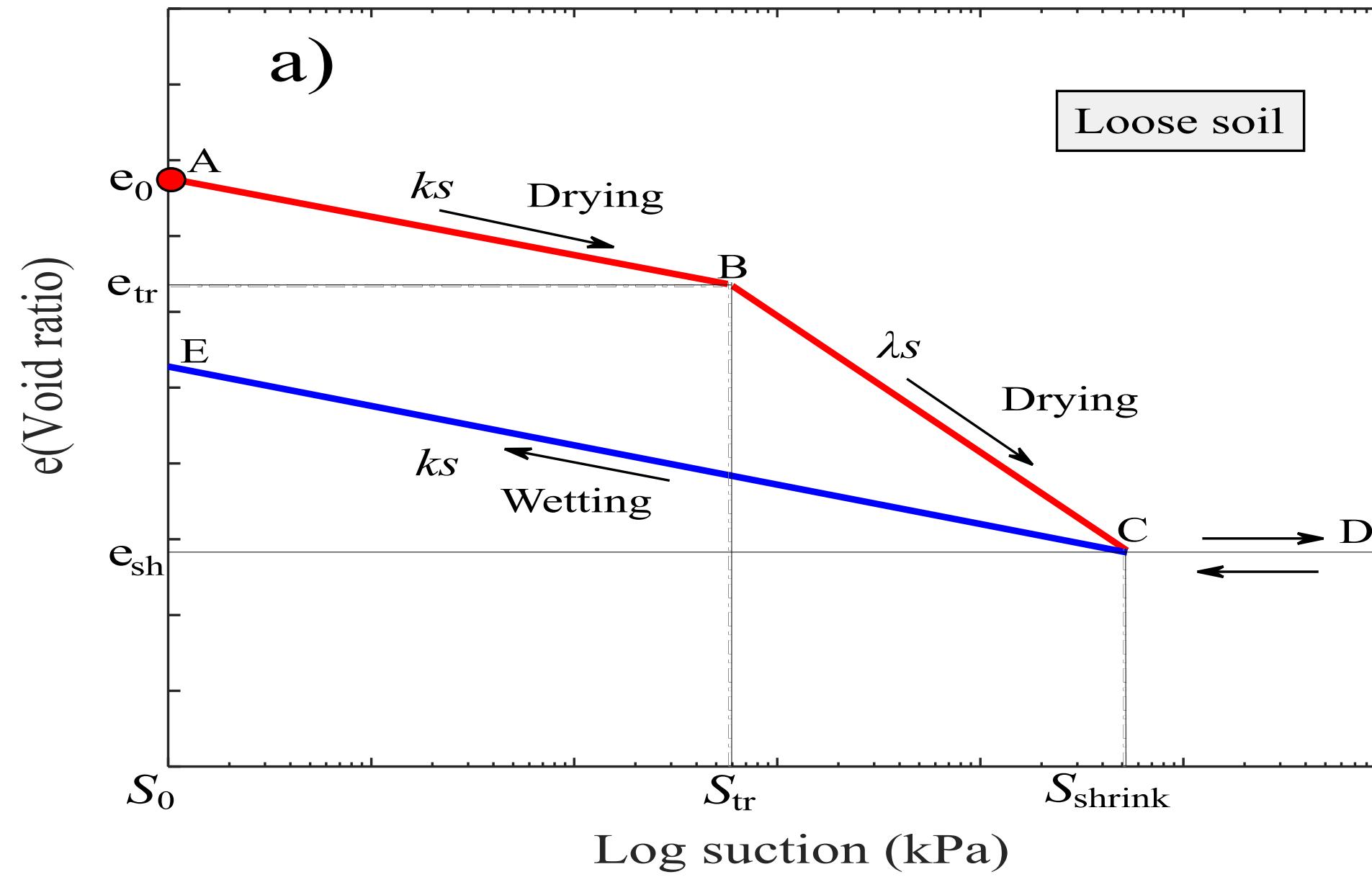
Root distribution function (Vrugt et al. 2002)



K_c Coefficient (Allen et al. 1998)



Tassement (Retrait-gonflement) :



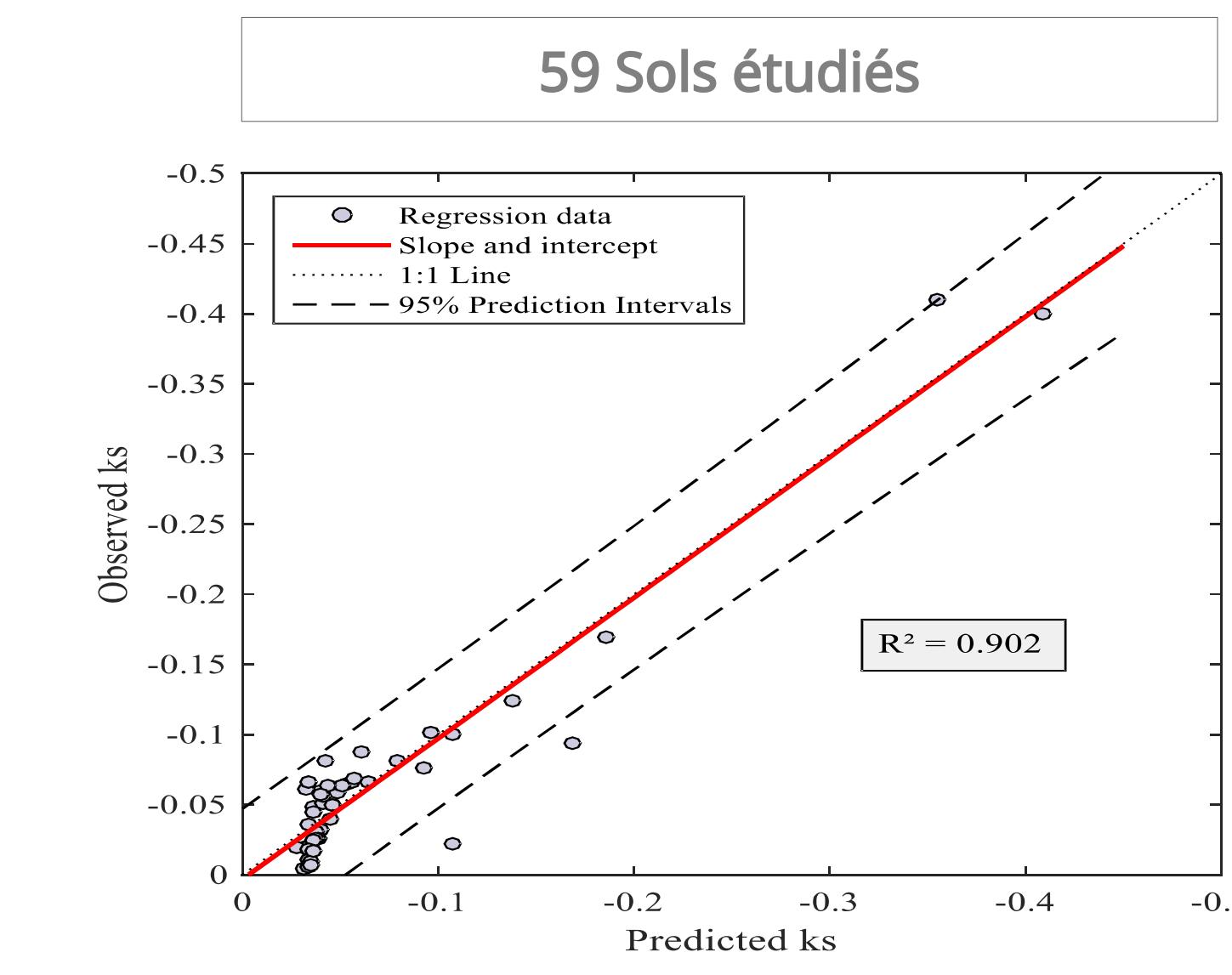
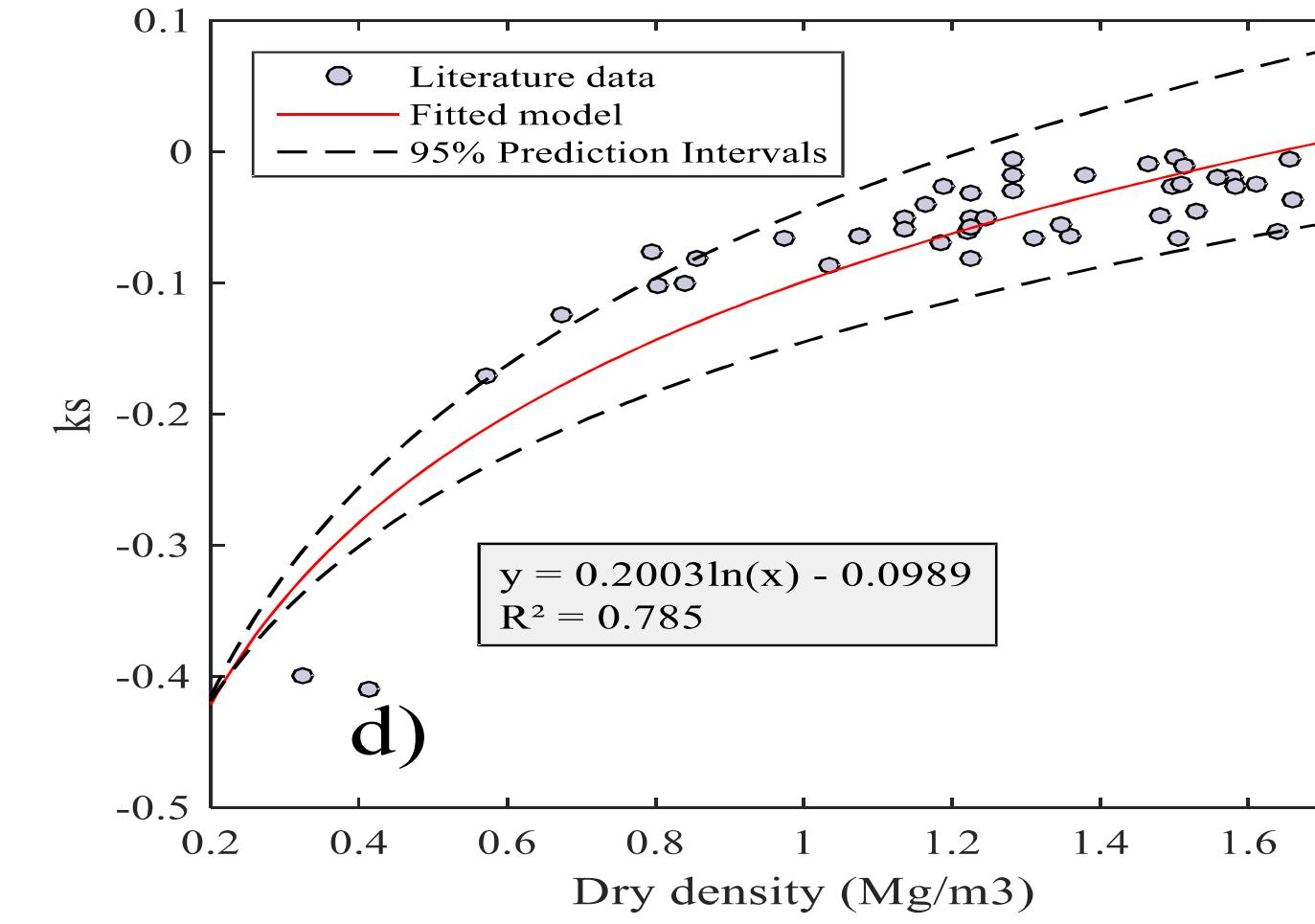
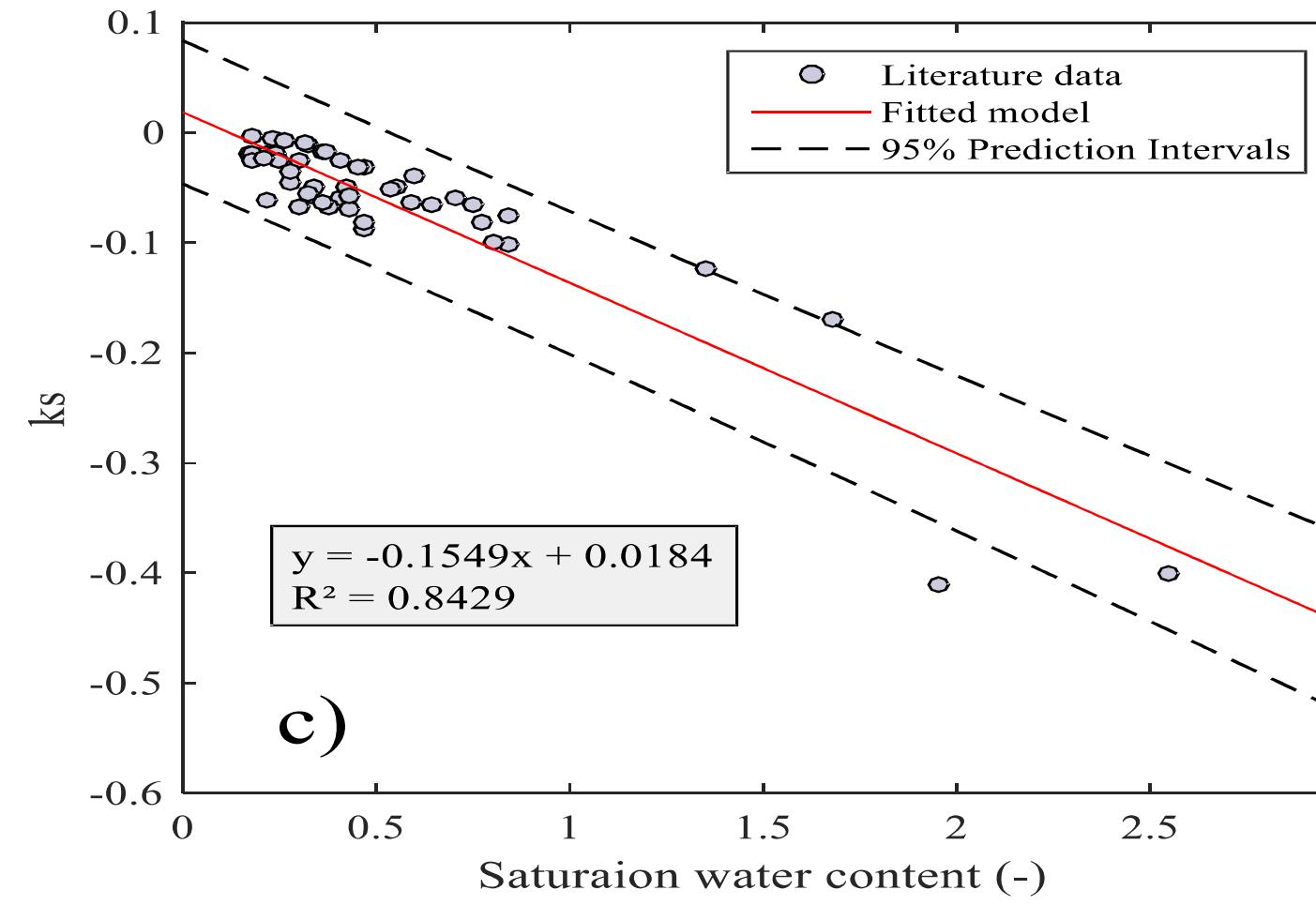
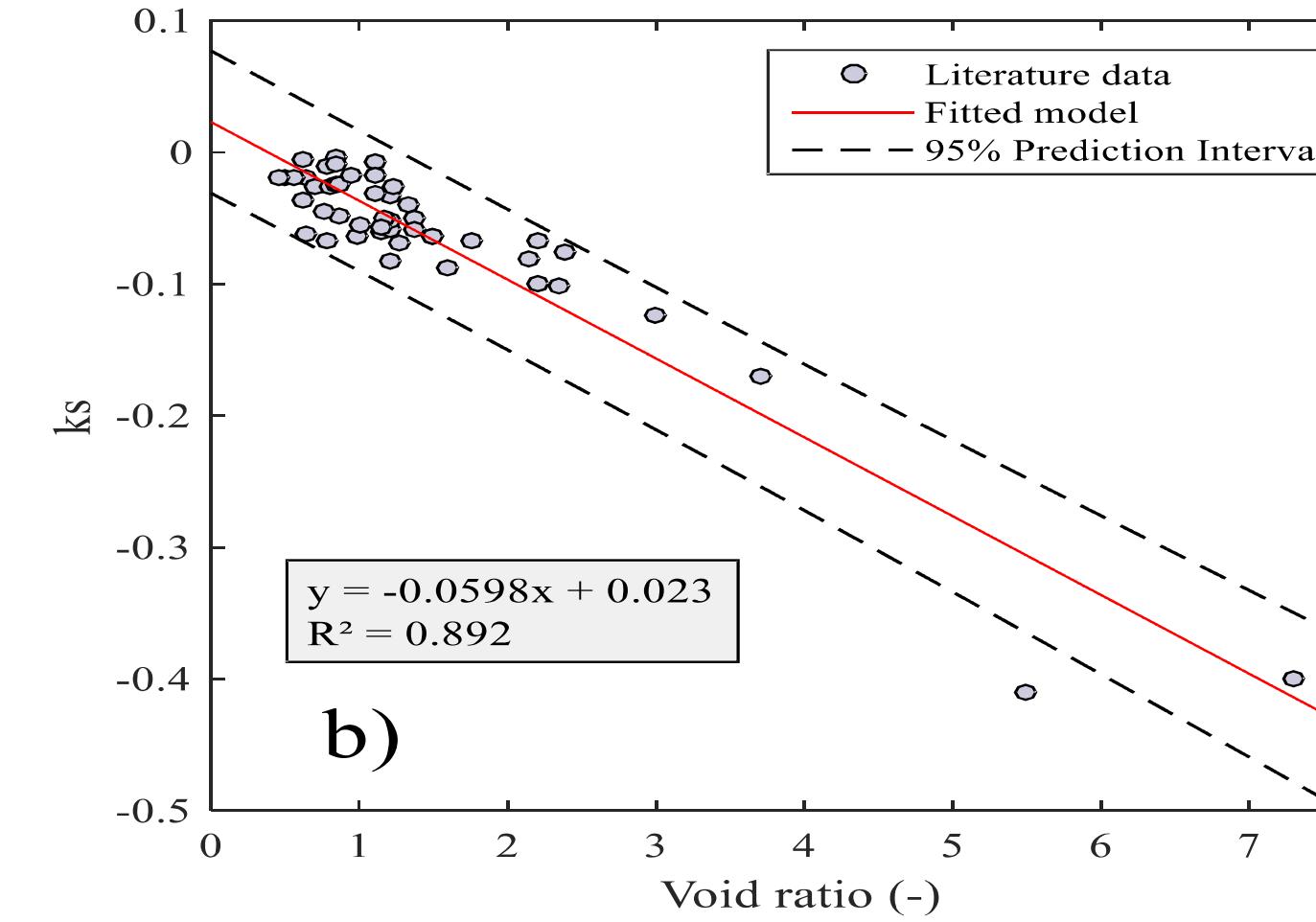
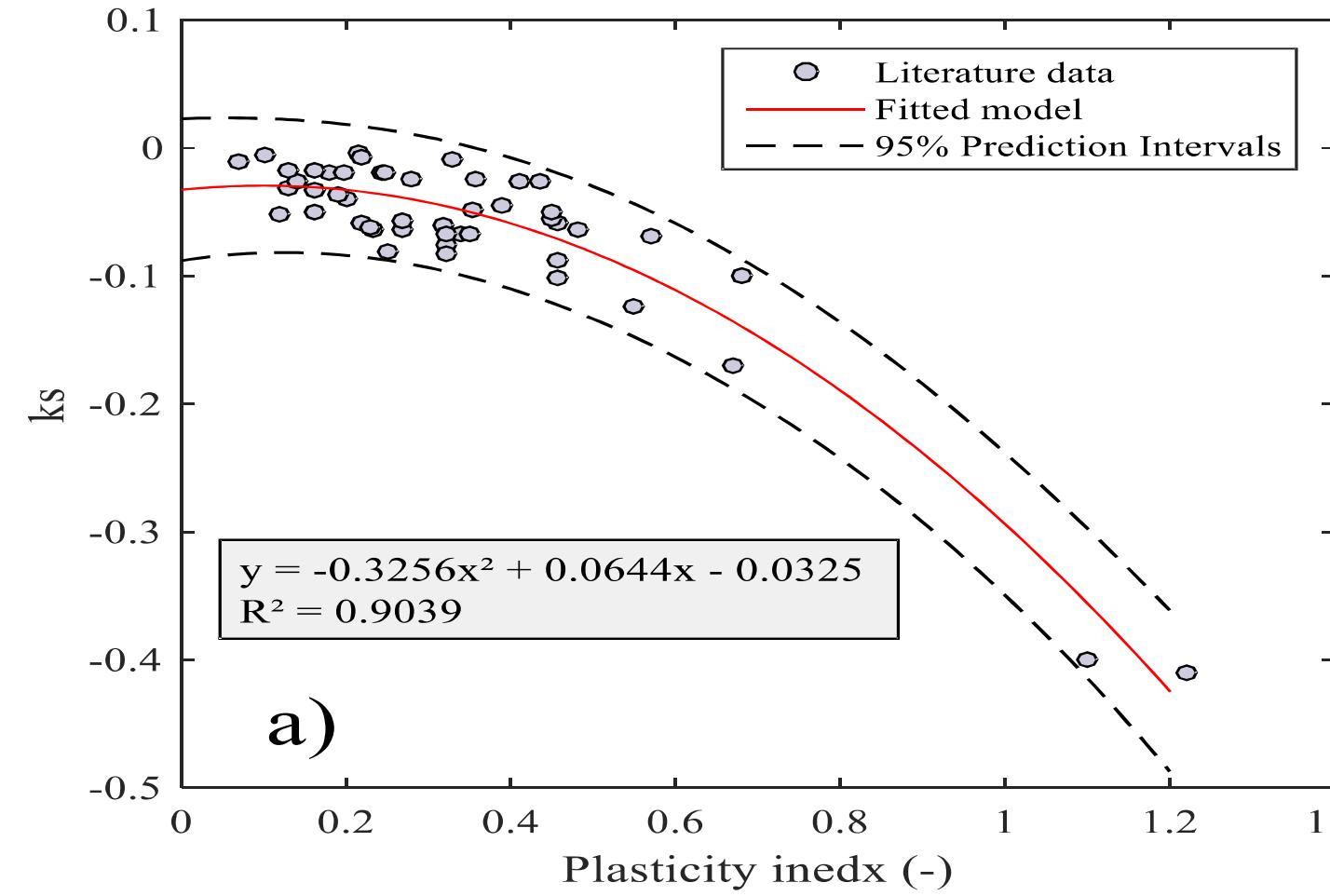
Based on Nowamooz et al. (2013 & 2016)

$$\left\{ \begin{aligned} &= \frac{e_0 - e}{\log\left(\frac{S_0}{S}\right)} \\ &= \frac{e - e_{sh}}{\log\left(\frac{S}{S_{shrink}}\right)} \end{aligned} \right. \quad \xrightarrow{\text{red arrow}} \quad \Delta = \sum_{i=1}^{+1} \frac{e_i - e_{i-1}}{1 + \frac{S_i - S_{i-1}}{S_0}}$$

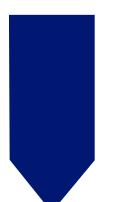


Tassement (Retrait-gonflement) :

Corrélation de k_s et λ_s avec les paramètres géotechnique de base :

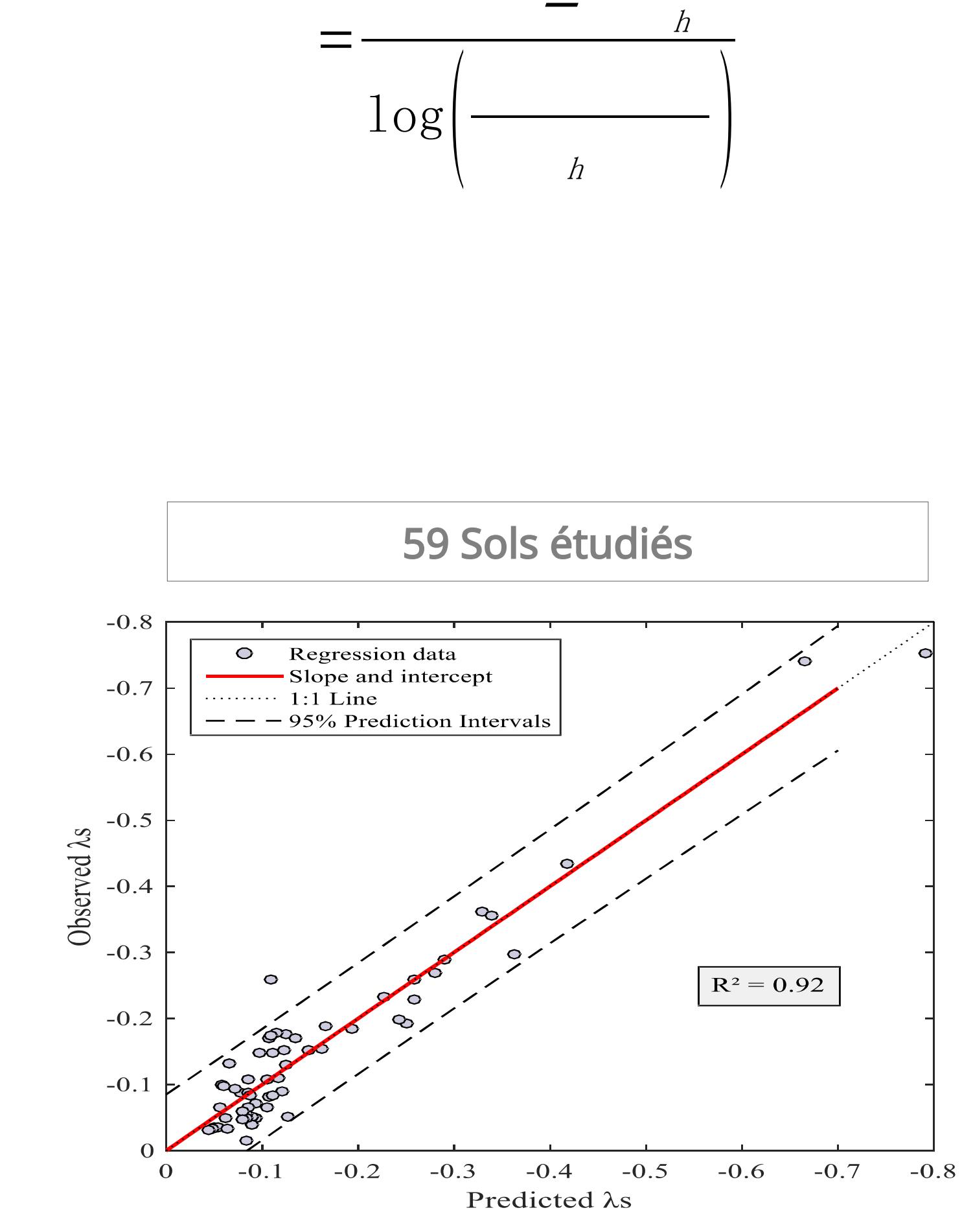
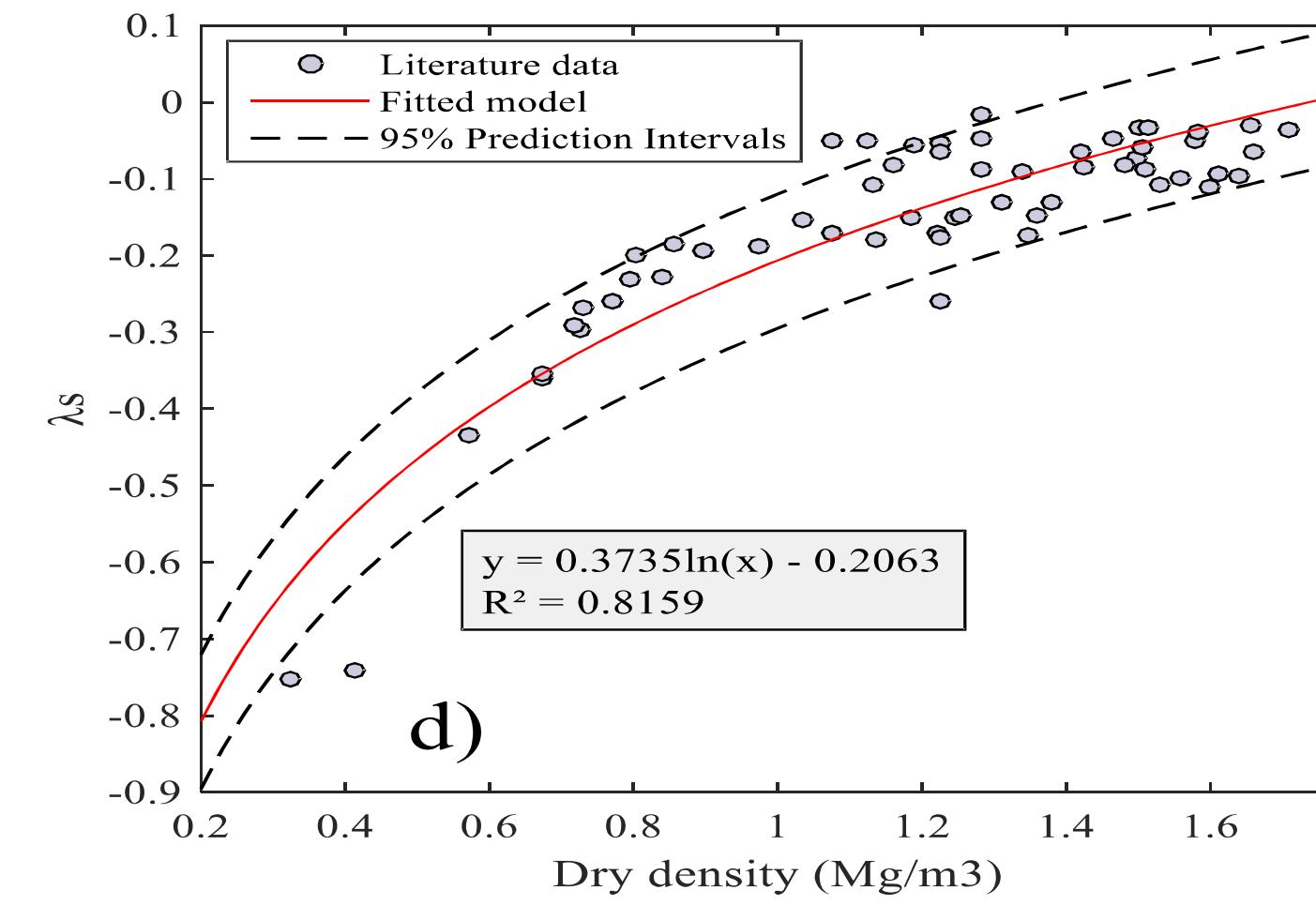
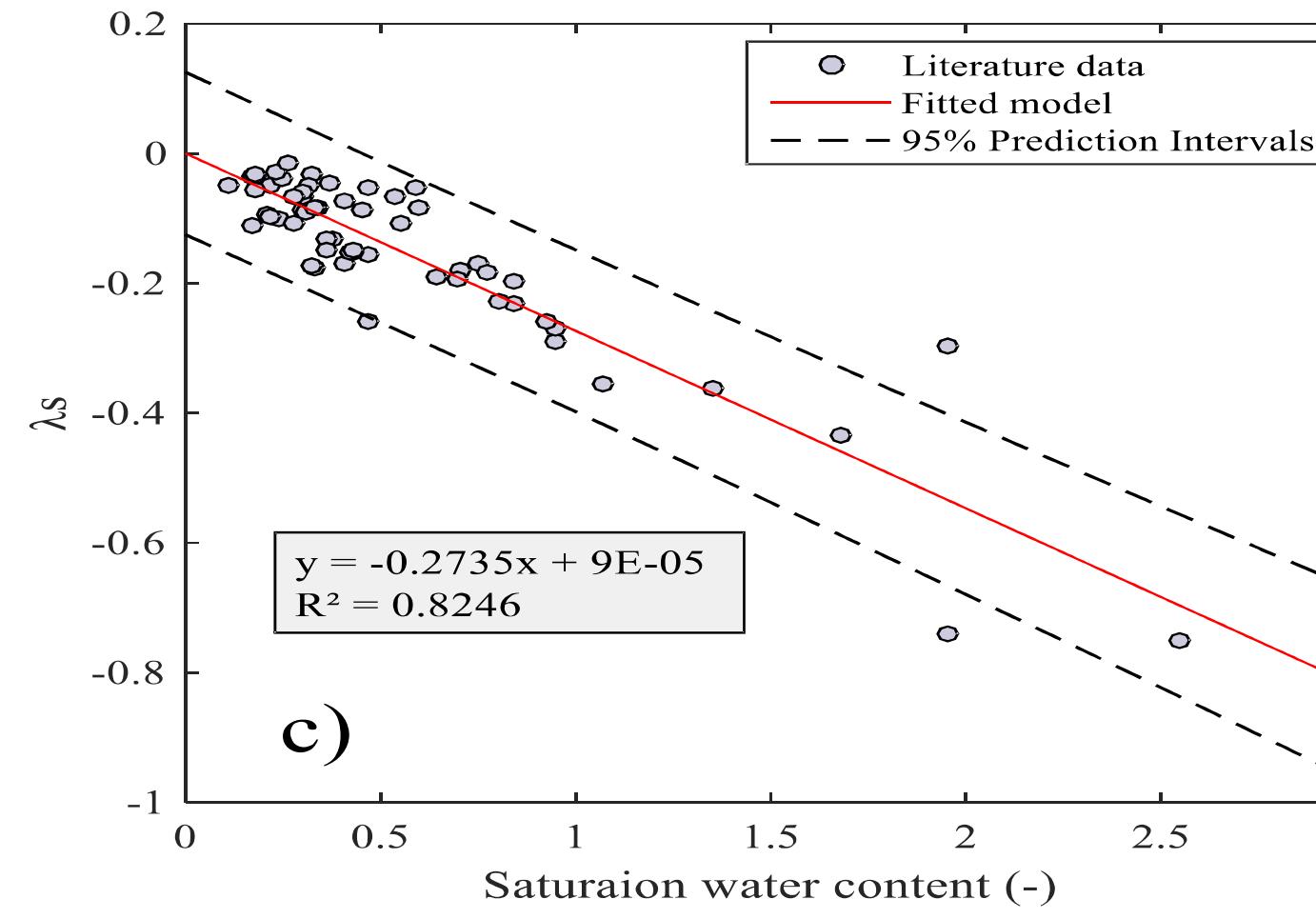
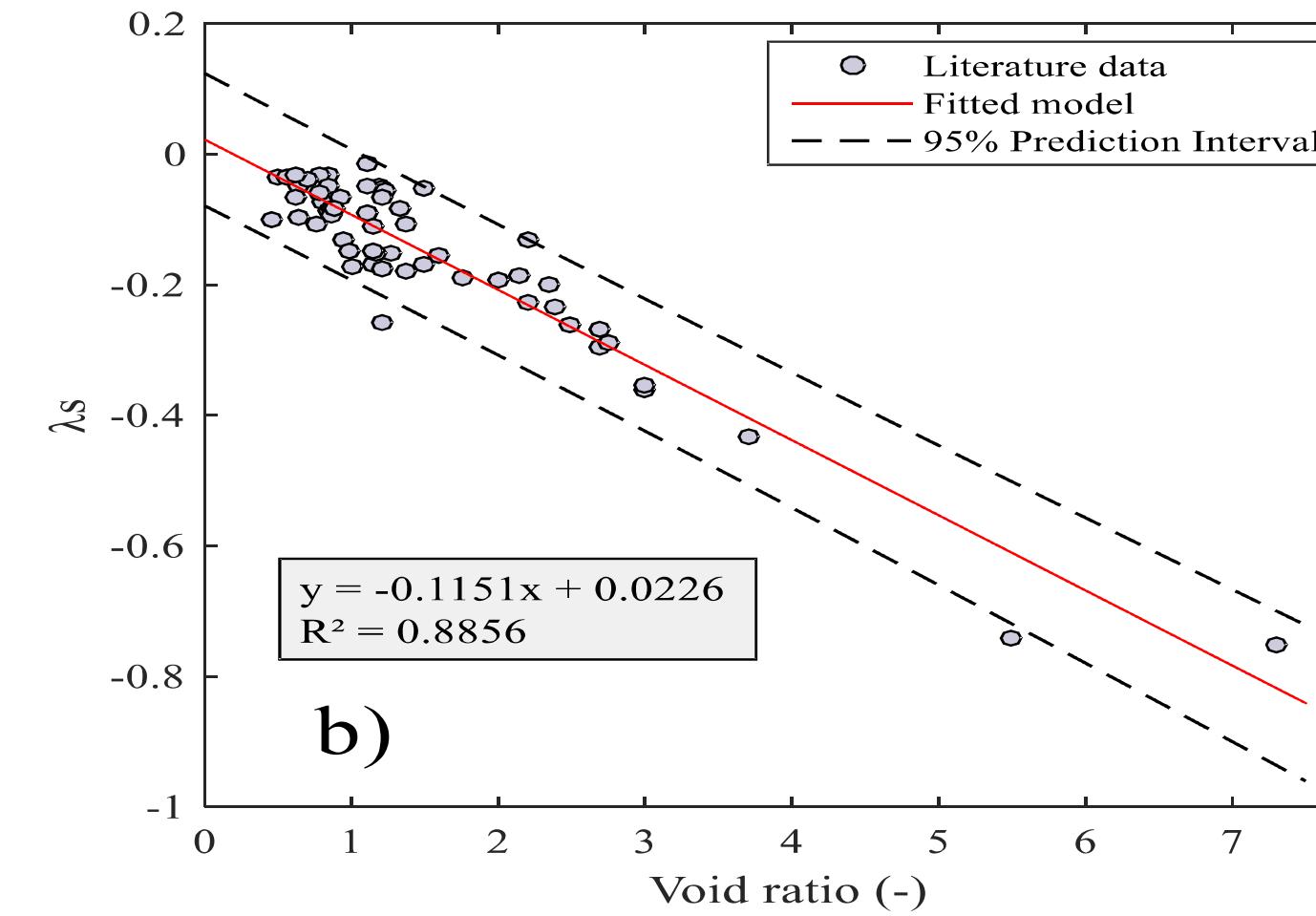
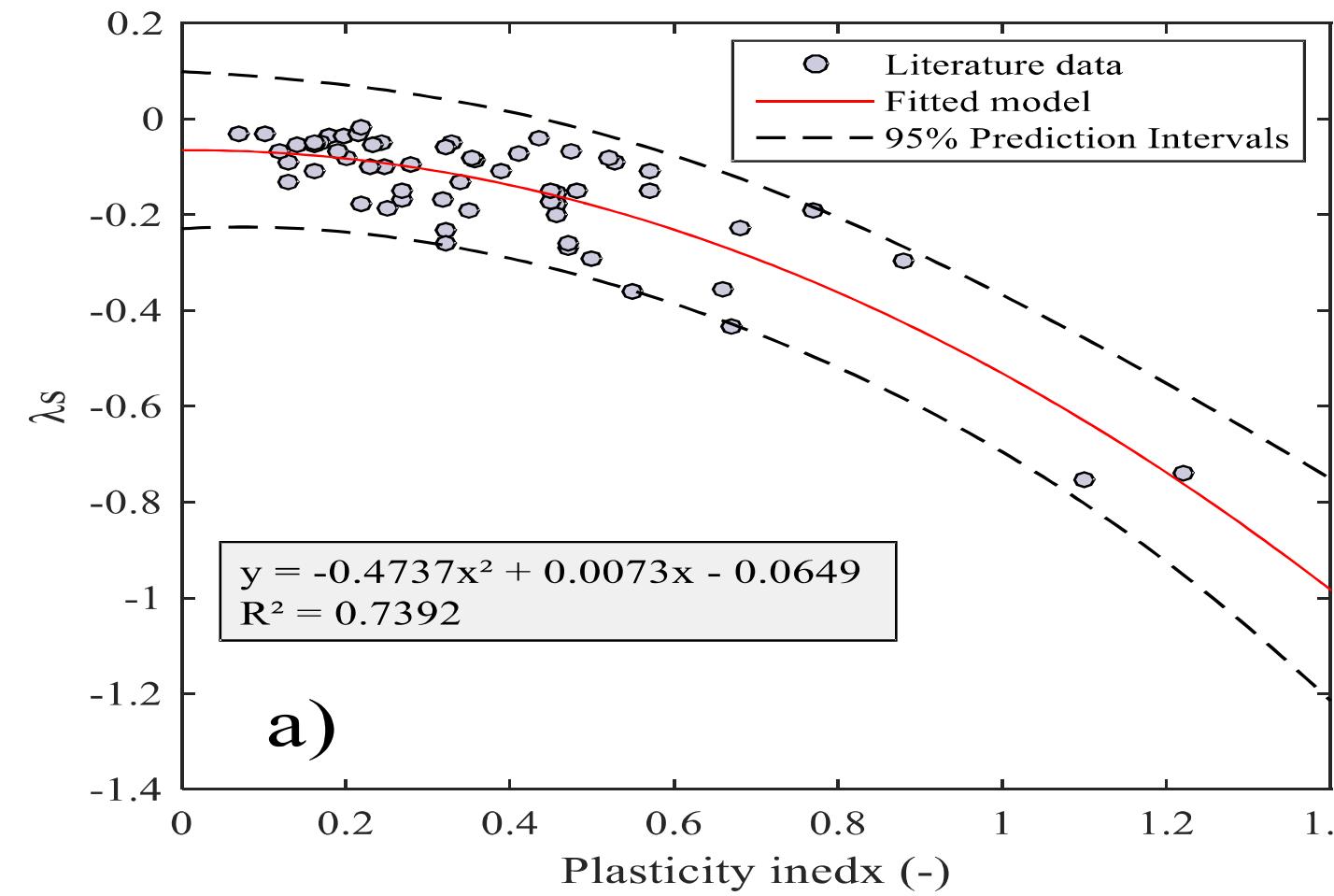


Corrélation de k_s avec les paramètres géotechniques de base, a) indice de plasticité b) indice des vides c) teneur en eau de saturation et d) densité sèche



Tassement (Retrait-gonflement) :

Corrélation de λ_s et λ_s avec les paramètres géotechnique de base :

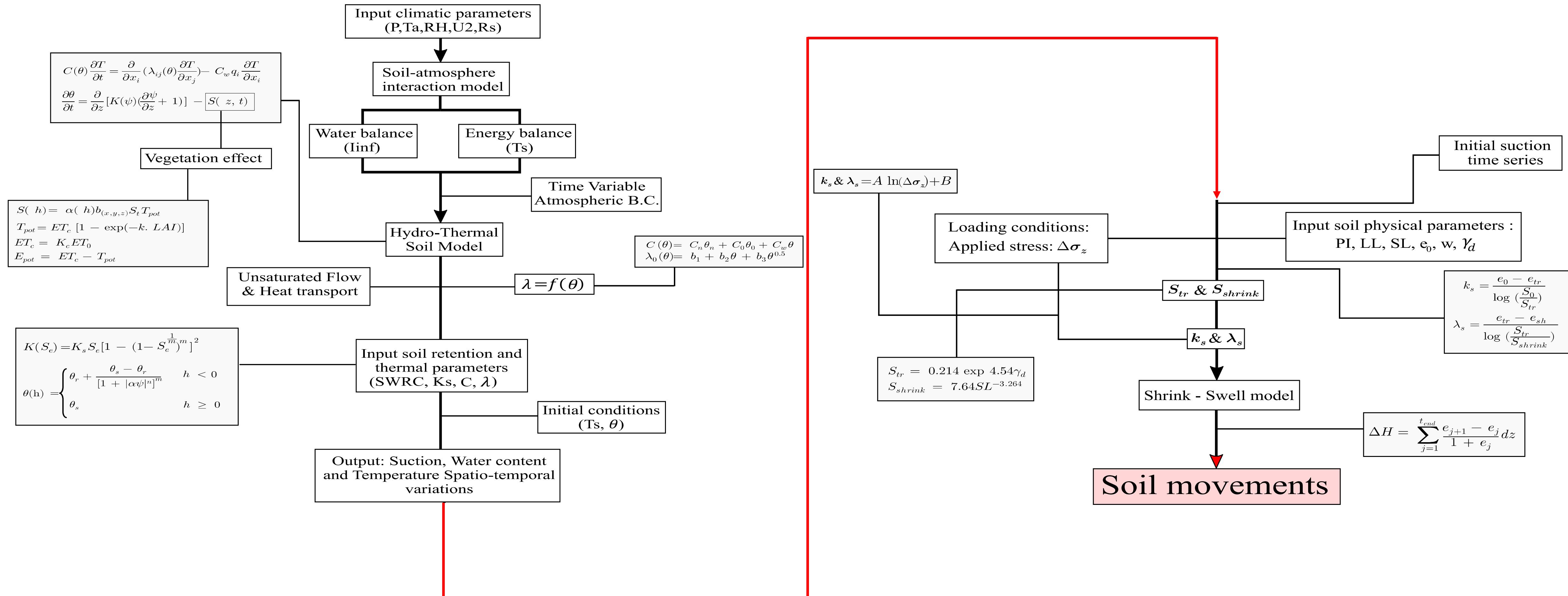


Corrélation de λ_s avec les paramètres géotechniques de base, a) indice de plasticité b) indice des vides c) teneur en eau de saturation et d) densité sèche

Régression linéaire de λ_s calculé et mesuré

Approche numérique

Organigramme de la modélisation numérique :

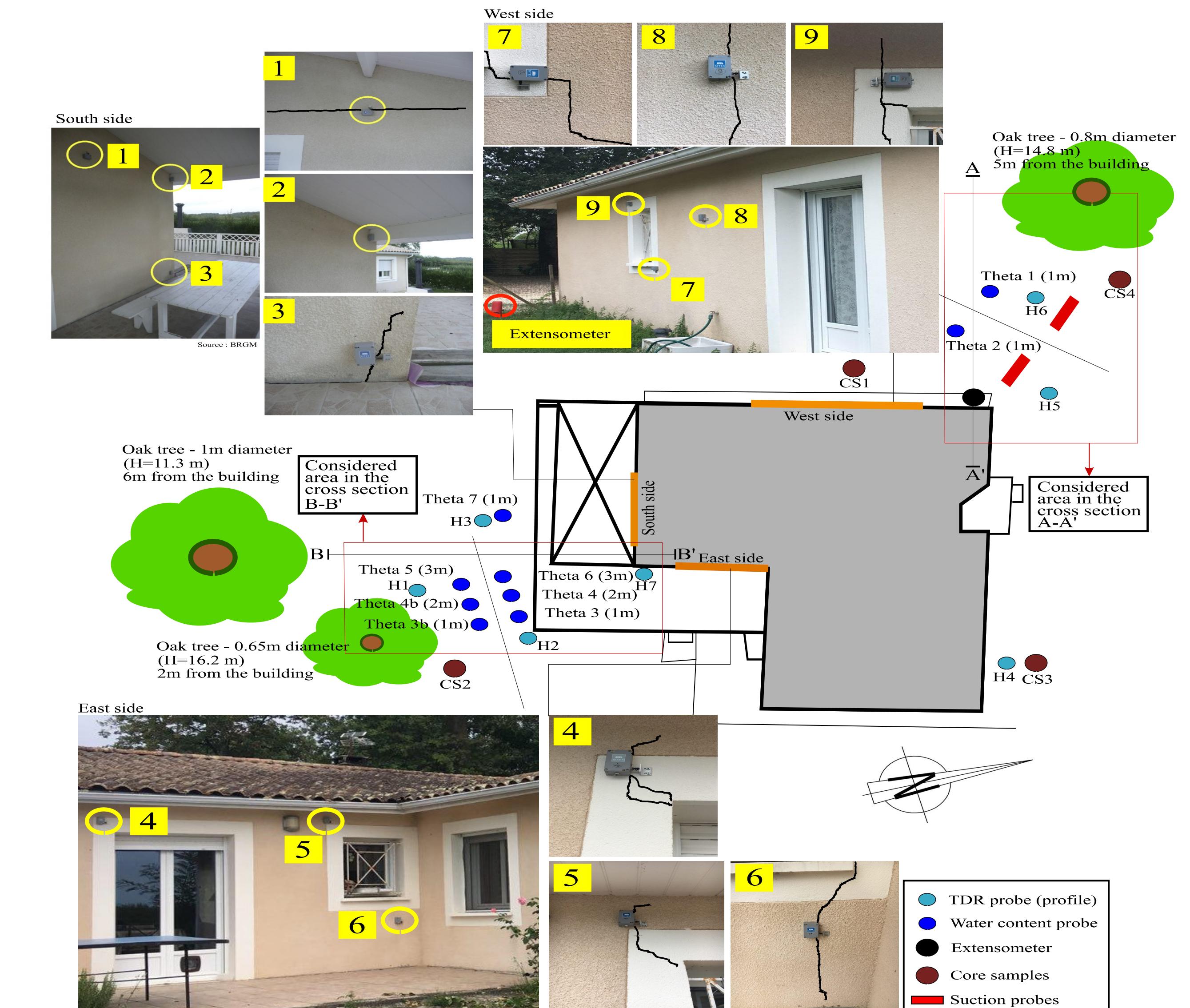


Application de l' approche :

Site de Roaillan, instrumenté dans le cadre du projet ARGIC :

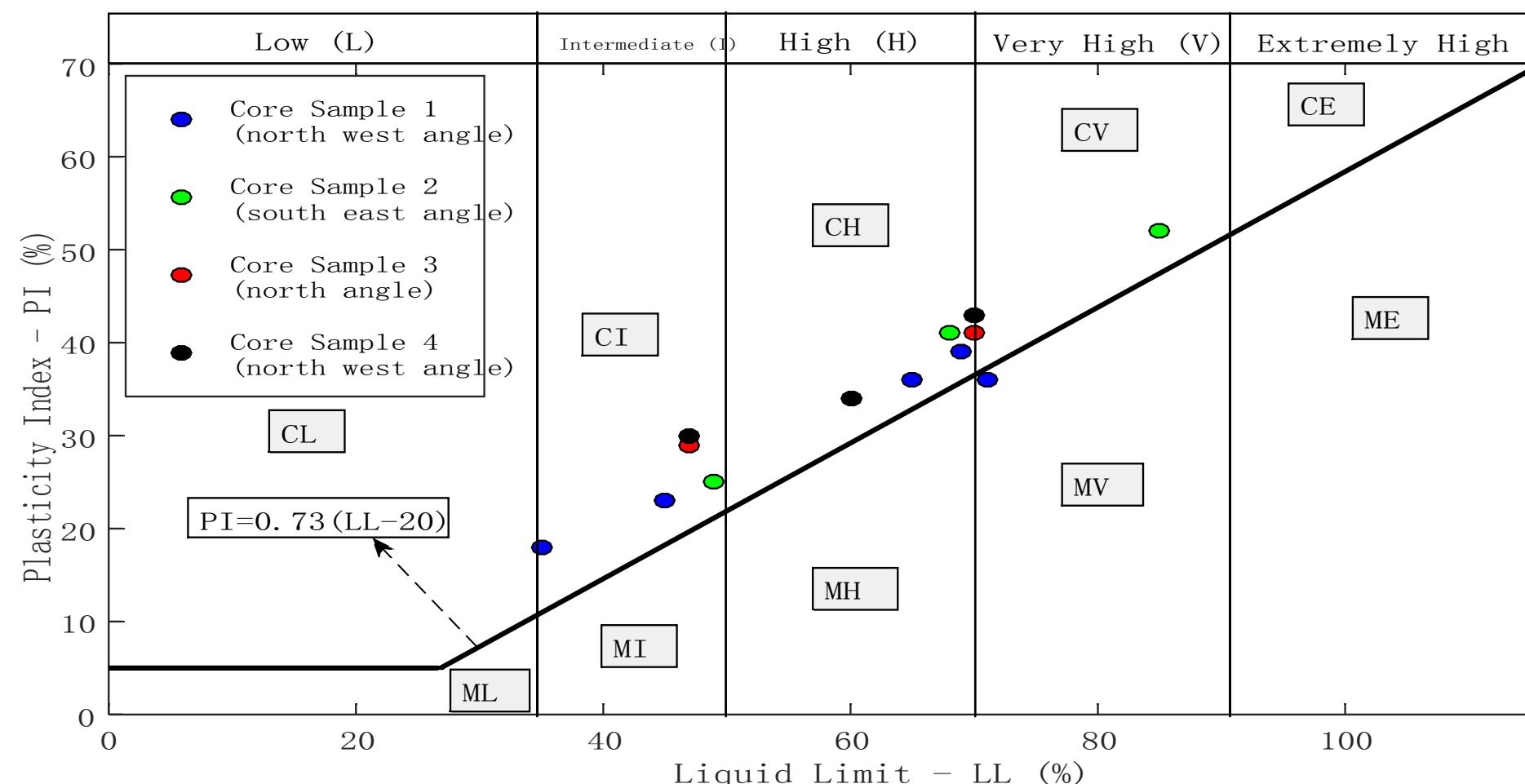
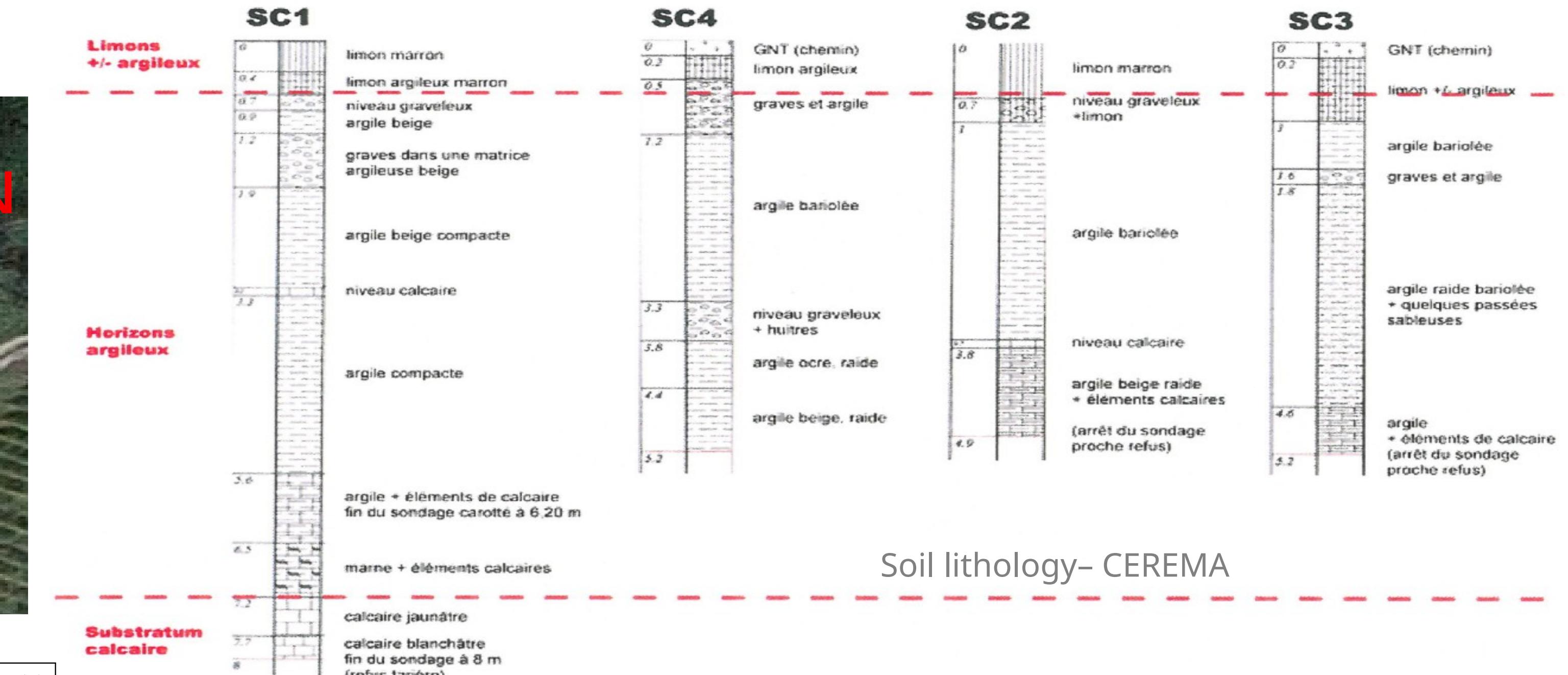
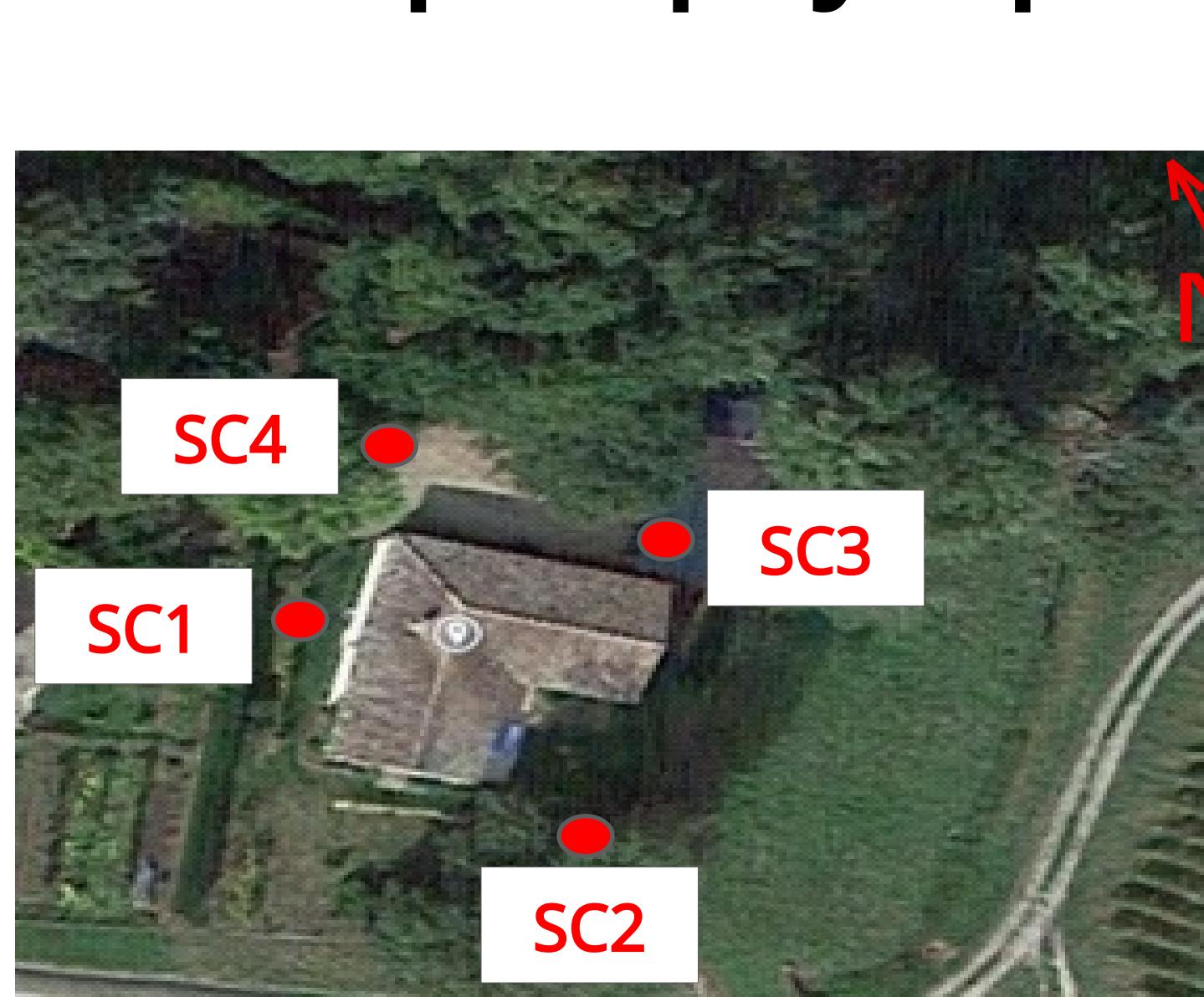


Situation of site studied by BRGM (Argic 2)



Representation of the building with the sensors.

Application de l' approche : Caractéristiques physiques des sols:



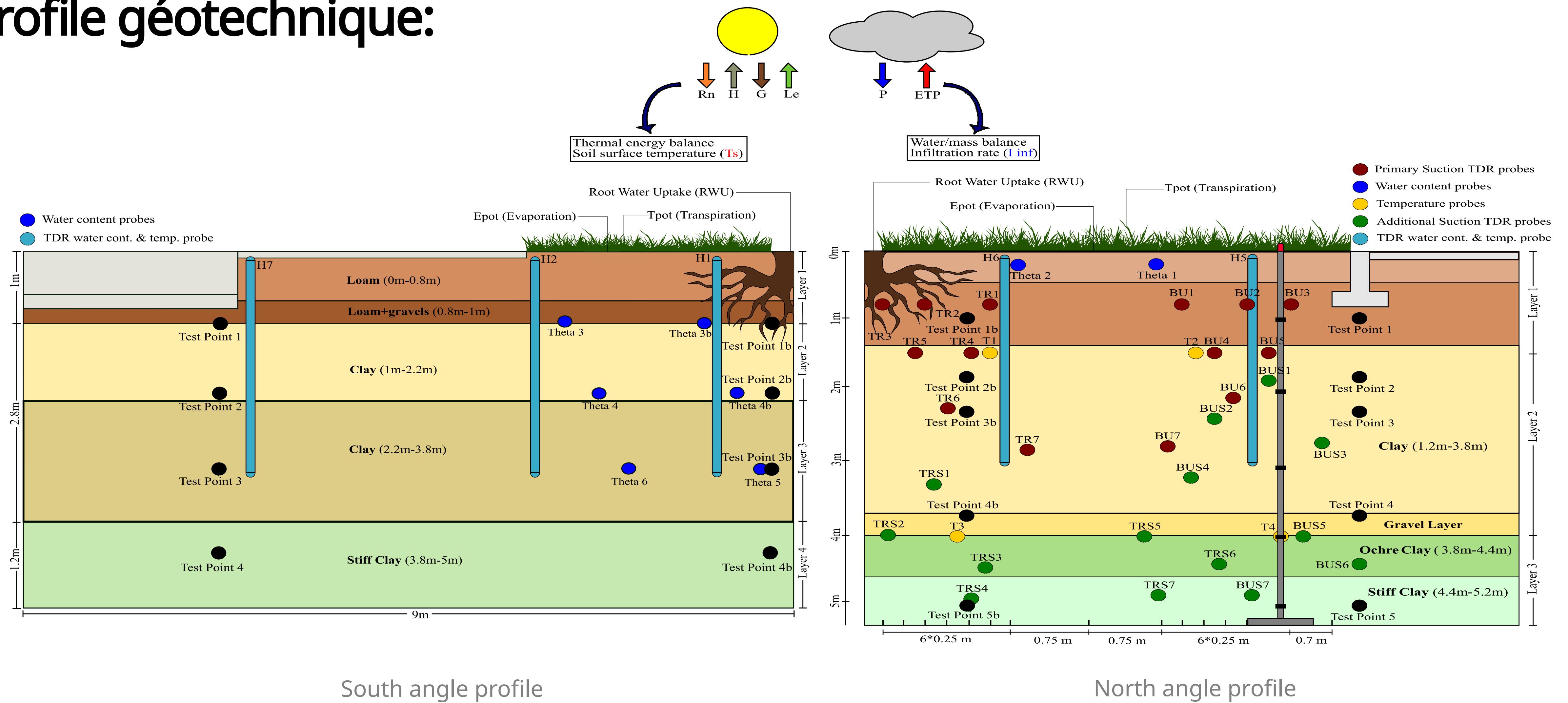
Plasticity index of the different layers

Depth (m)	SC	Geological formation	(%)	Clay particles content (%)	Liquid Limit (LL)	Plastic Limit (PL)	Plasticity index (PI)	VBS	Activity (%)	GTR class.	USCS class.
0.4-0.8 m	CS1	Clayey silt	66.8	29	35	17	18	-	62.07	A2	CL
0.9-1m	CS1	Clay	98.6	70	71	35	36	9.09	51.42	A4	MH
1.2-1.6 m	CS2	Colored clay	95.3	73	85	33	52	9.58	71.23	A4	CH
1.2-2m	CS4	Colored clay	99.6	76	70	27	43	9.63	56.57	A4	CH
1.3-1.6m	CS3	Colored clay	69.8	49	47	18	29	3.5	59.18	A3	CL
2.3-2.6m	CS1	Compacted clay	99.4	-	69	30	39	7.55	-	A3	CH
2.4-2.8m	CS3	Stiff clay + sand	93.1	75	70	29	41	9.01	54.66	A4	CH
3.1-3.2m	CS2	Colored clay	99.8	-	68	27	41	7.95	-	A4	CH
3.6-3.8m	CS1	Compacted clay	99.2	80	65	29	36	8.11	45	A4	CH
3.8-4.4m	CS4	Stiff Ocher clay	99.9	79	60	26	34	9.8	43.04	A4	CH
4.2-4.3m	CS2	Stiff clay + limestone	87.6	-	49	24	25	6.71	-	A2	CL
4.4-5.2m	CS4	Stiff beige clay	99.1	62	47	18	29	5.51	46.77	A2	CL
5.2-5.6m	CS1	Compacted clay	96.5	63	45	22	23	5.14	36.5	A2	CL

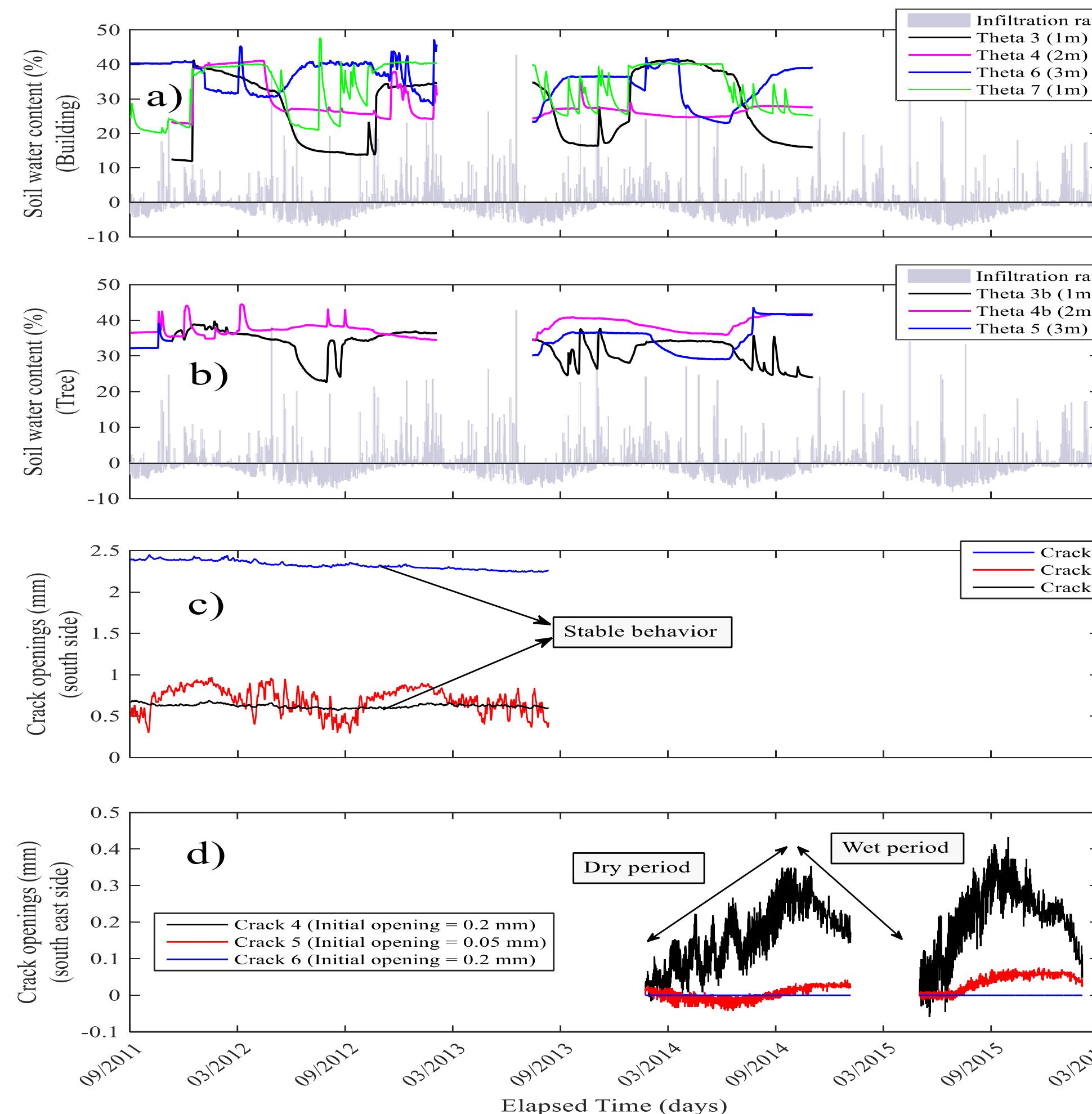
Soil identification parameters (Mathon and Godefroy, 2015).

Application de l'approche :

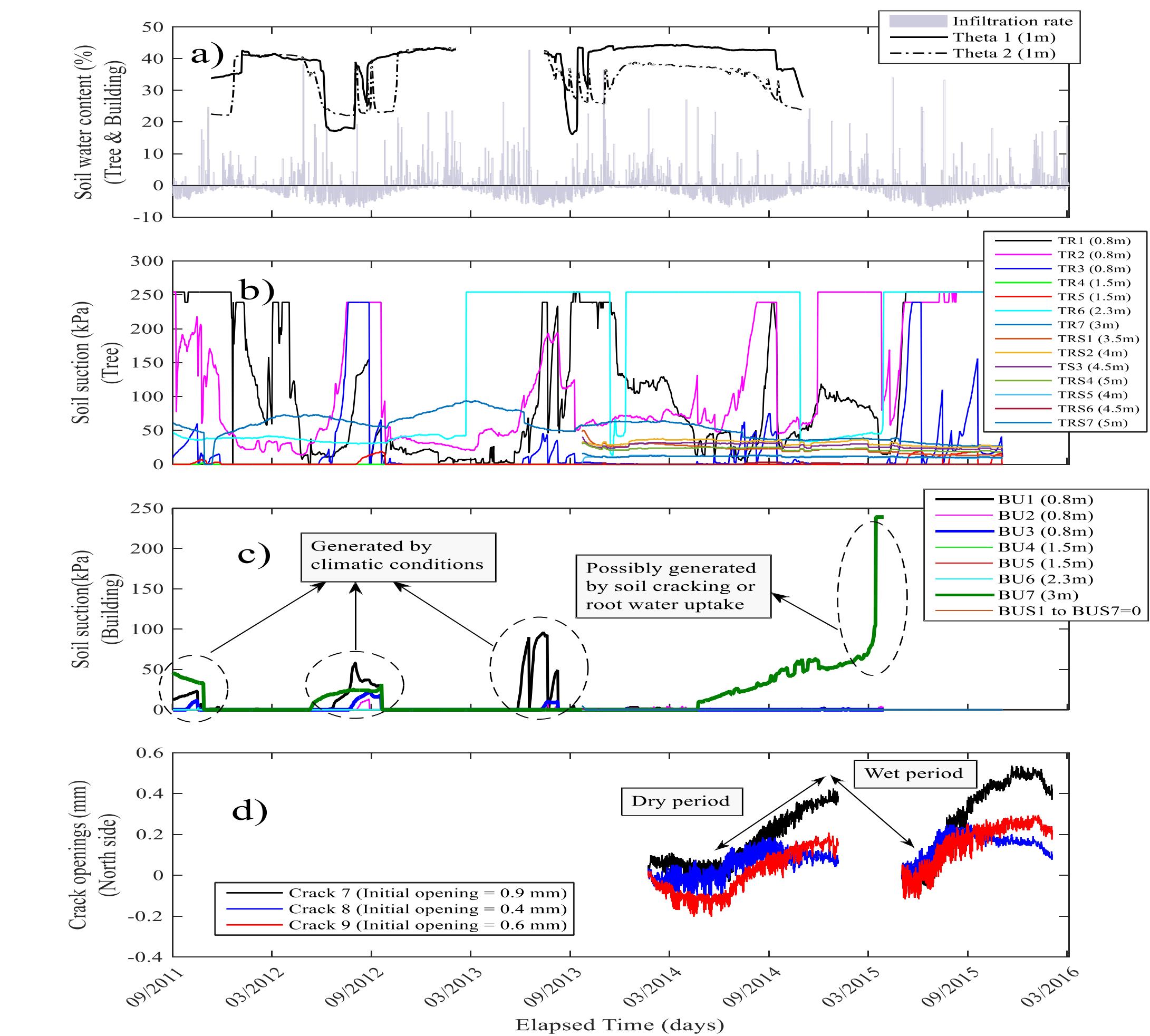
Profile géotechnique:



Application de l'approche : Instrumentation In-situ:



Instrumentation results for the south angle

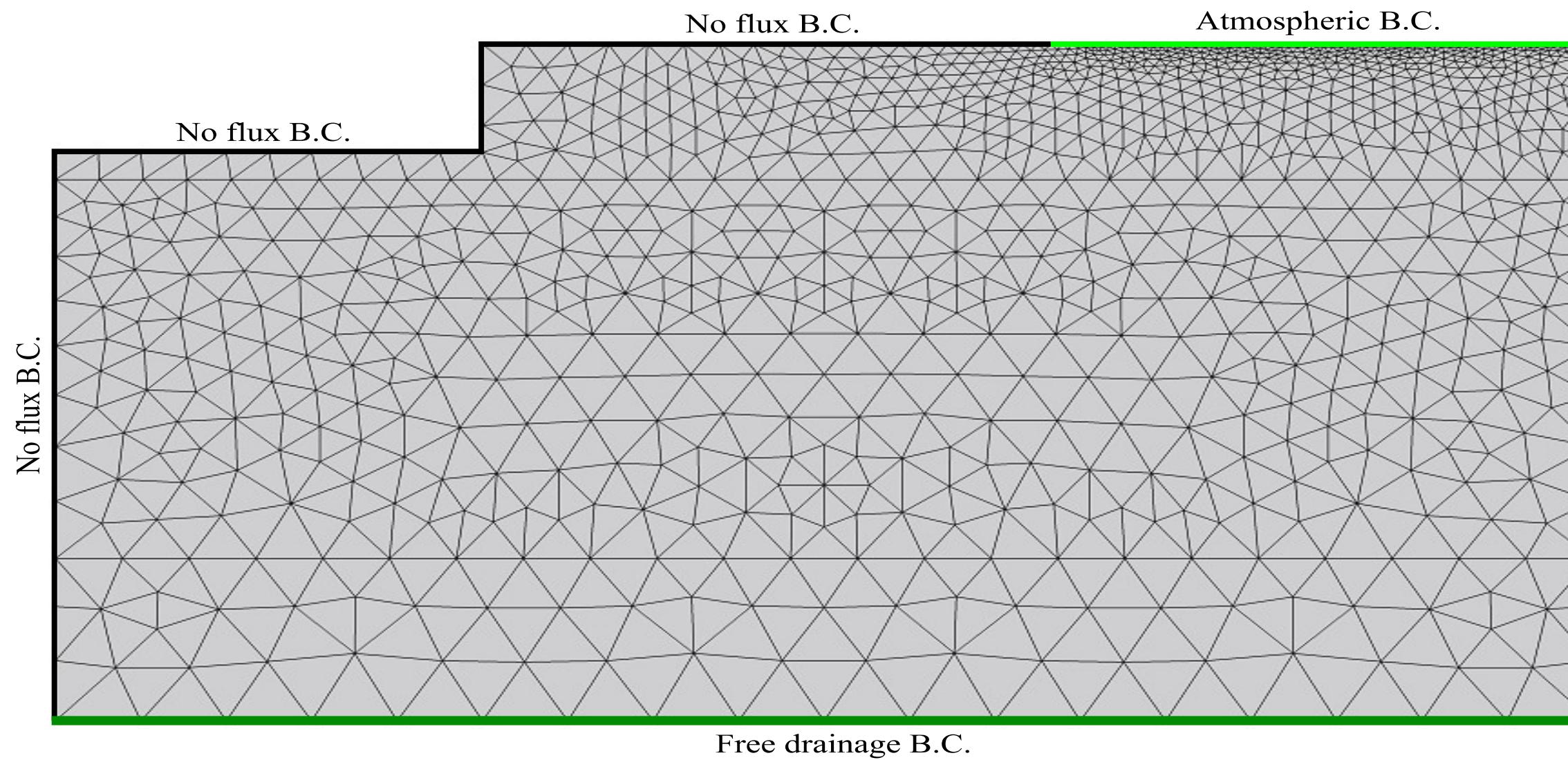


Instrumentation results for the North angle

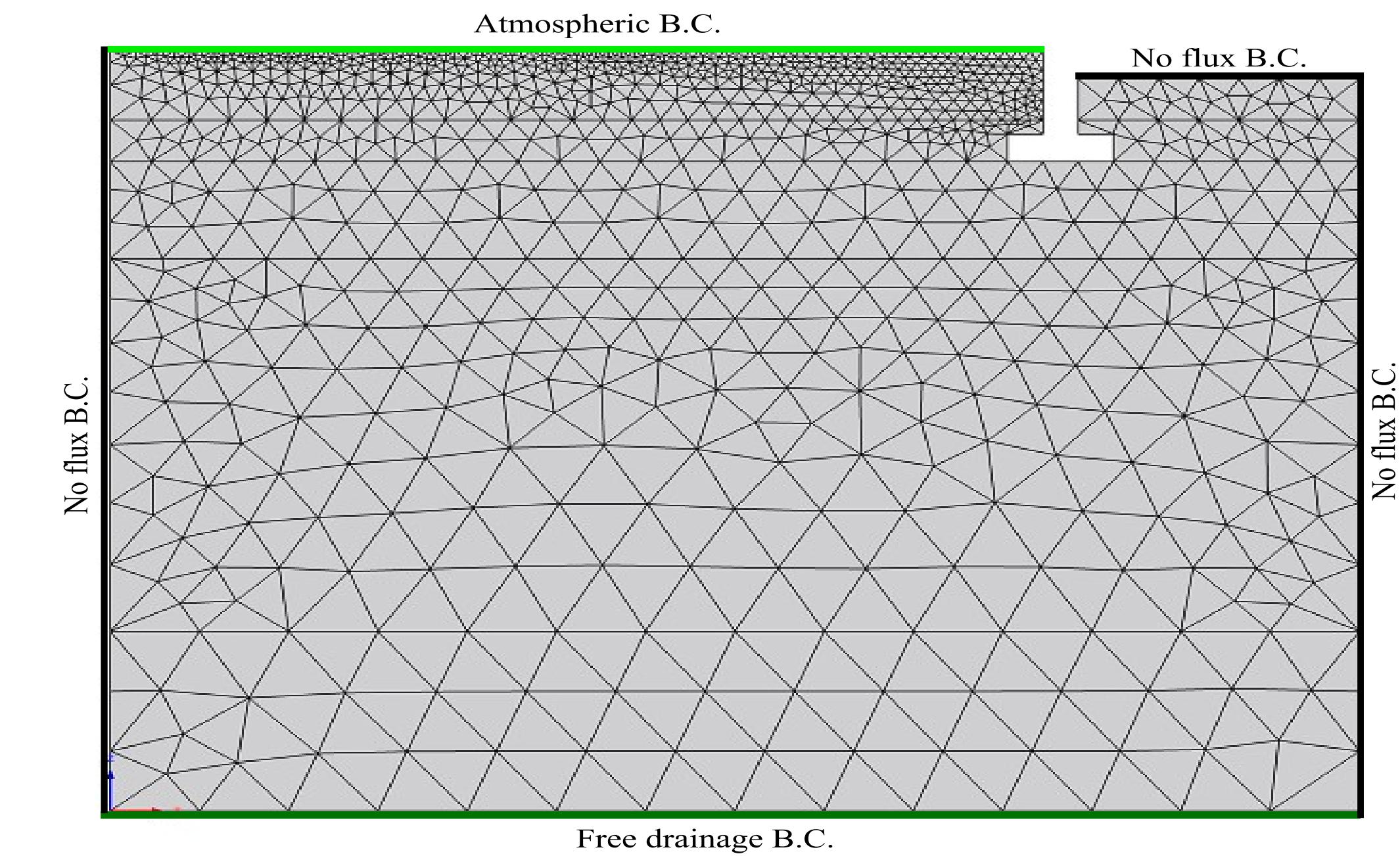


Application de l'approche :

Maillage d'éléments finis:



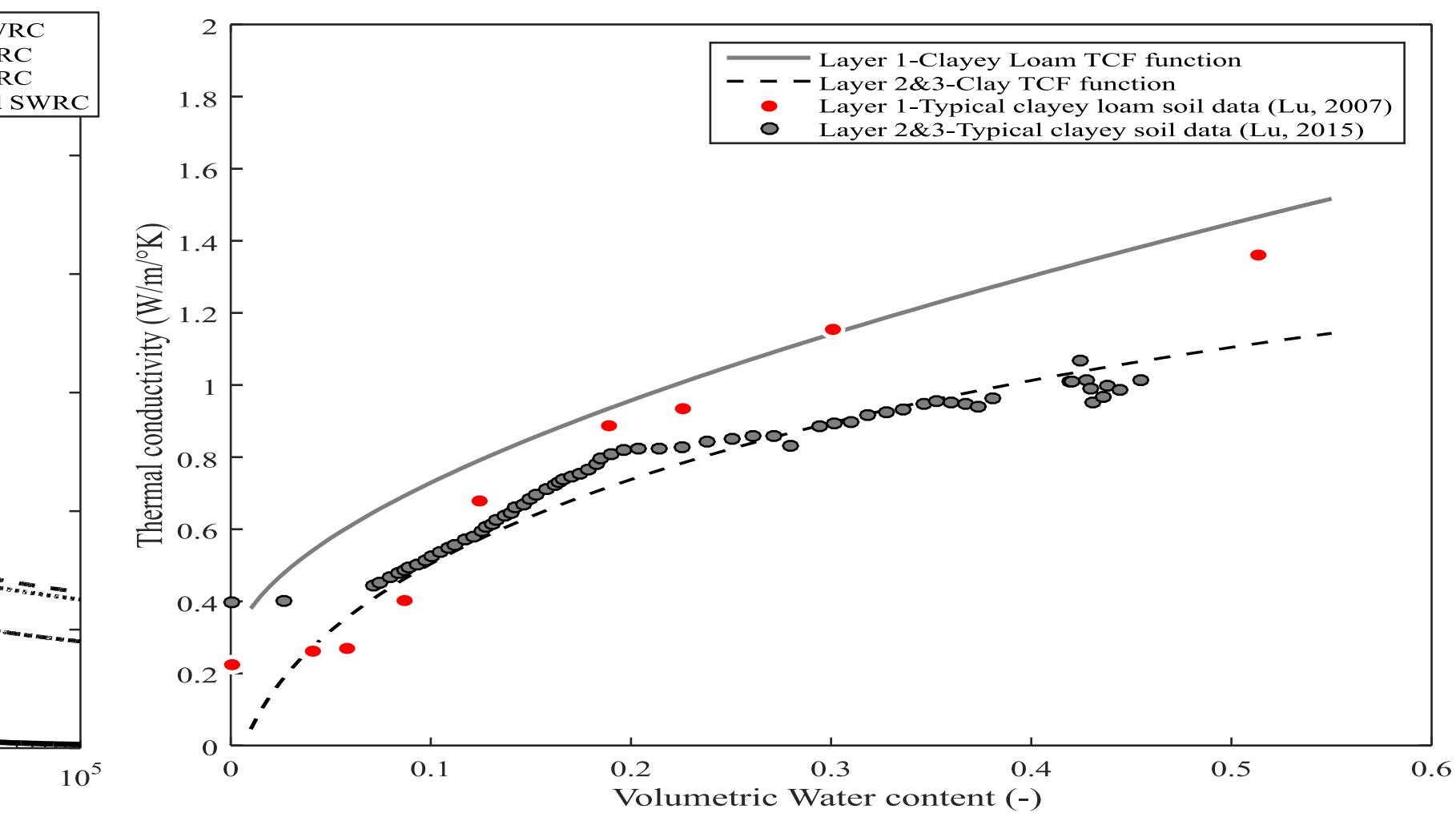
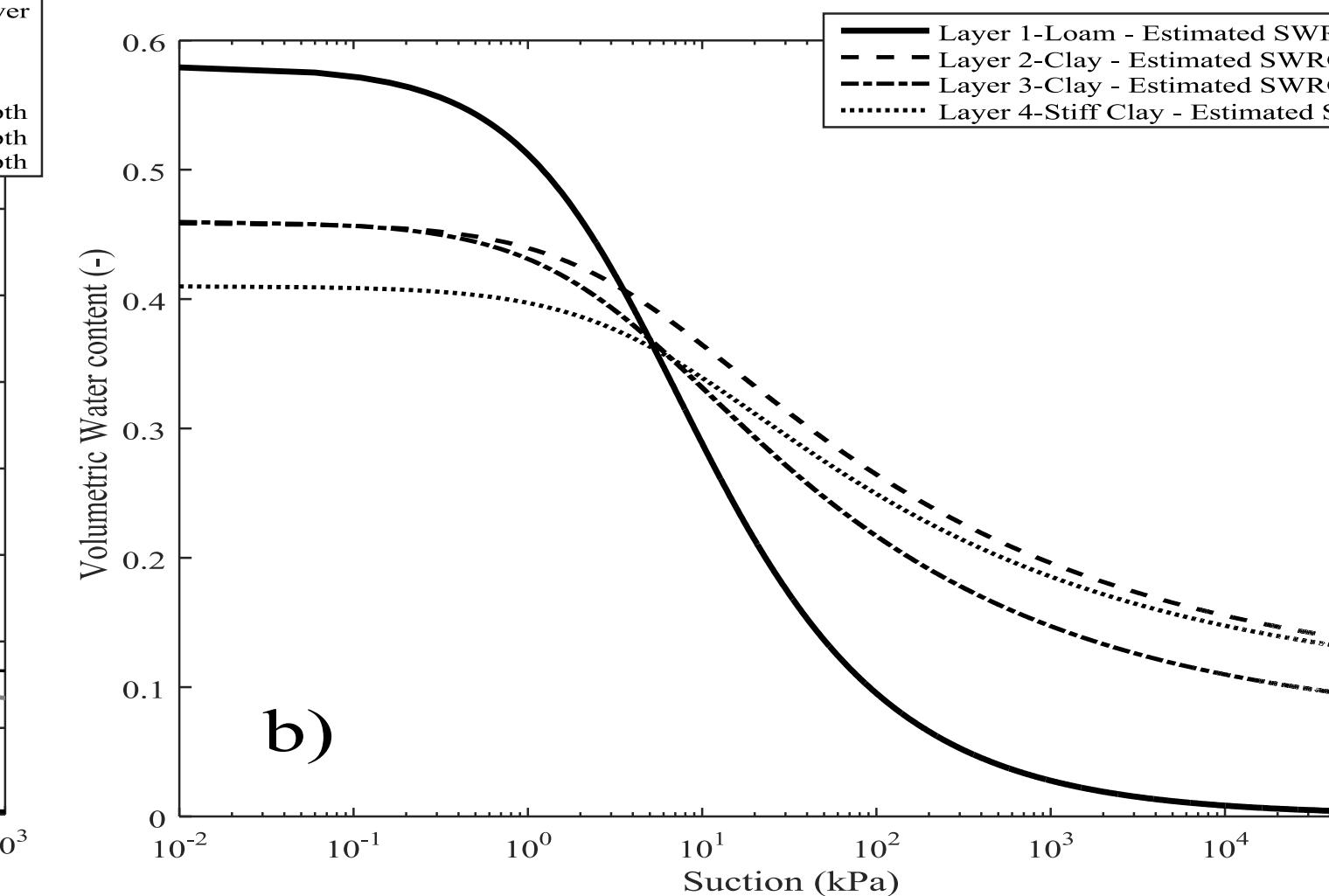
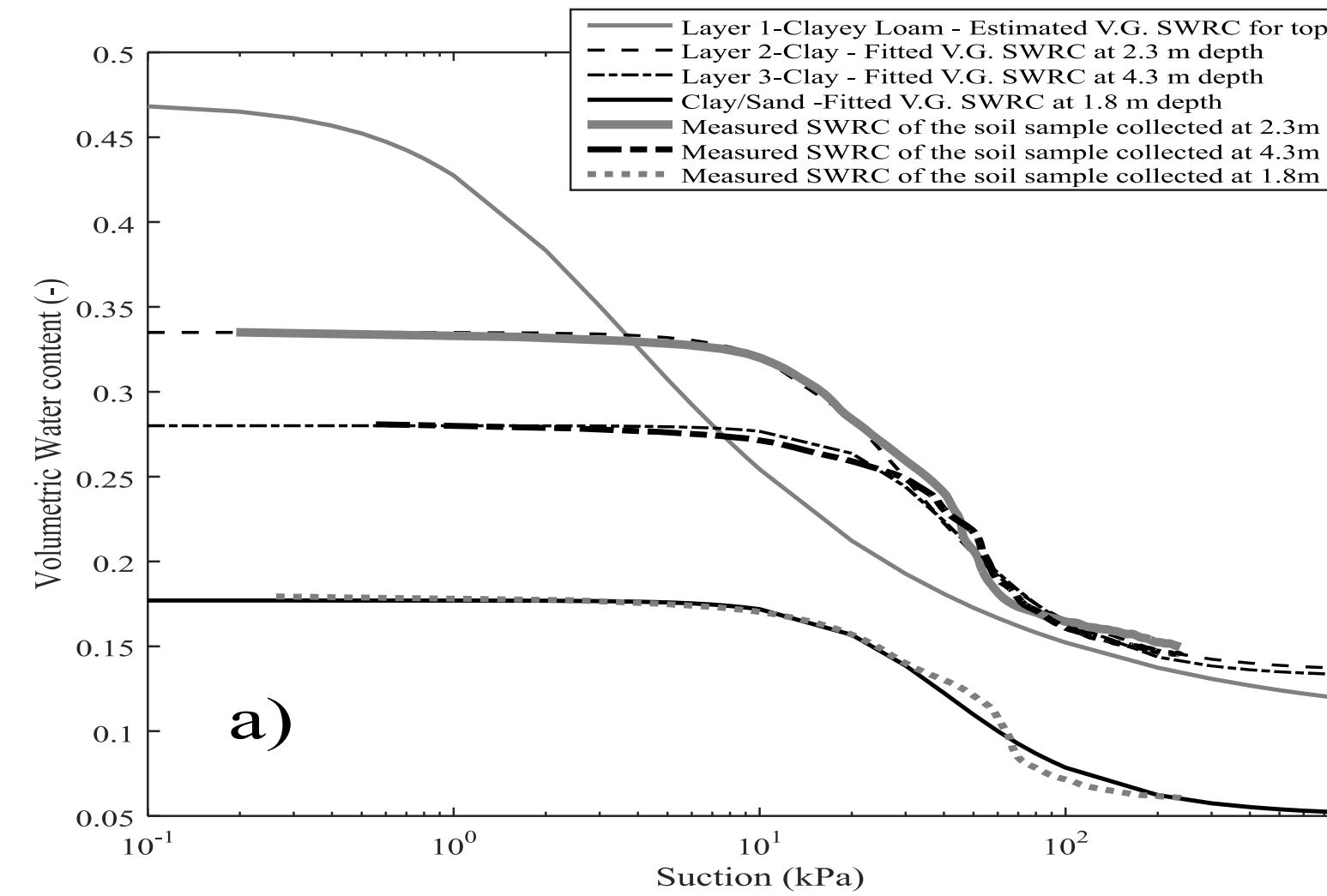
Finite element mesh and the boundary conditions-
South angle



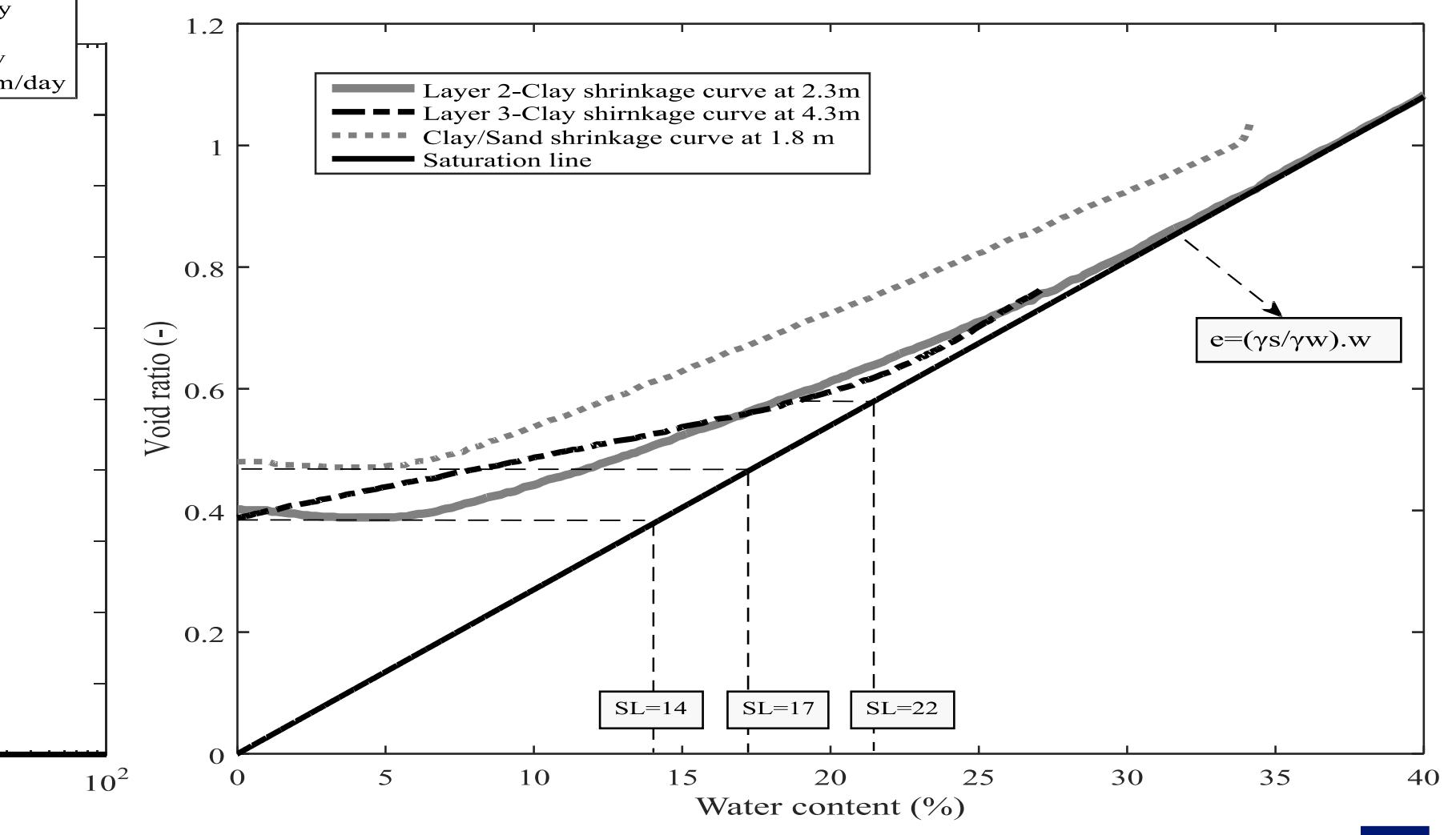
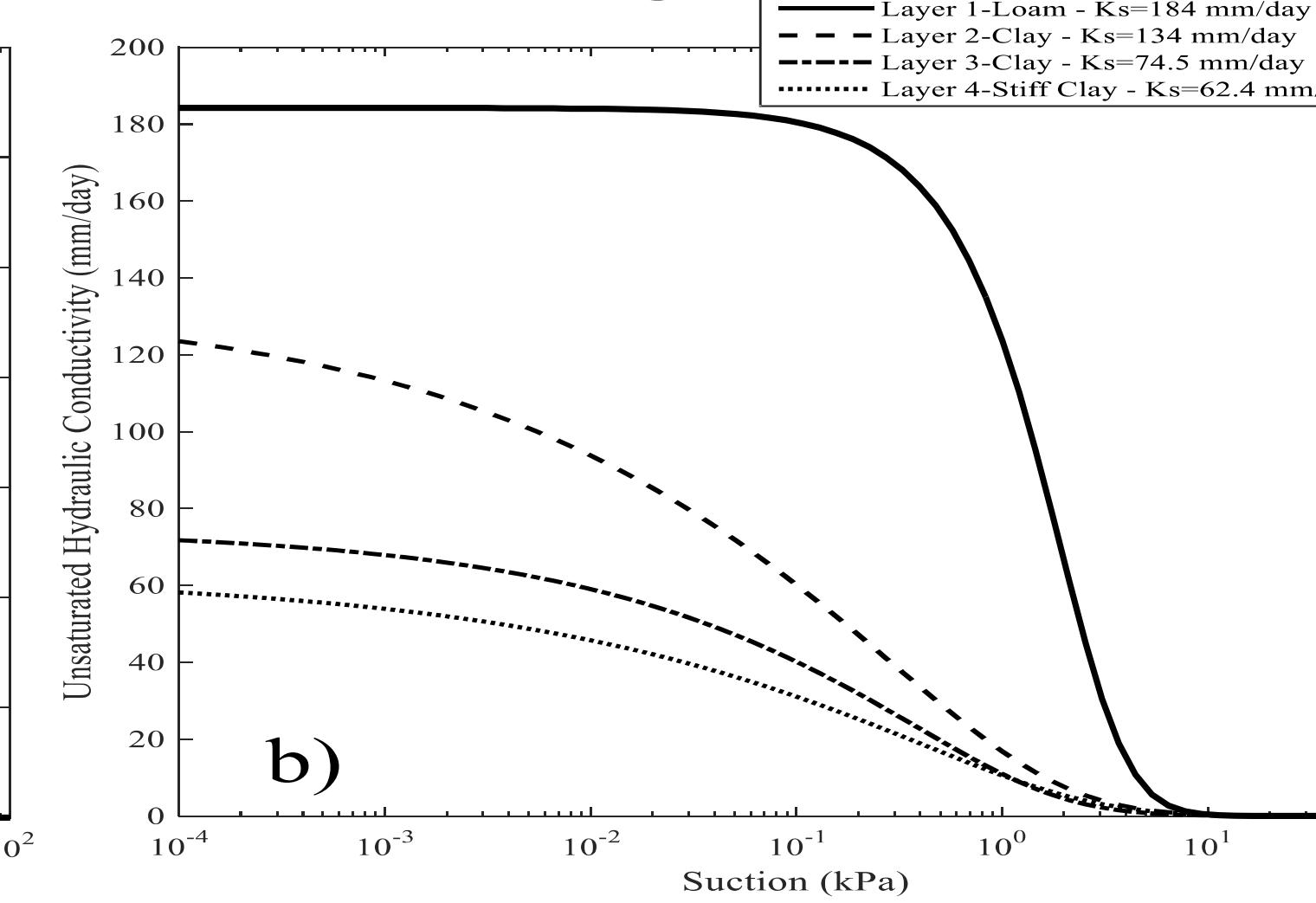
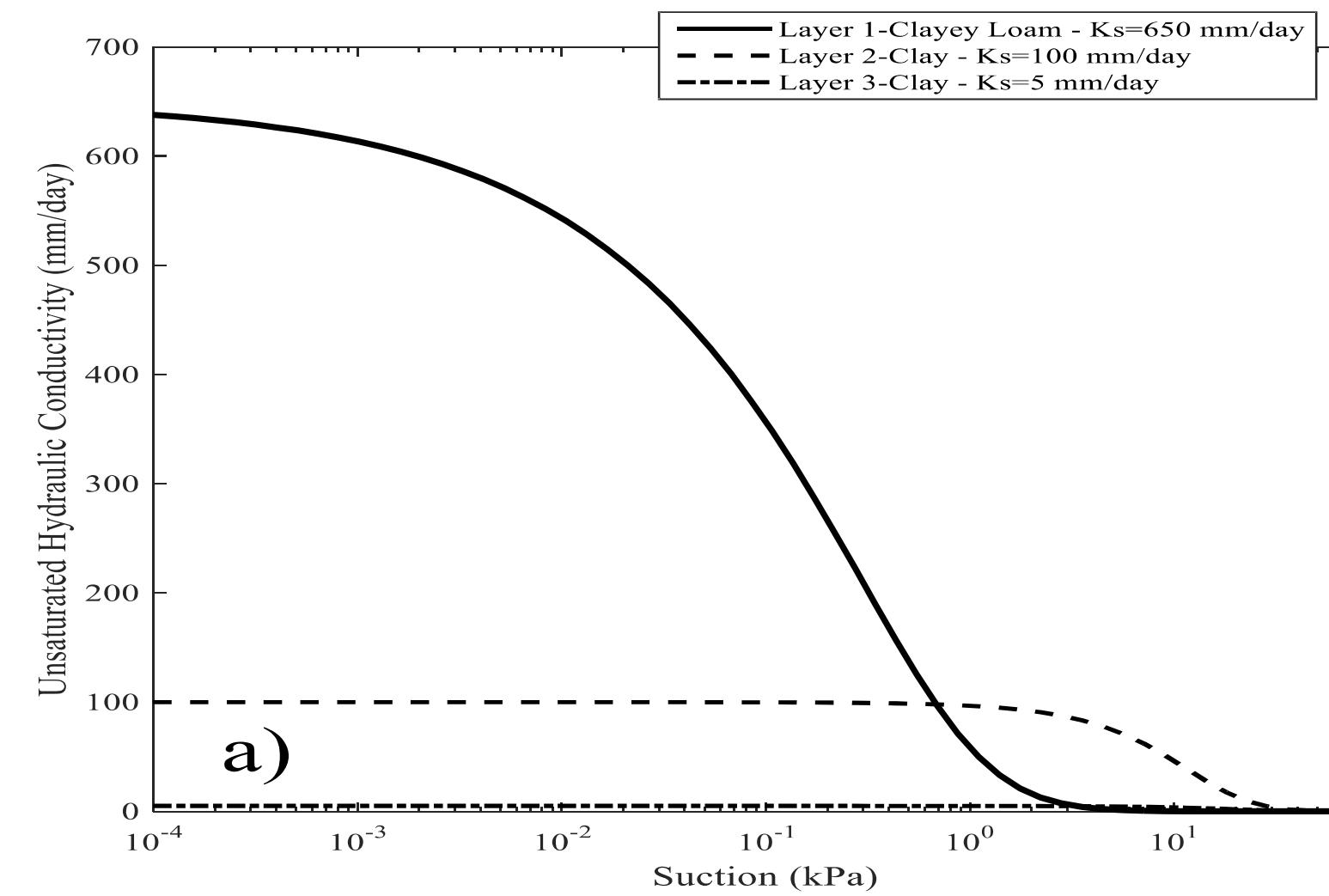
Finite element mesh and the boundary conditions-
North angle



Application de l'approche : Paramètres des sols



Water retention and permeability curves a) North angle and b) South angle



Application de l' approche :

Paramètres des sols

Model Hydro-thermal parameters

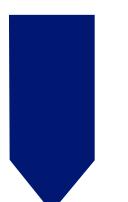
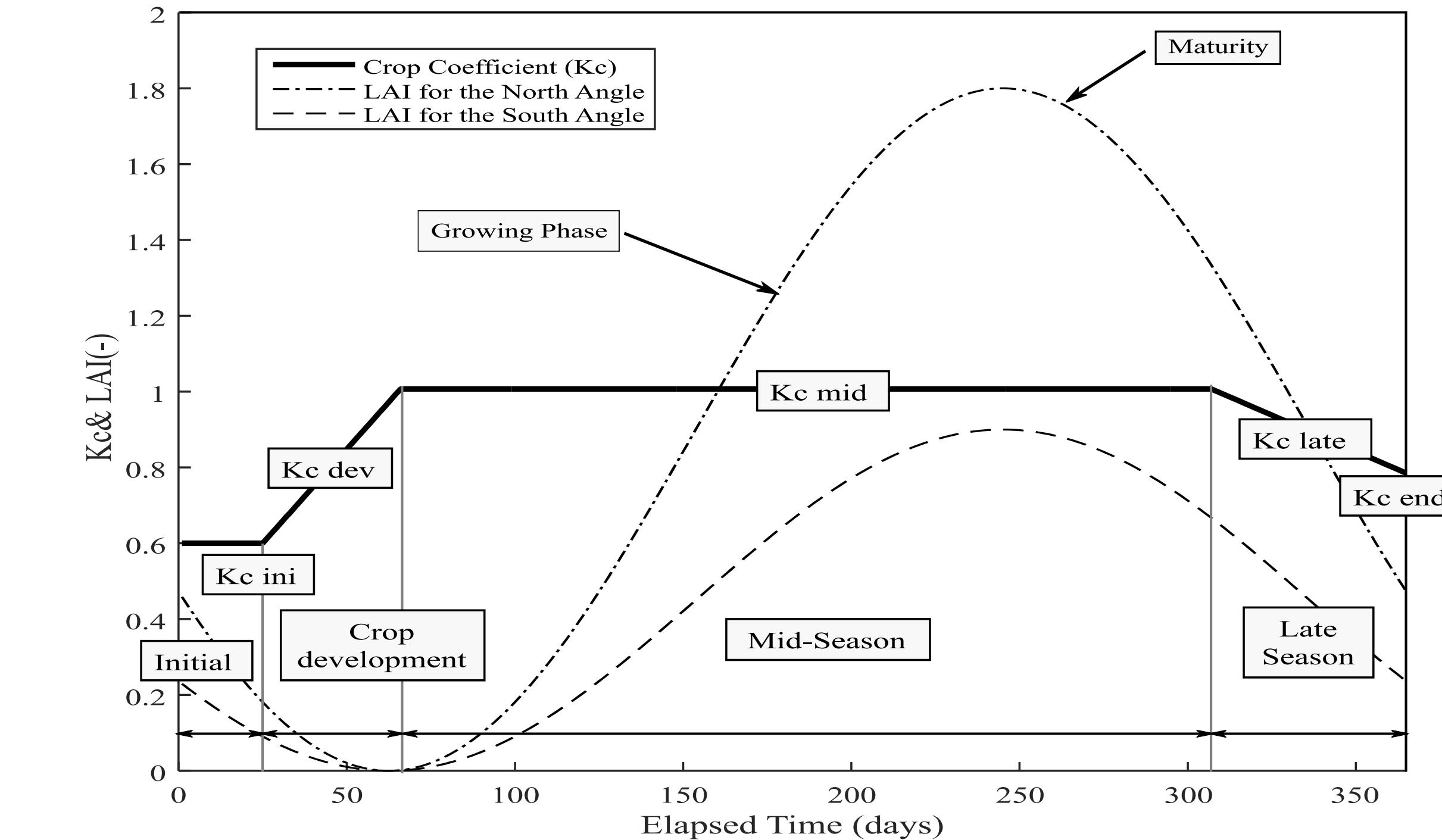
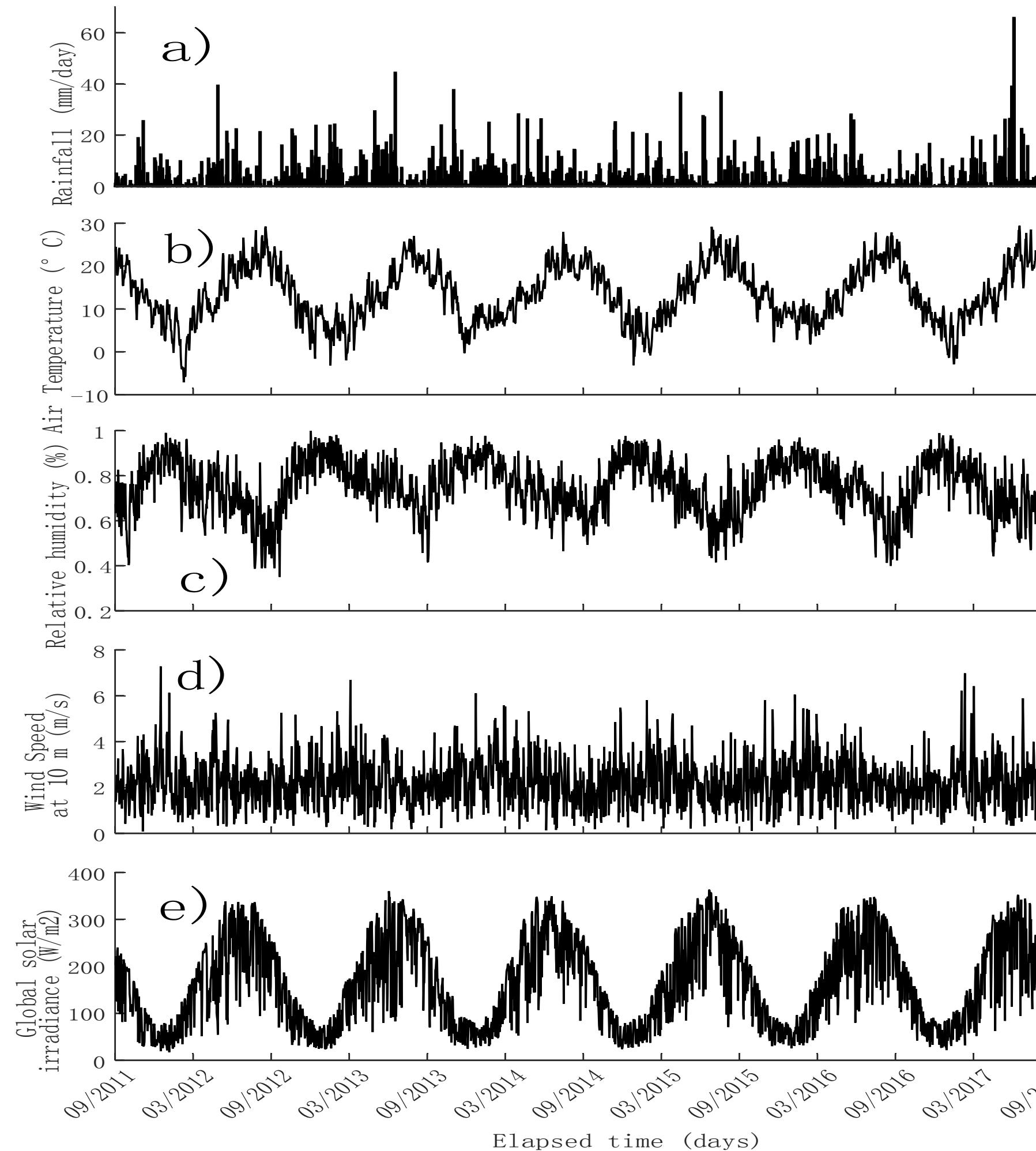
Angle	Couche	Profondeur (m)									
Nord	1	0-1.5 m	0.0059	1.48	0.47	0.1	0.5	650	0.243	0.393	1.534
	2	1.5-4 m	0.00042	2.3	0.335	0.135	0.5	100	-0.197	-0.962	2.531
	3	4-5.5 m	0.00027	2.5	0.28	0.132	0.5	5	-0.197	-0.962	2.531
Sud	1	0-1 m	0.00248	2.25	0.58	0.001	0.5	184.2	0.243	0.393	1.534
	2	1-2 m	0.0026	1.305	0.458	0.0982	0.5	134.1	-0.197	-0.962	2.531
	3	2-3.8 m	0.00312	1.384	0.46	0.068	0.5	74.5	-0.197	-0.962	2.531
	4	3.8-5m	0.0019	1.31	0.41	0.095	0.5	62.4	-0.197	-0.962	2.531

Model swelling-shrinkage parameters (north angle)

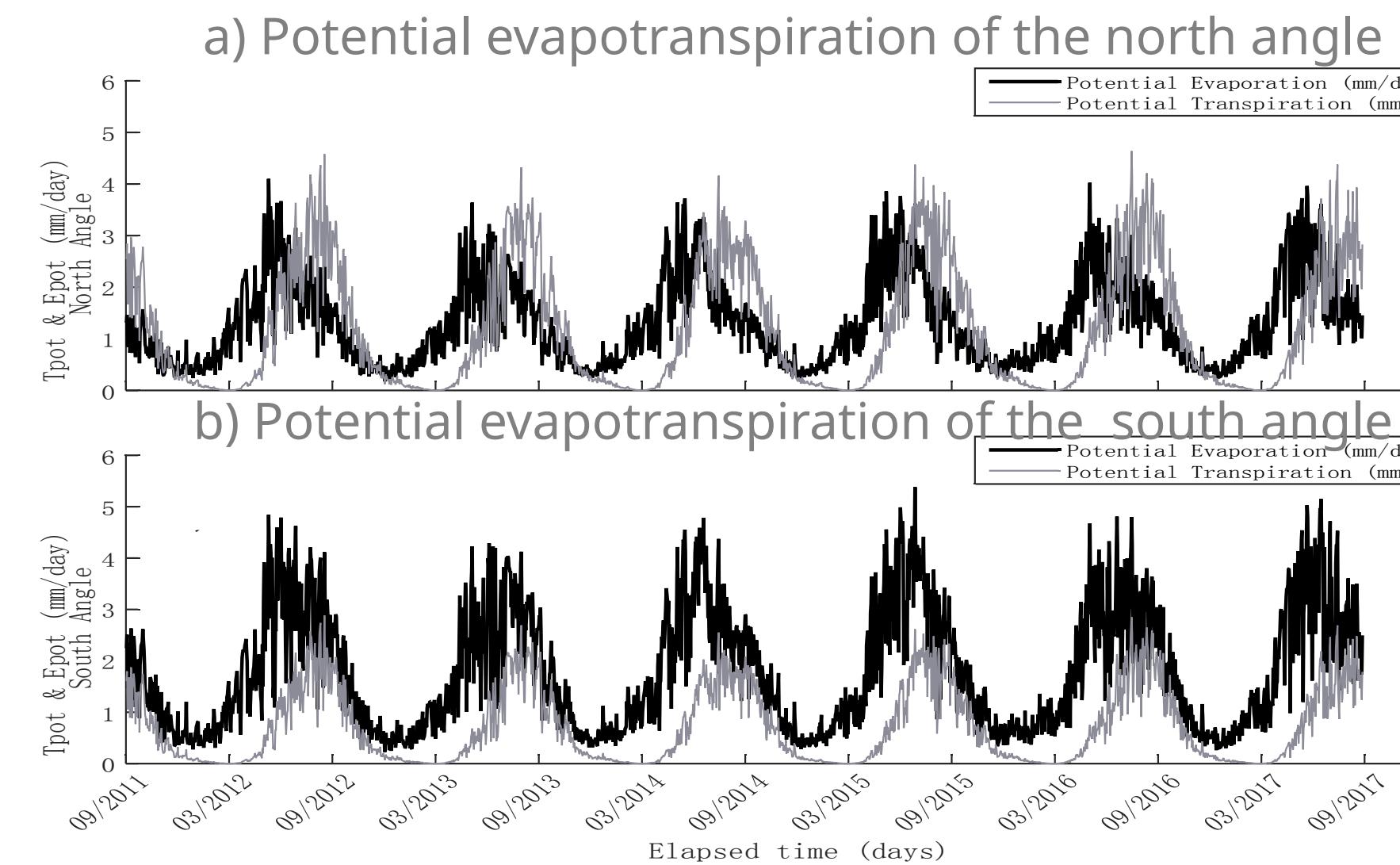
Depth (m)	PI (%)	LL (%)	SL (%)	w% Sat.	e_0	(Mg/m³)			(kPa)	(kPa)
1	36	71	27	0.46	0.95	1.38	-0.0381	-0.0596	112.55	
2	39	69	14	0.33	0.89	1.42	-0.0371	-0.0541	134.96	4678.76
3	36	65	22	0.33	0.89	1.42	-0.0359	-0.0532	134.96	1070.1



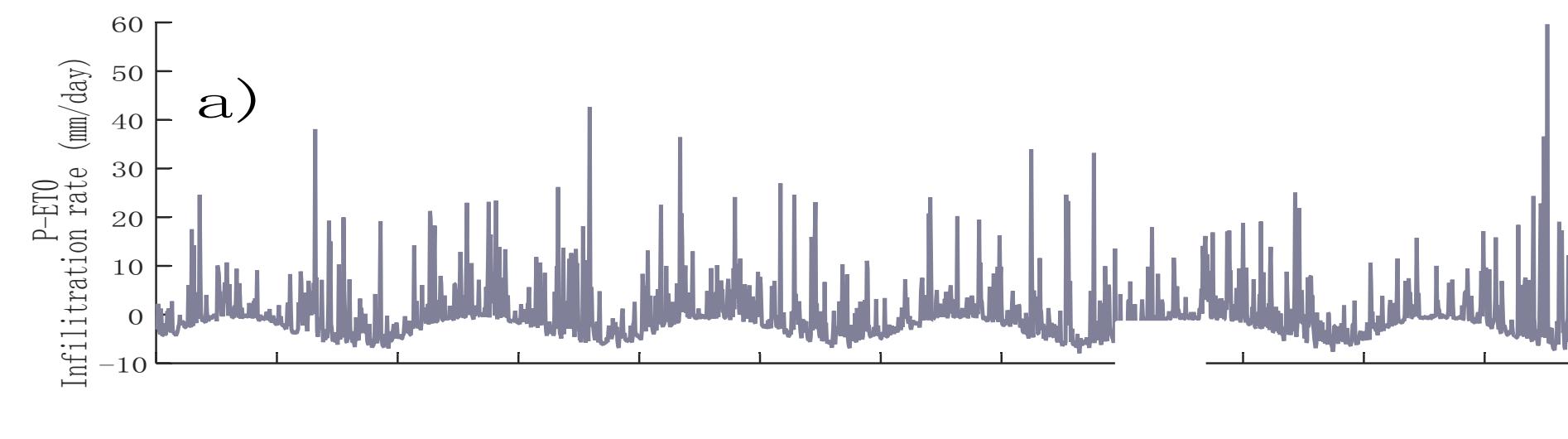
Application de l' approche : Paramètres (Climat + Végétation) :



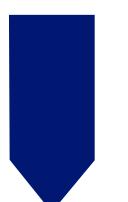
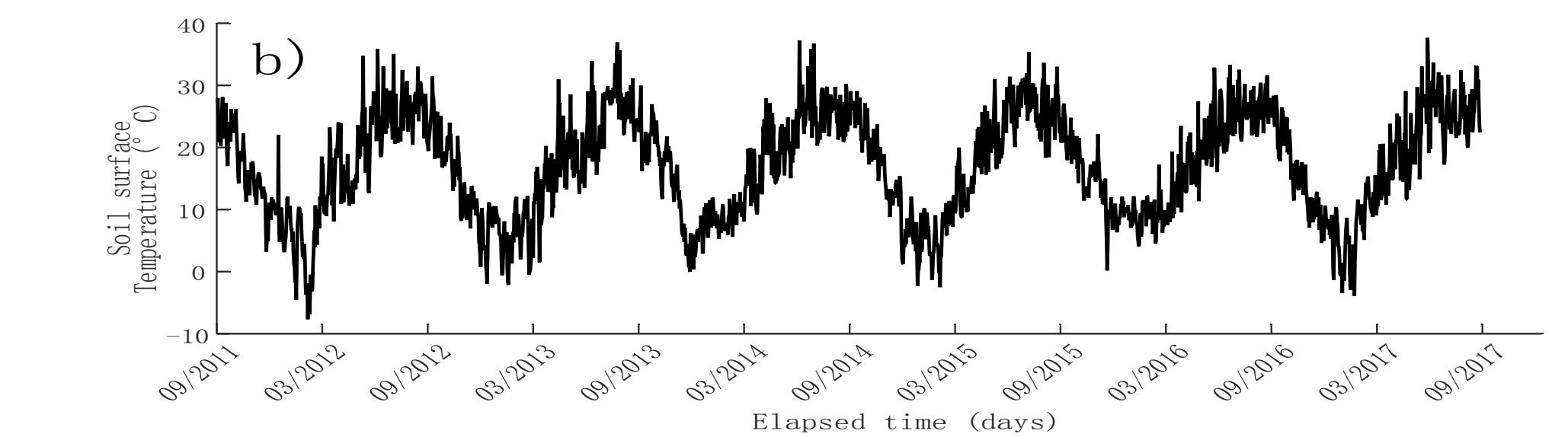
Application de l'approche : Conditions (évapotranspiration, infiltration et la température de surface):



a) Infiltration rate (Water balance)



b) Soil surface temperature (Energy balance)

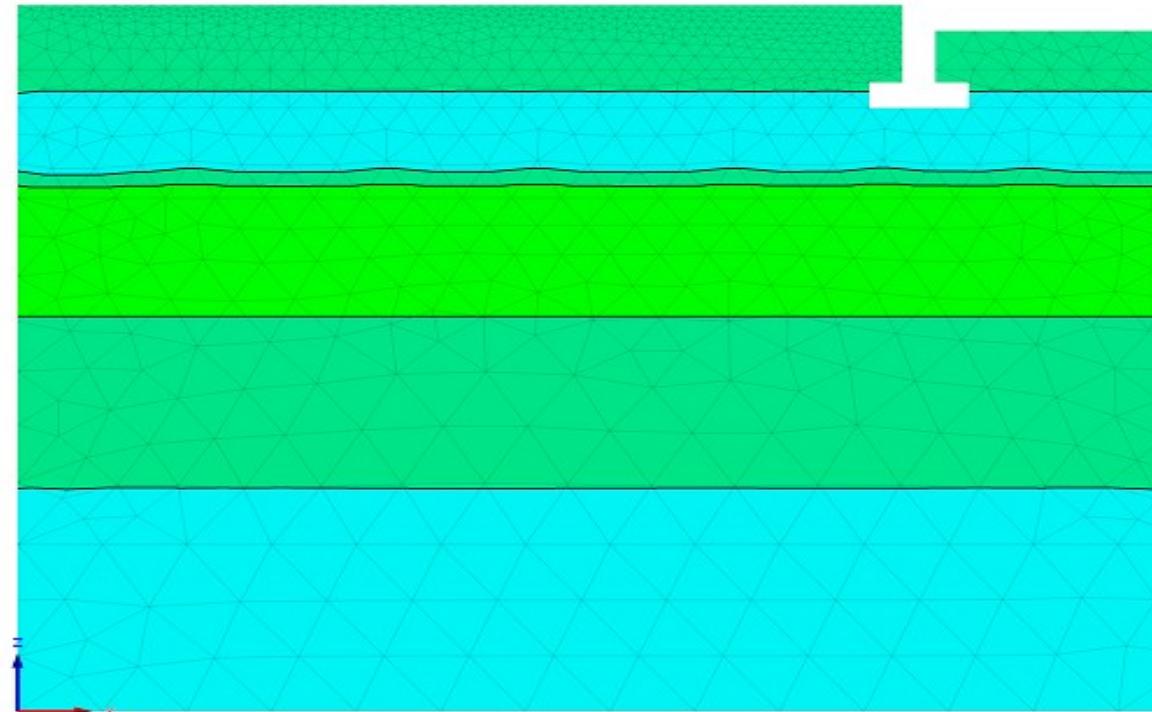


Application de l'approche :

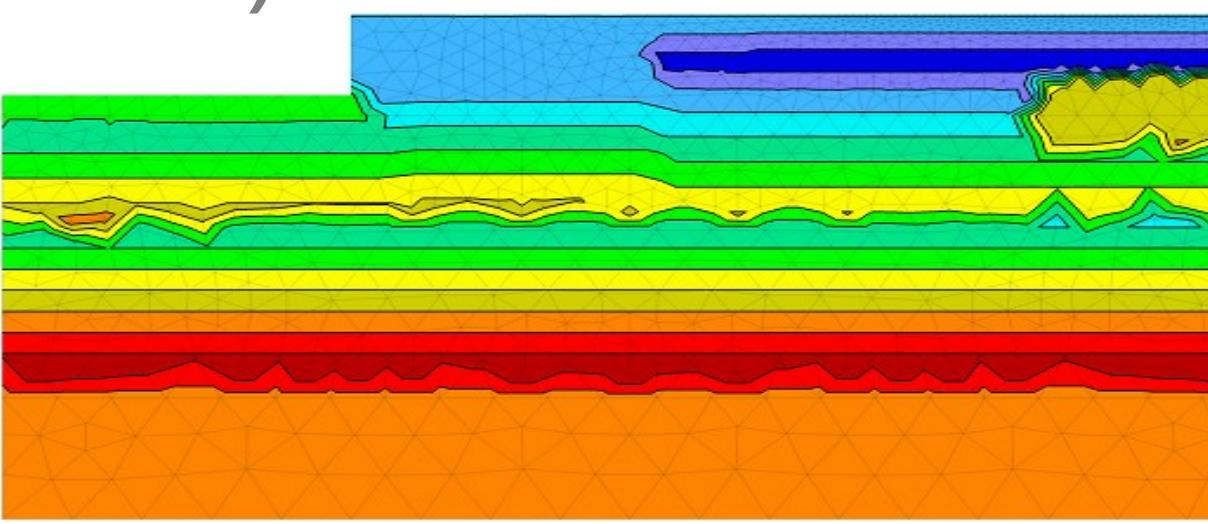
Conditions initiales:

Water content

a) North



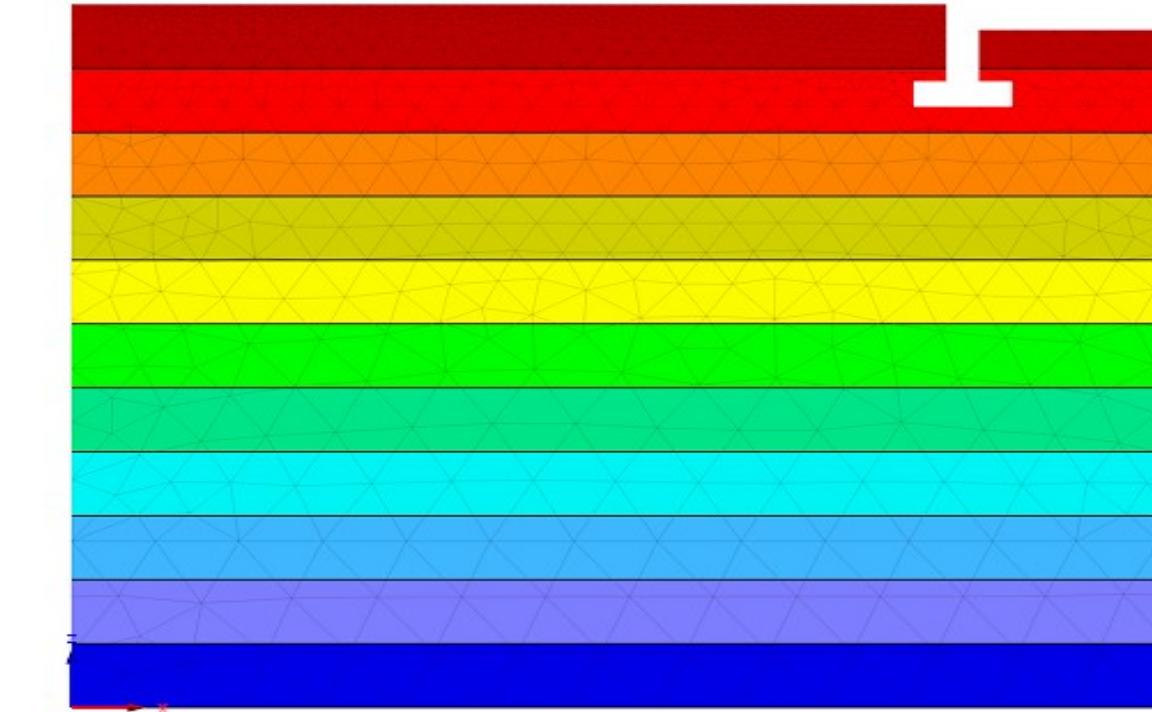
b) South



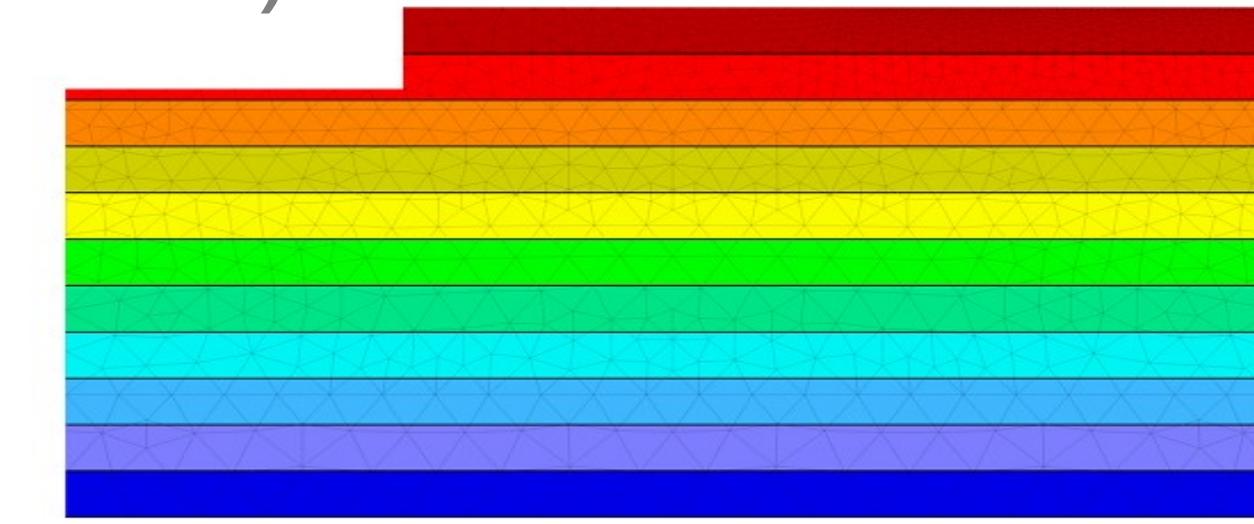
Water Content - th[mm], Min=0.055, Max=0.500

Temperature

a) North



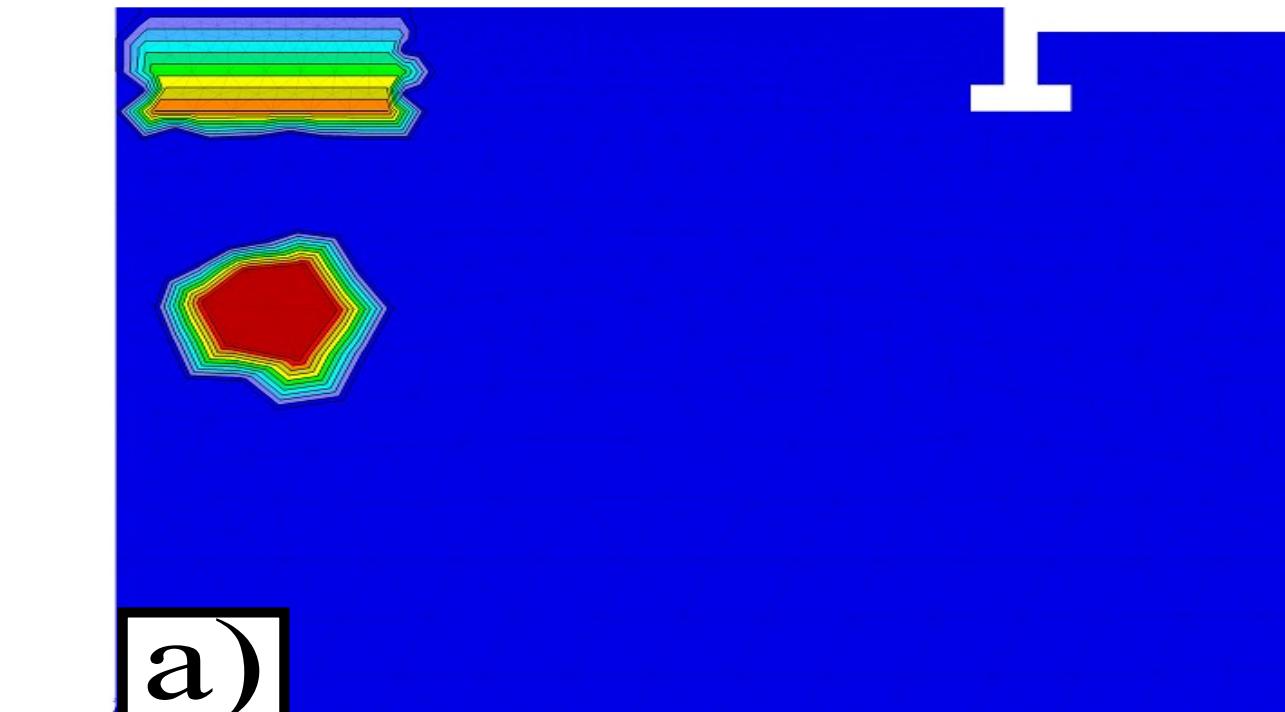
b) South



Temperature - T[°C], Min=13.000, Max=25.000

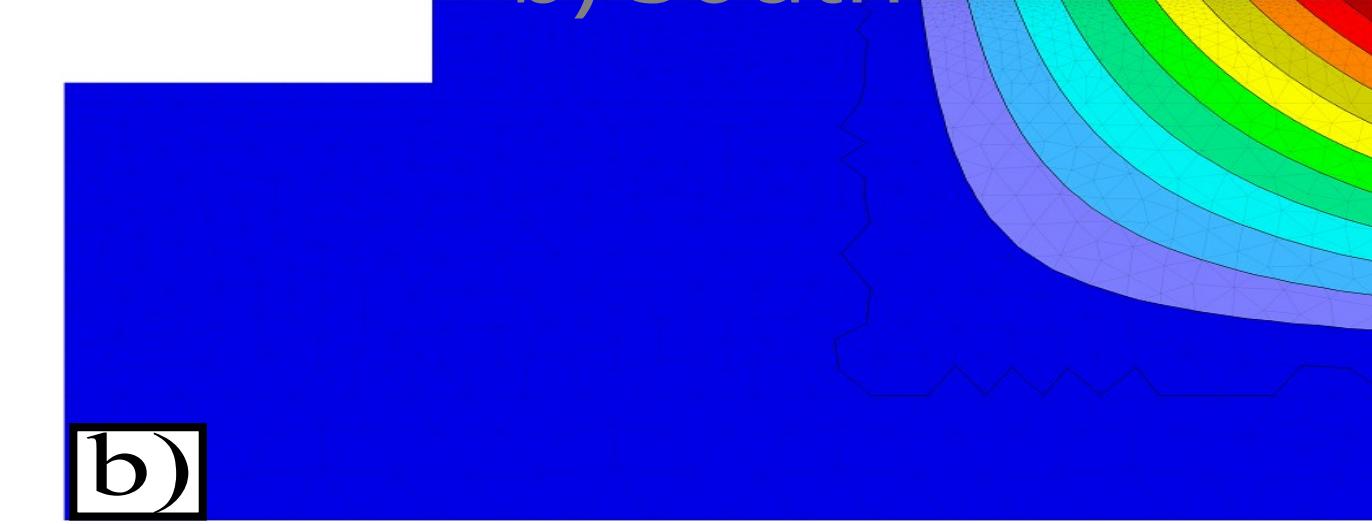
Root Distribution

a) North

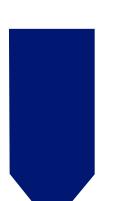


a)

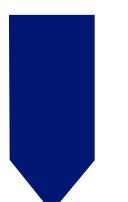
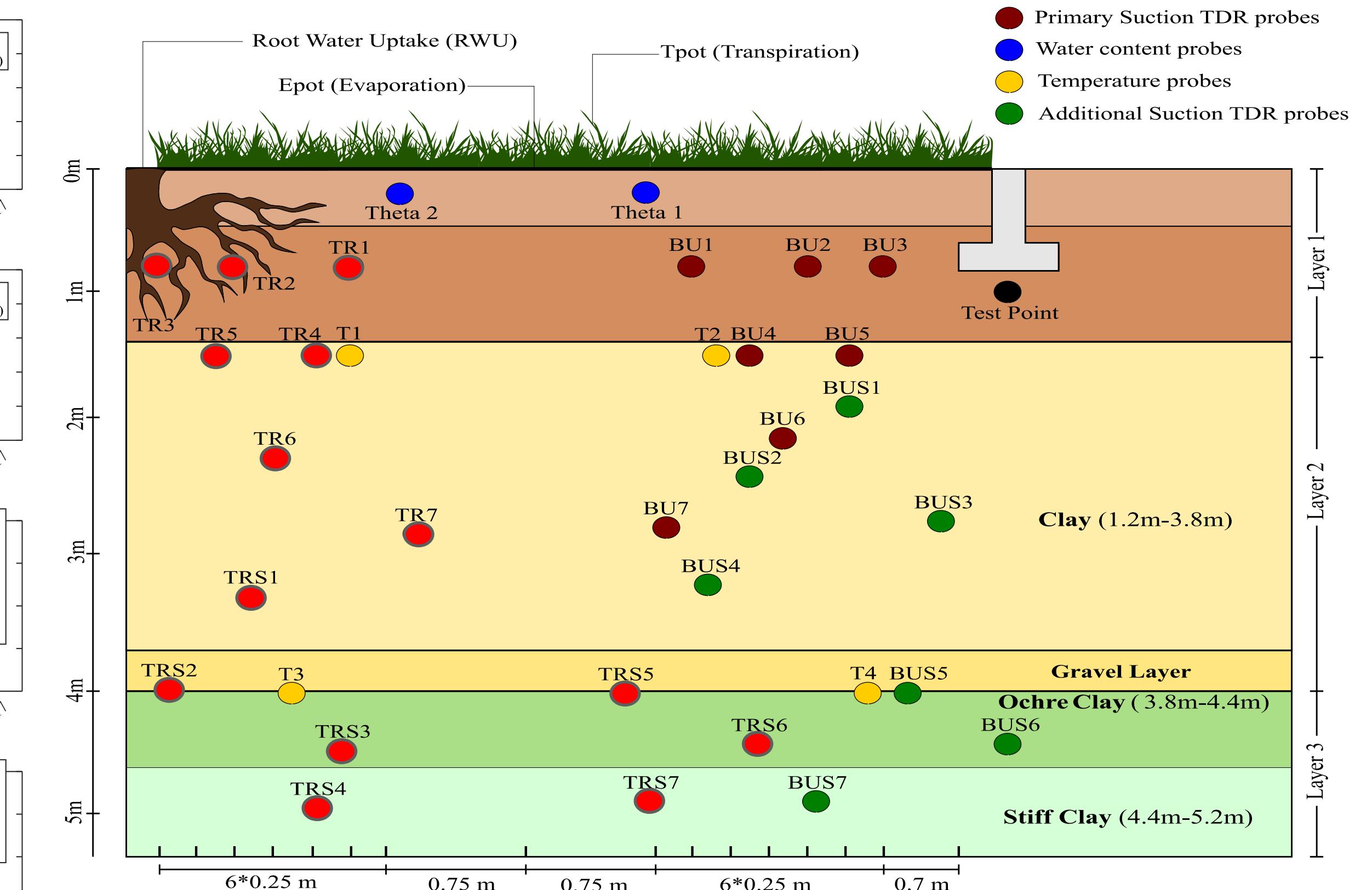
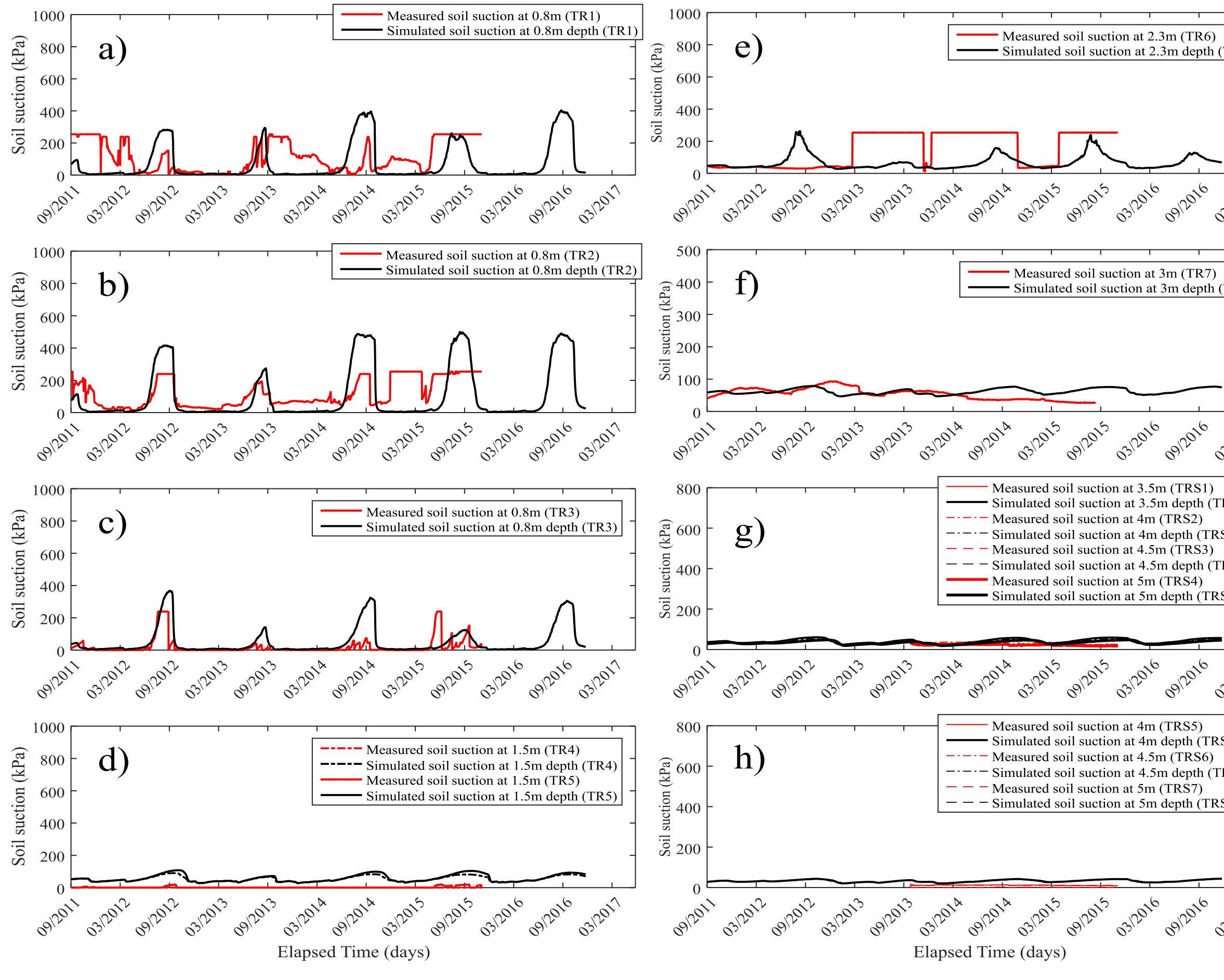
b) South



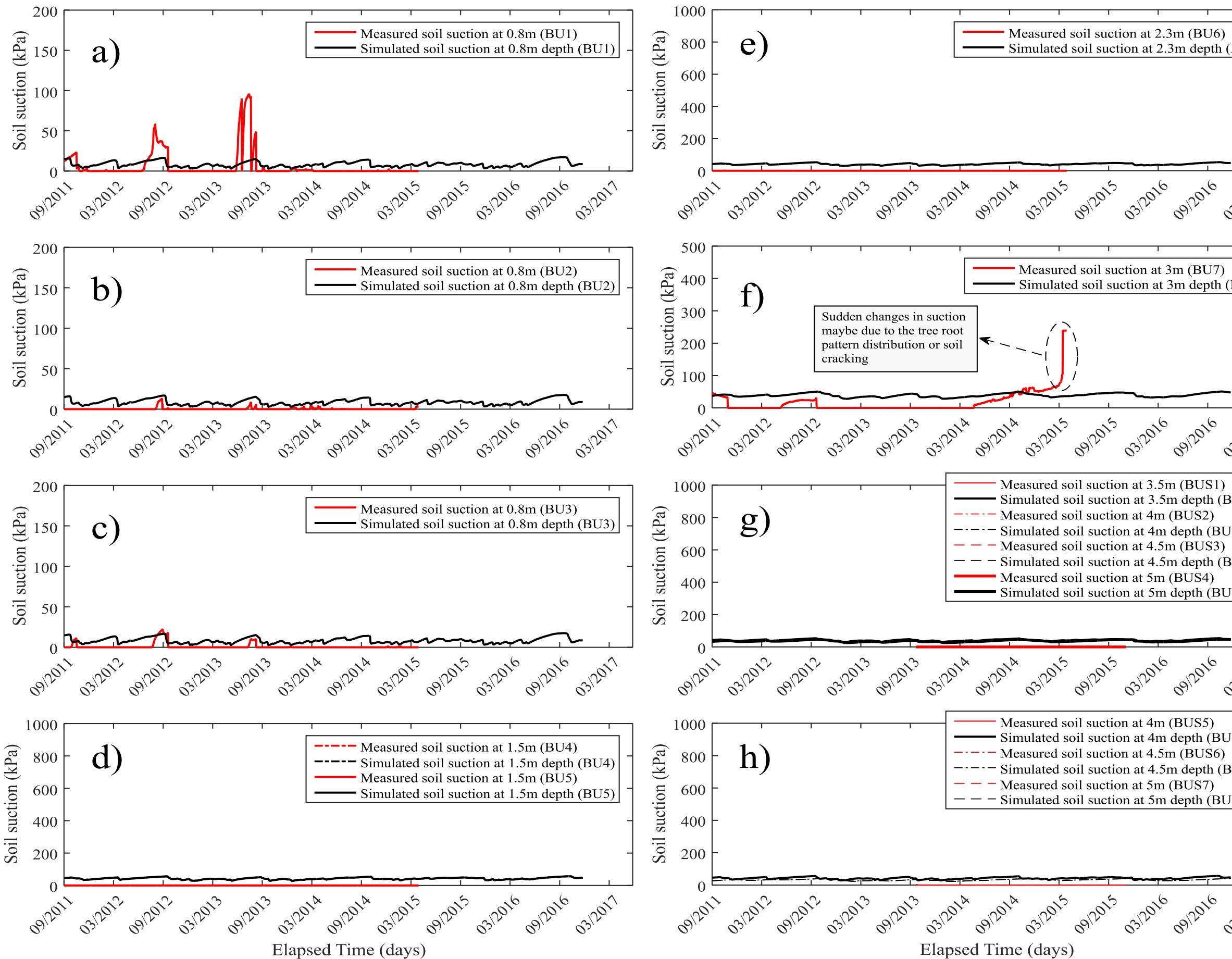
b)



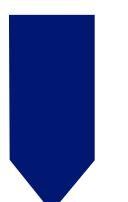
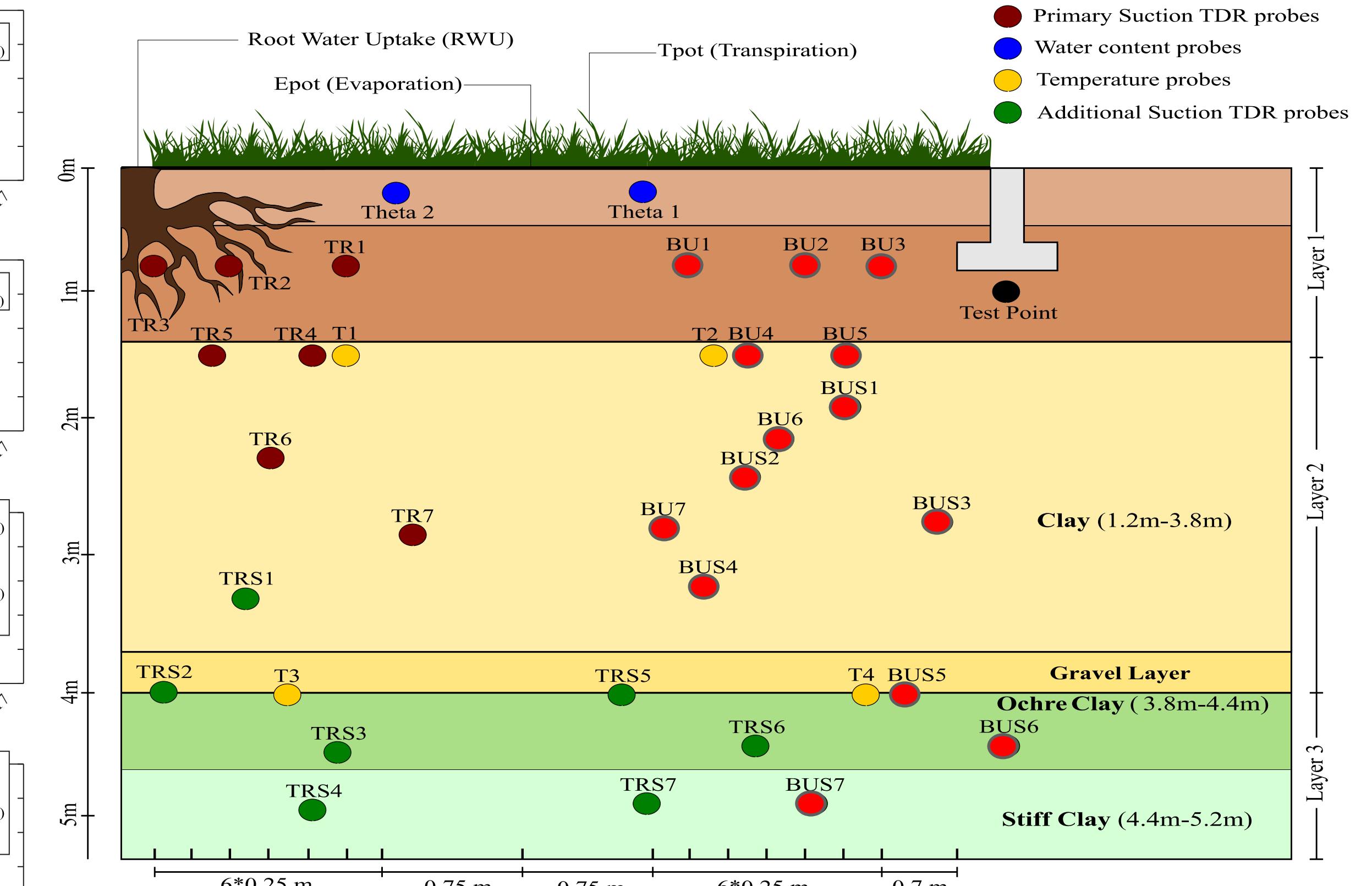
Application de l'approche : Comparaison entre les mesures in-situ et les prédictions de l'approche: (Succion- proche de l'arbre- Nord)



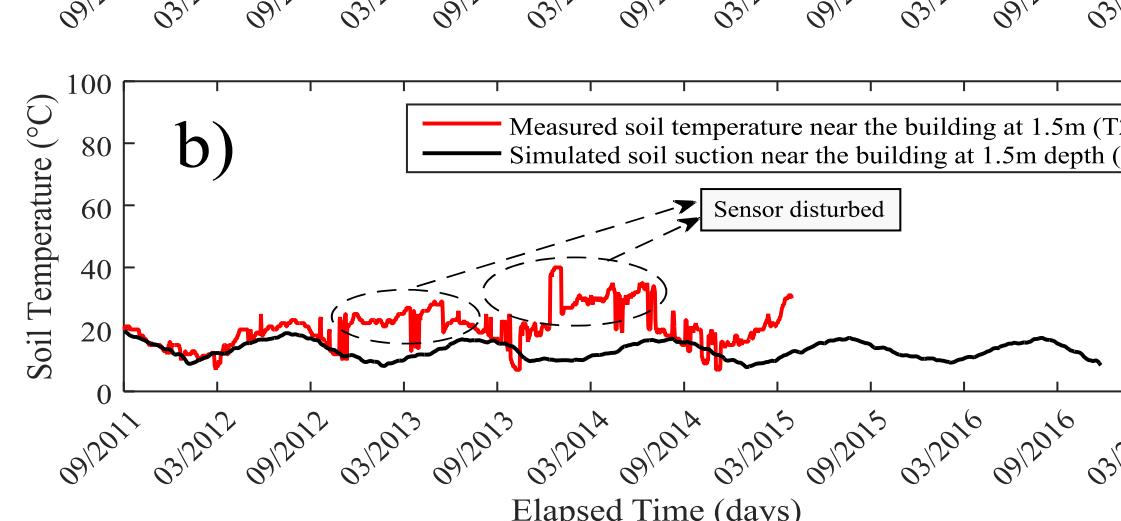
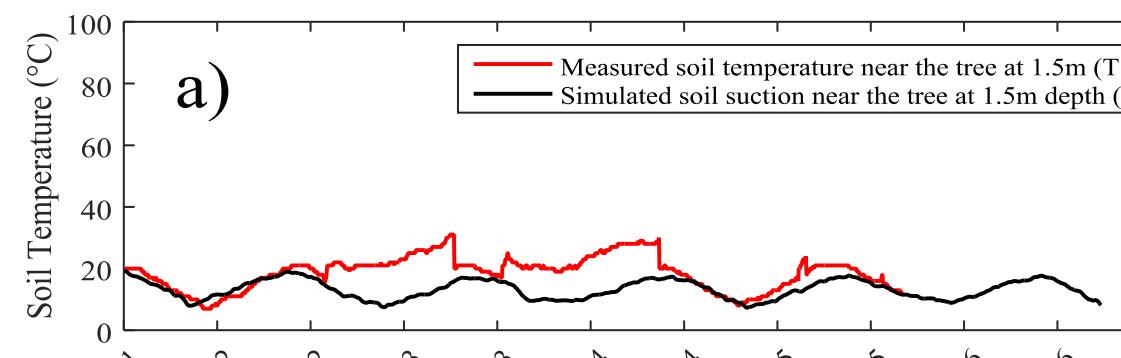
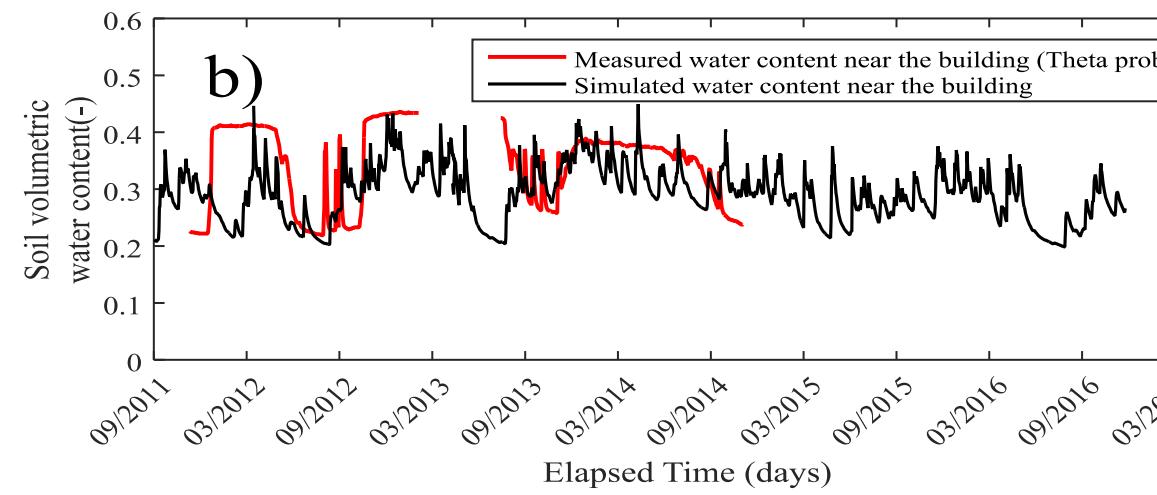
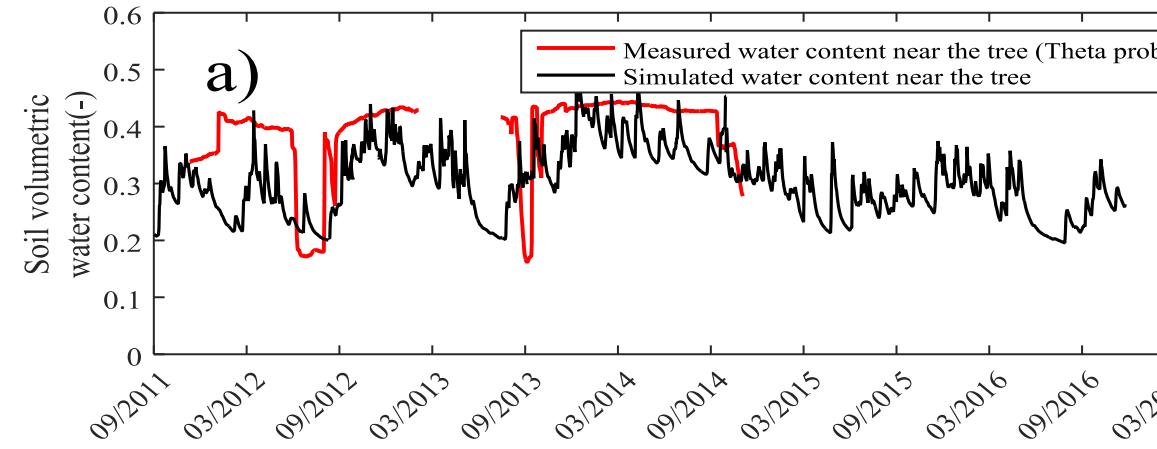
Application de l'approche : Comparaison entre les mesures in-situ et les prédictions de l'approche: (Succion- proche du bâtiment- Nord)



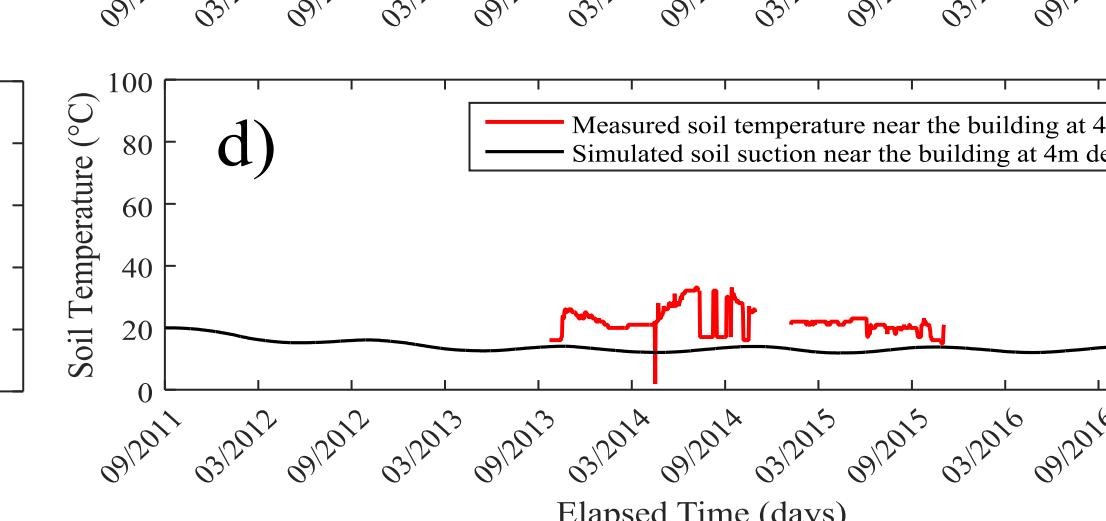
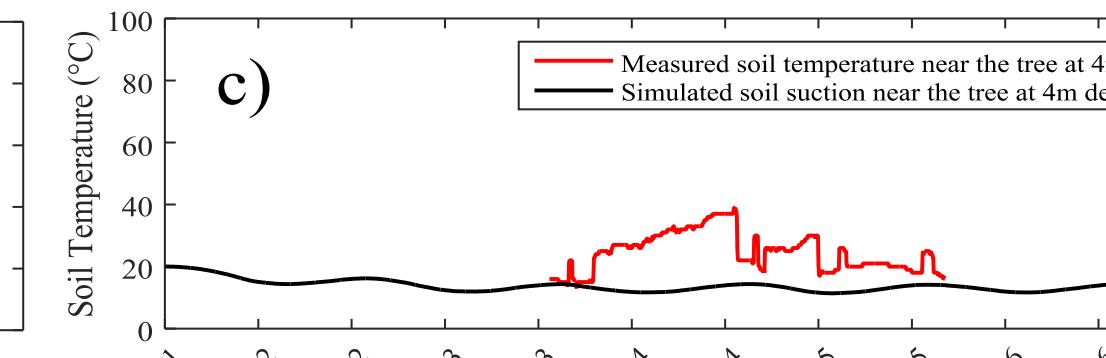
Suction close to the building.



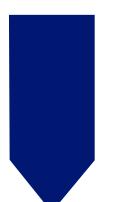
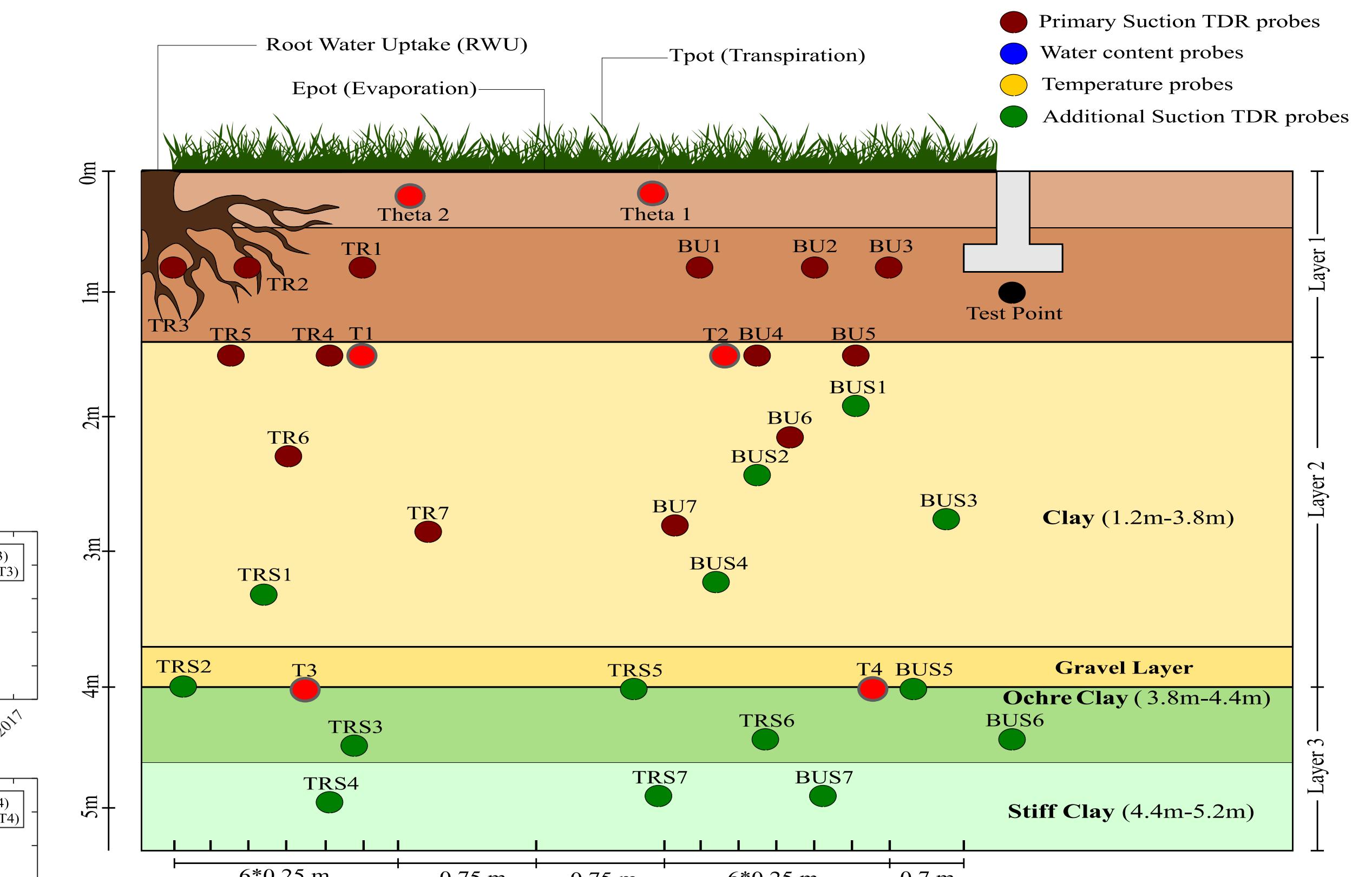
Application de l'approche : Comparaison entre les mesures in-situ et les prédictions de l'approche: (w% and température -Nord)



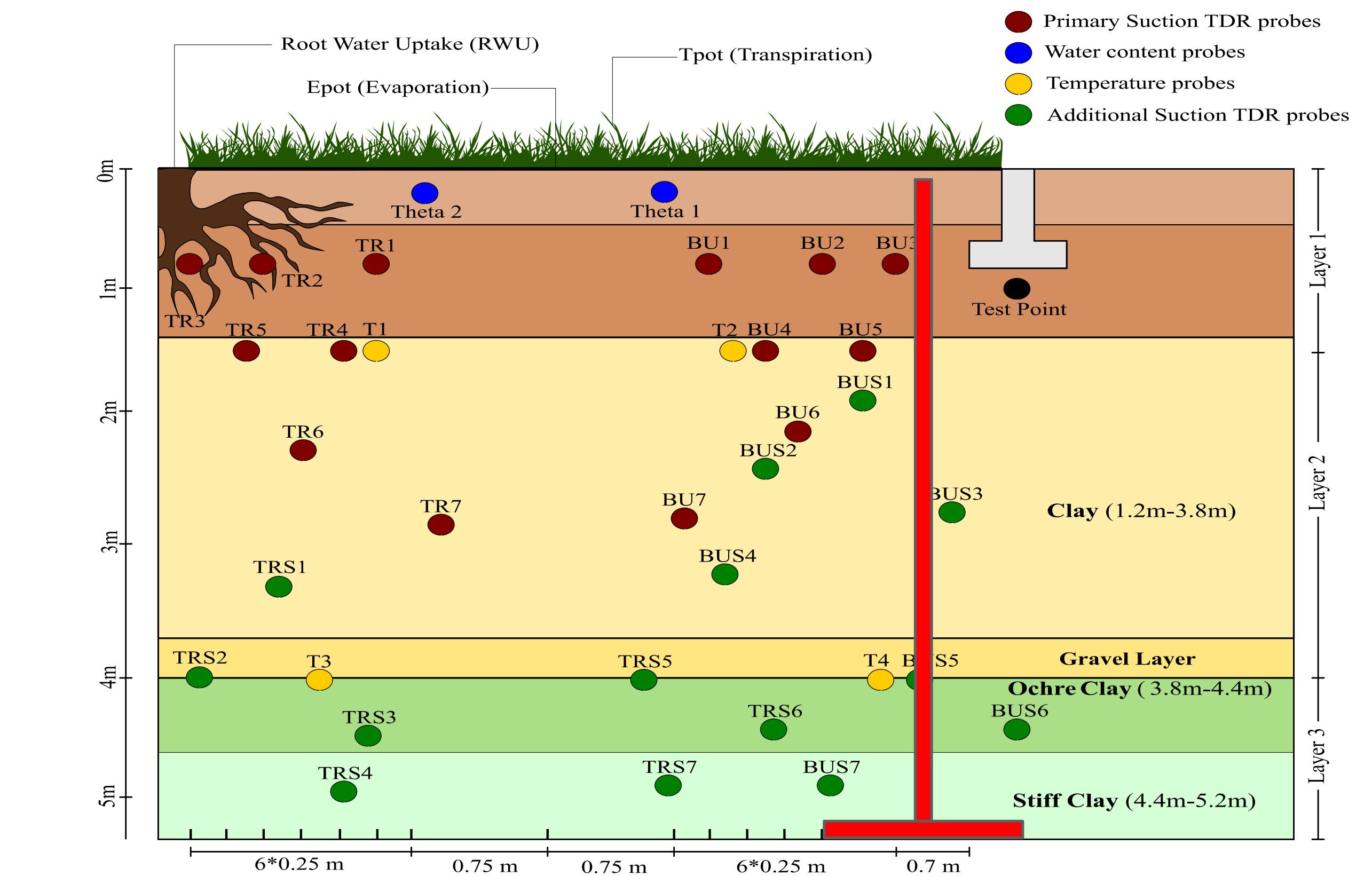
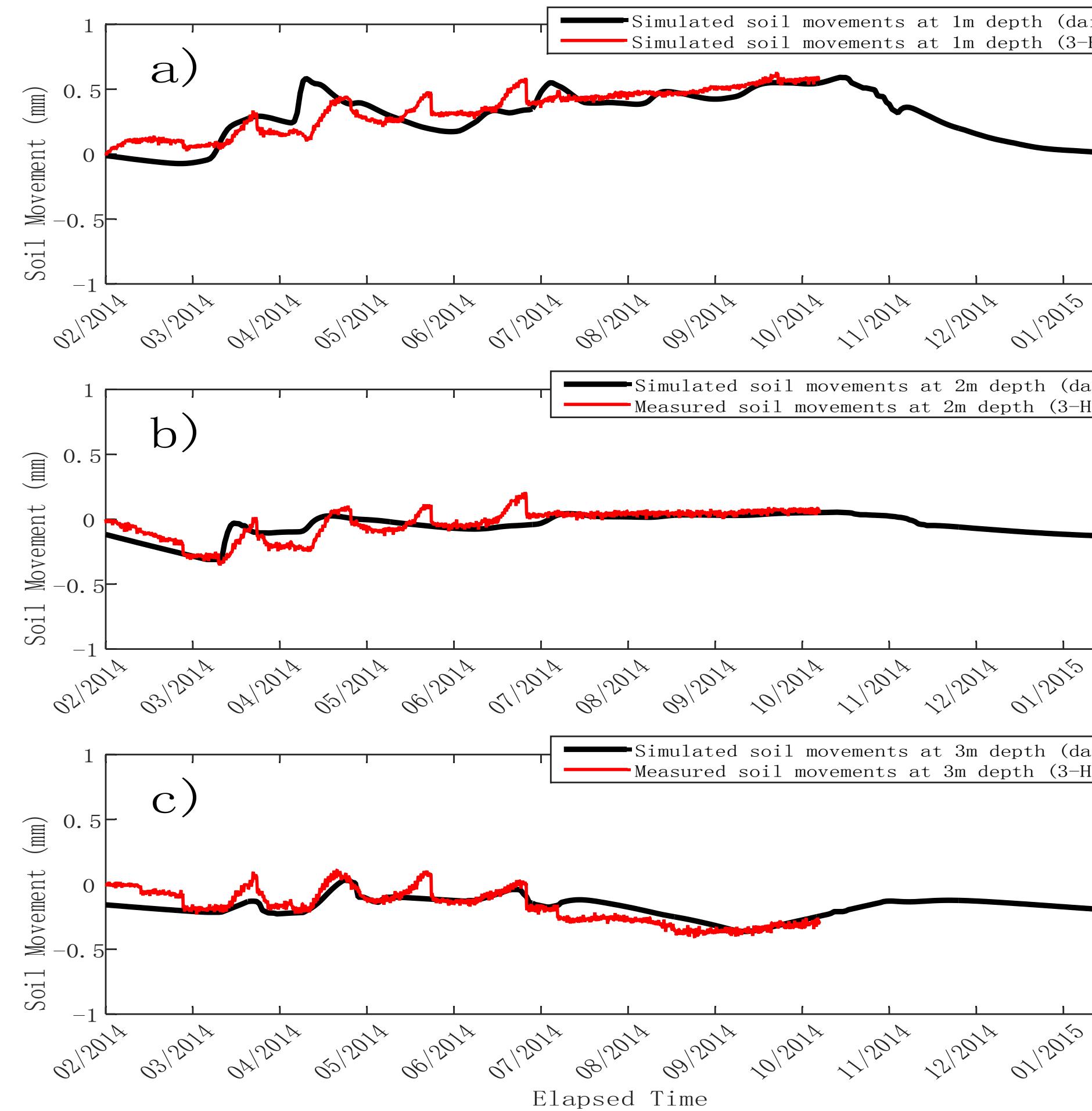
Volumetric water content



Temperature



Application de l'approche : Comparaison entre les mesures in-situ et les prédictions de l'approche: (Tassement - Nord)

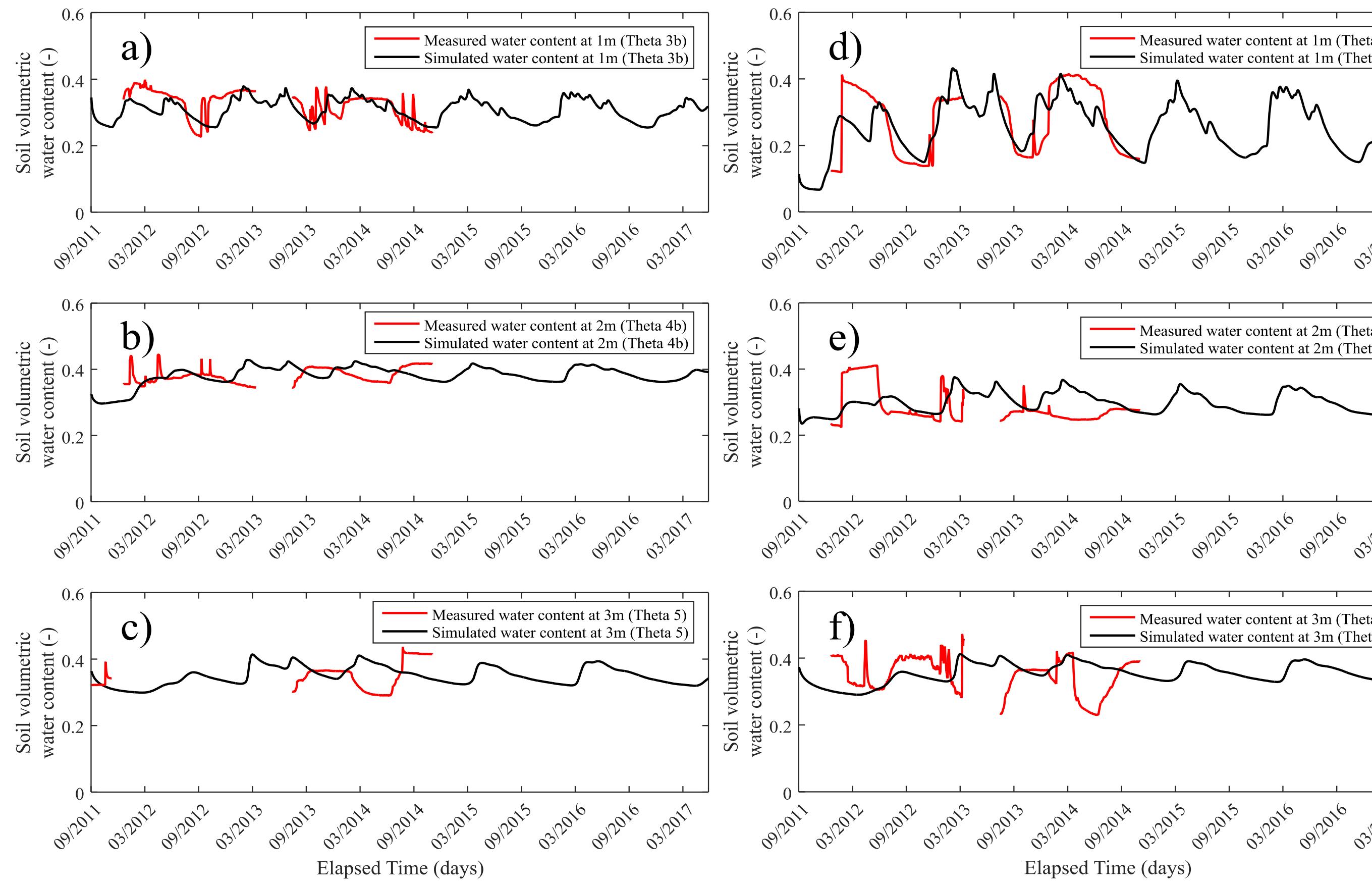


Soil settlement

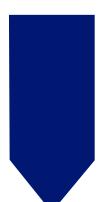
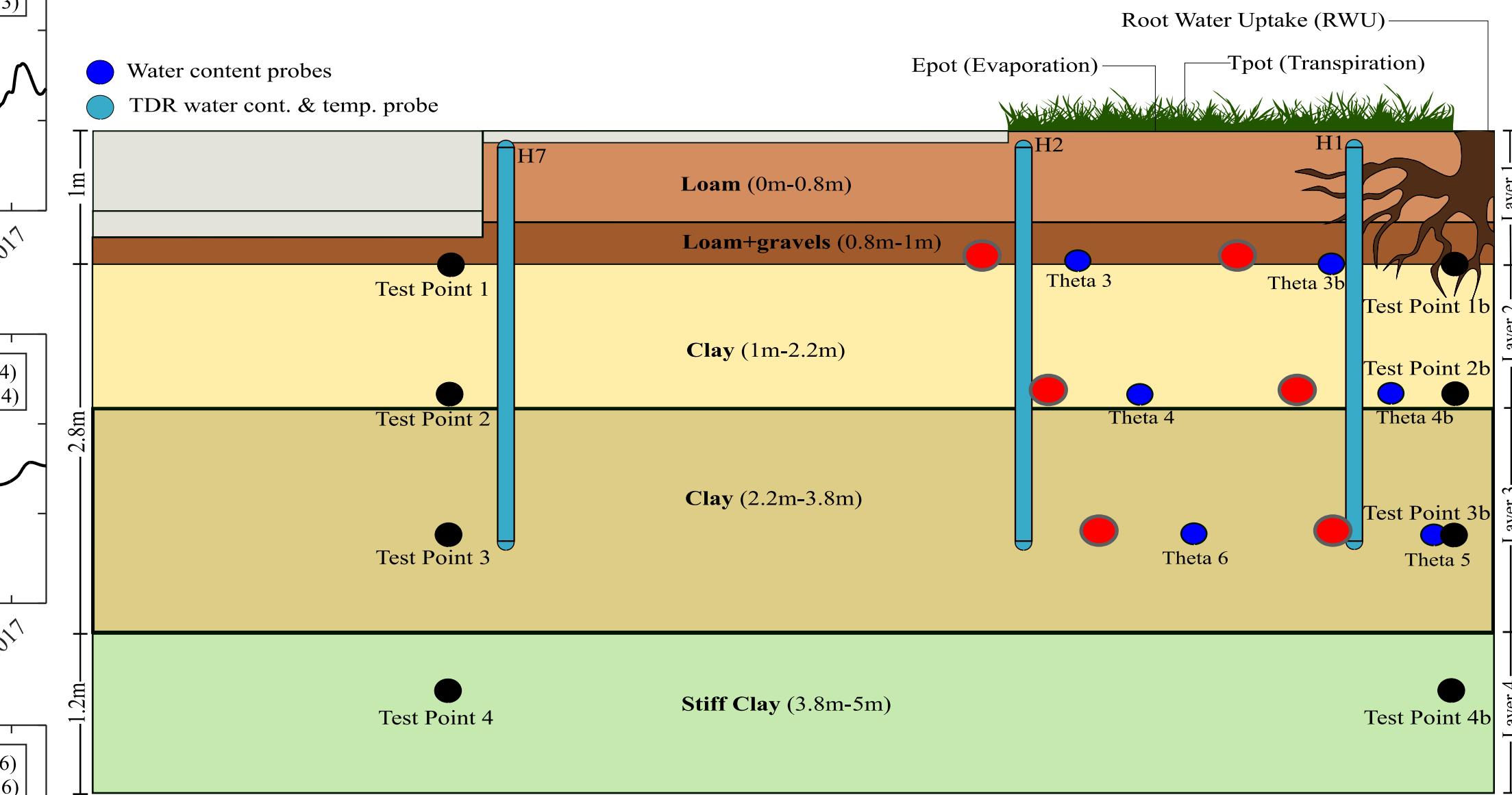


Application de l'approche :

Comparaison entre les mesures in-situ et les prédictions de l'approche: (w% - Sud)

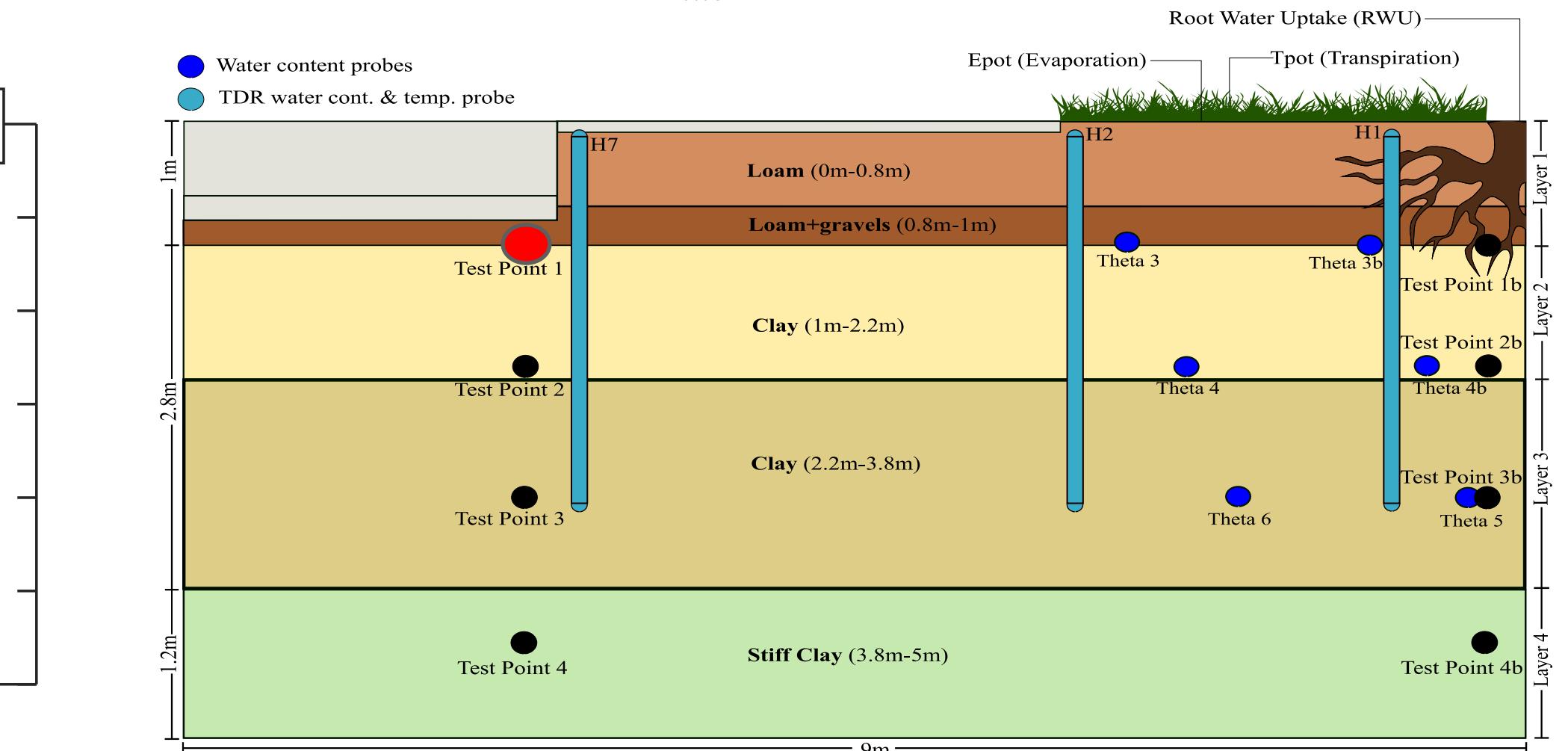
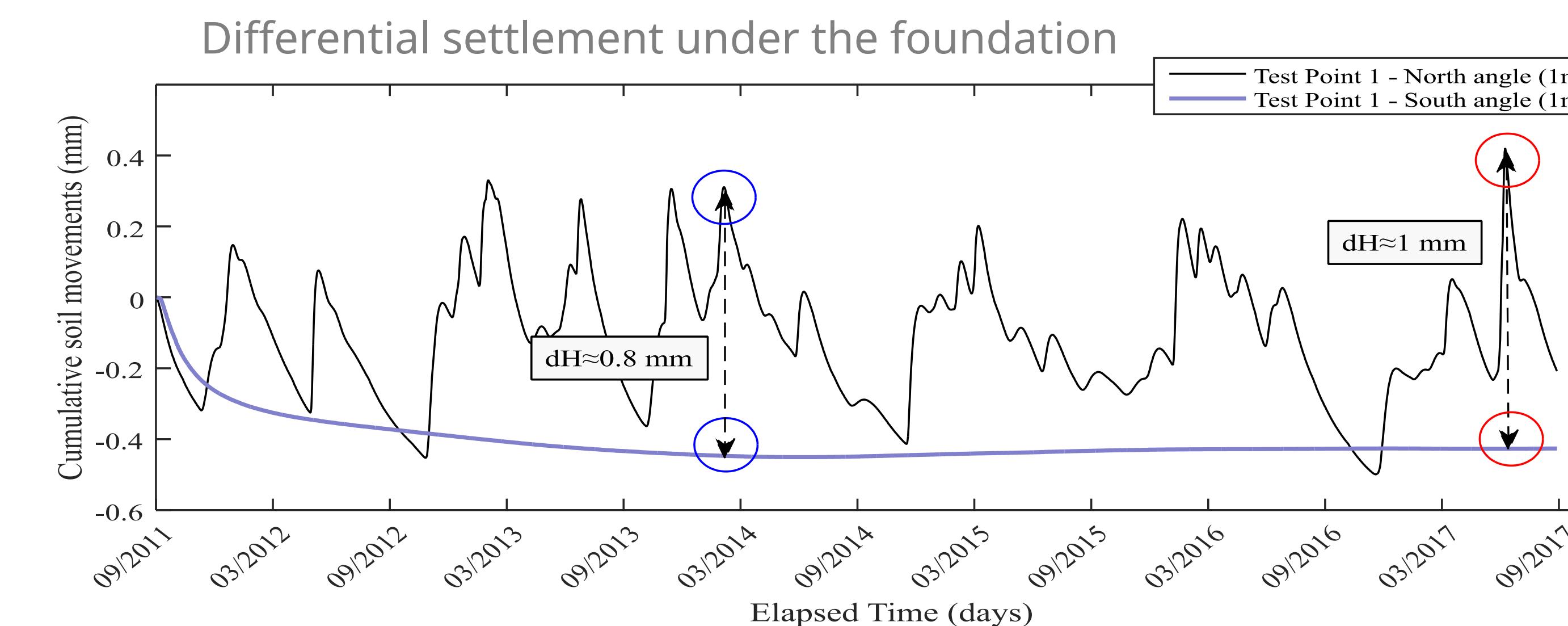
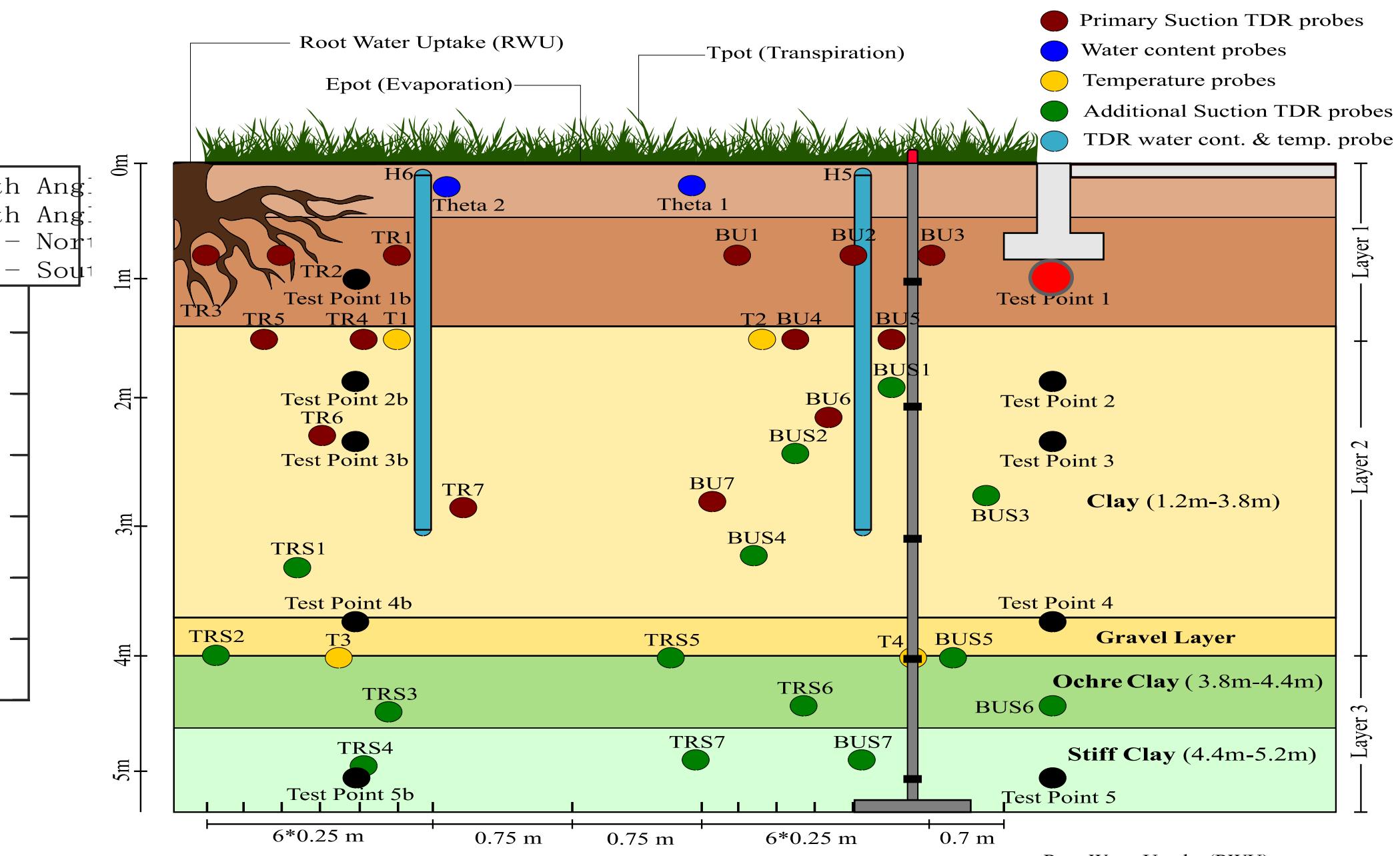
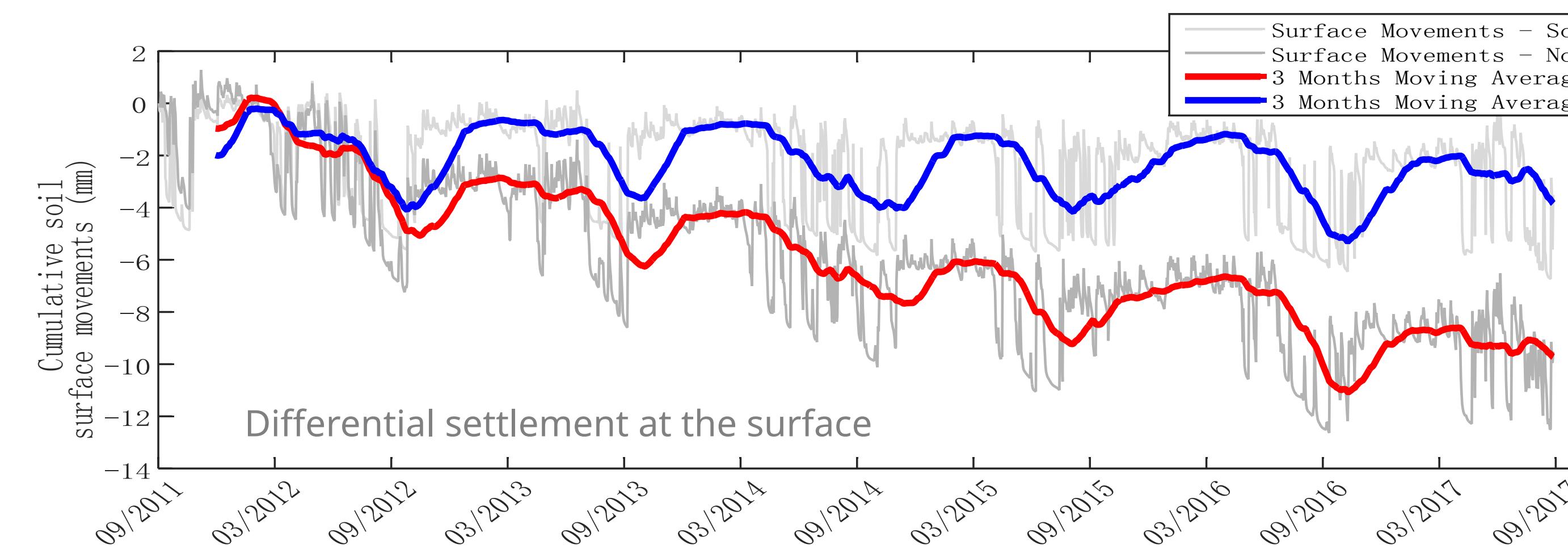


Volumetric water content – South angle



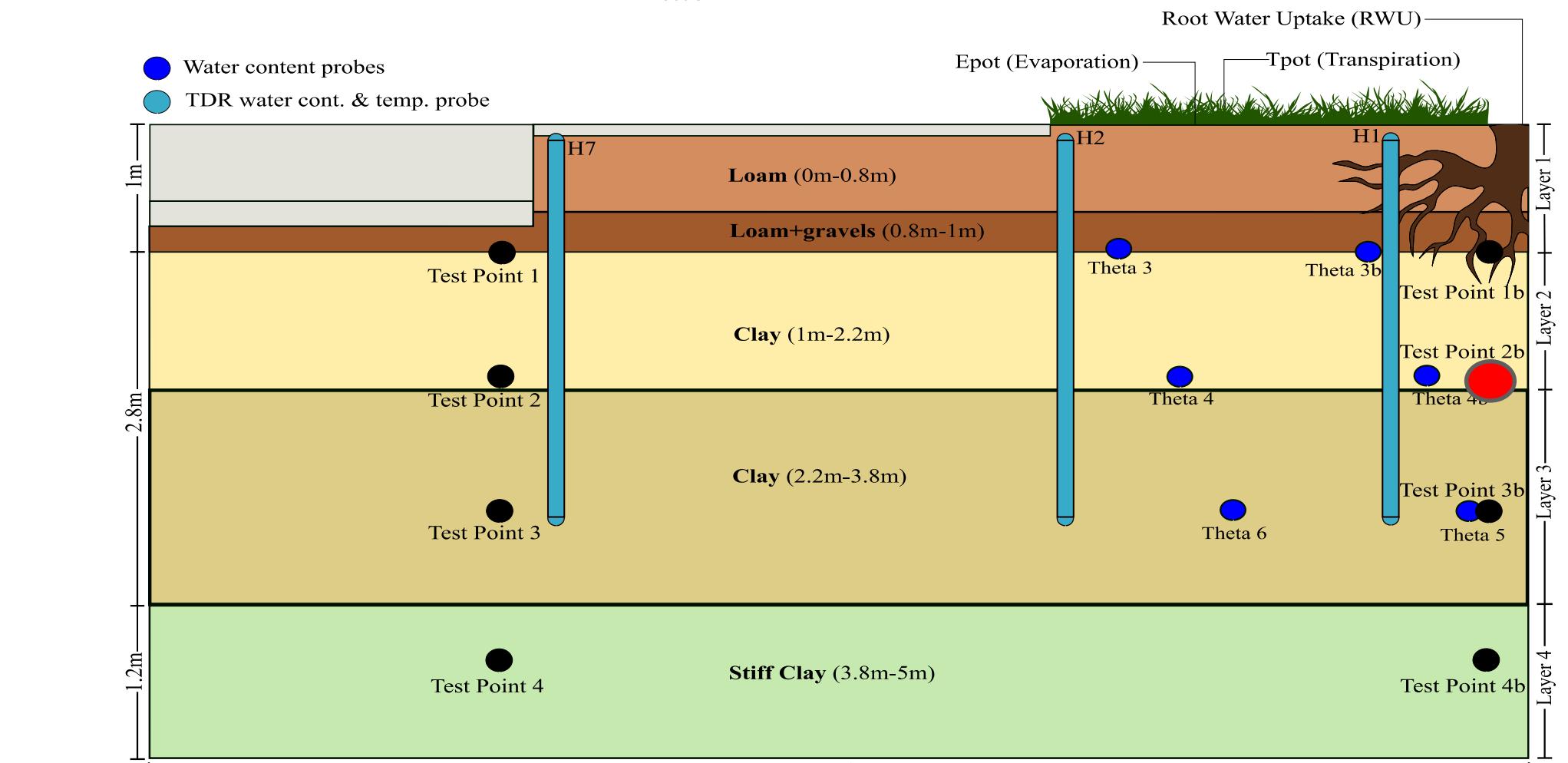
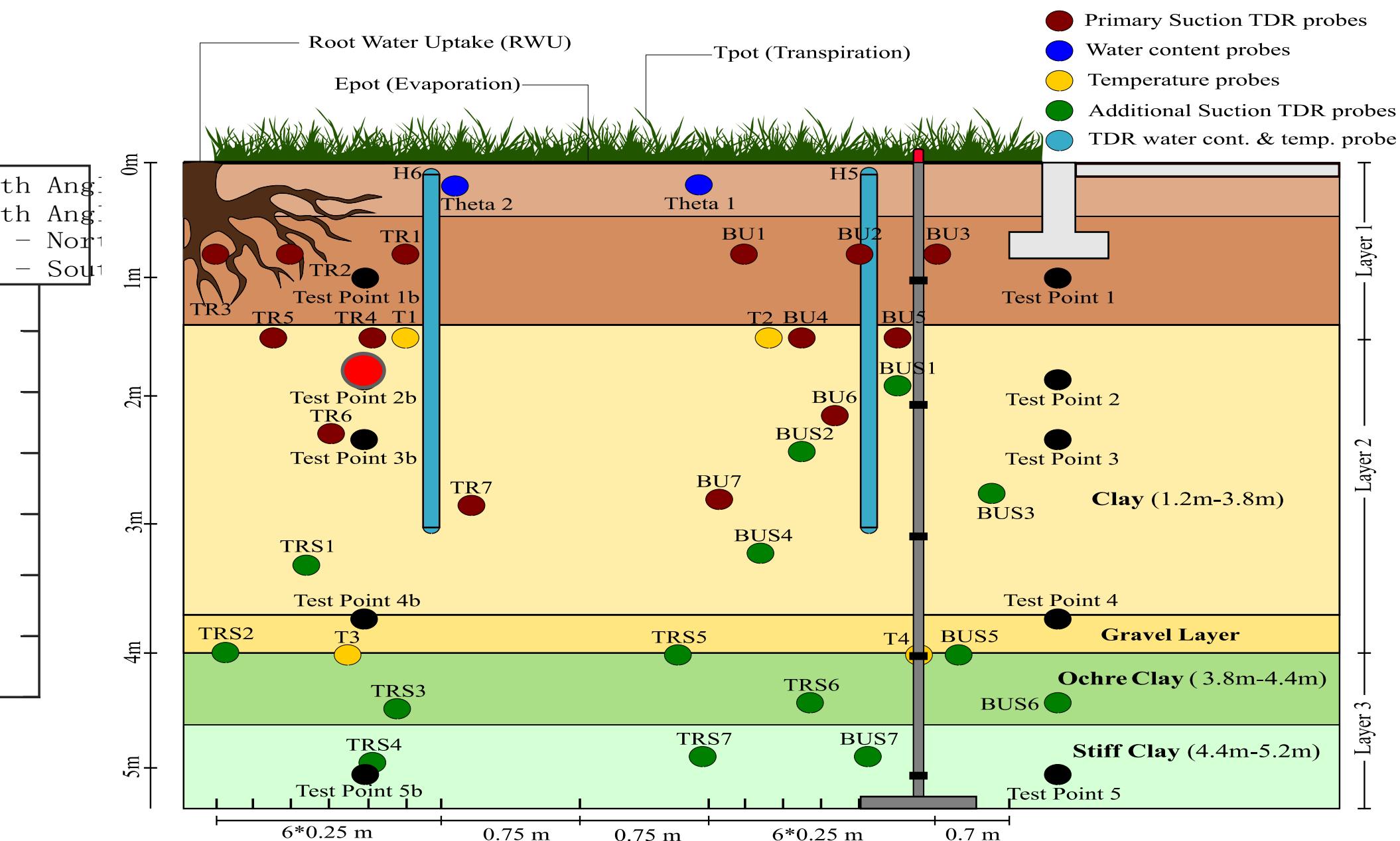
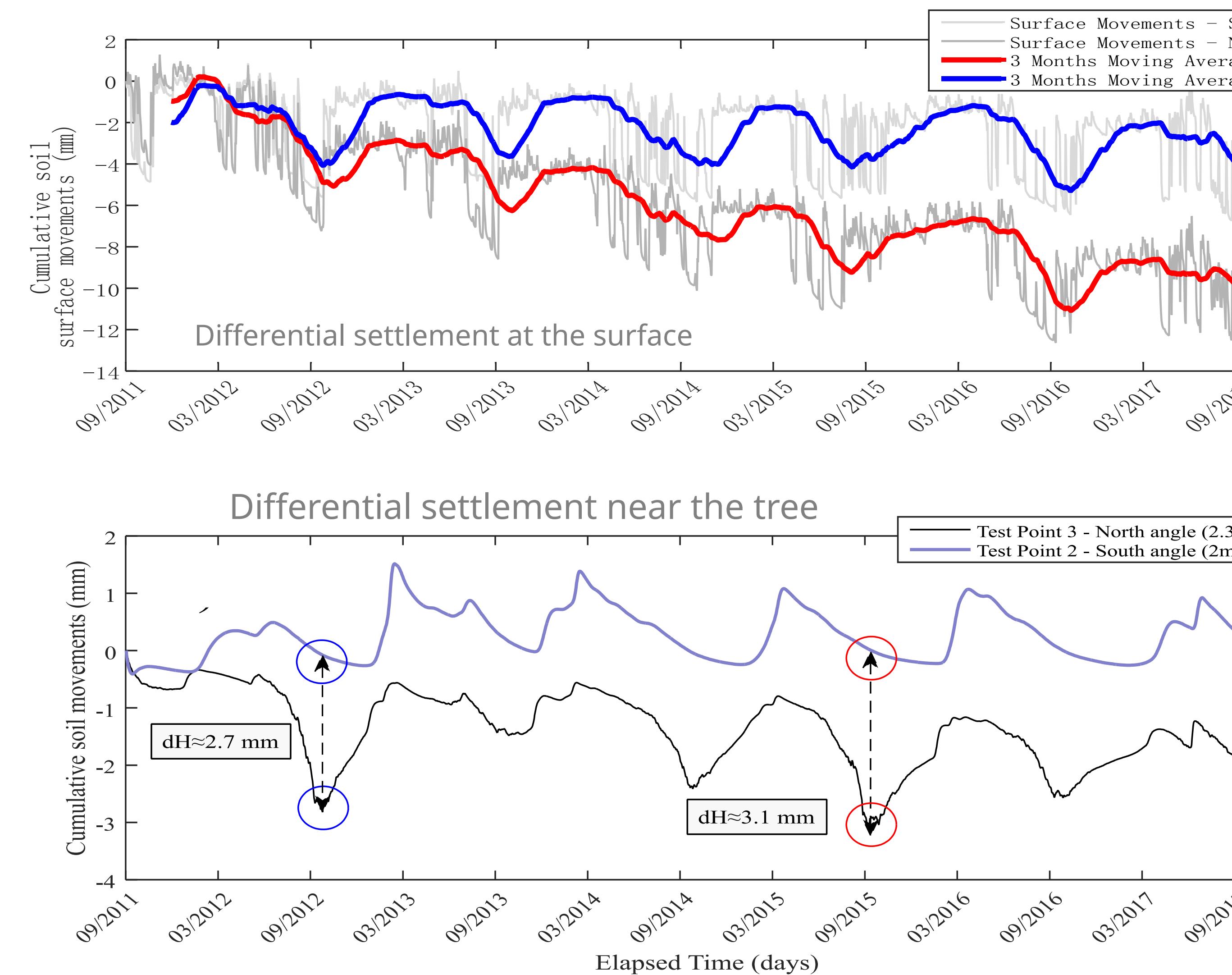
Application de l'approche :

Tassement différentiel (fondation):



Application de l'approche

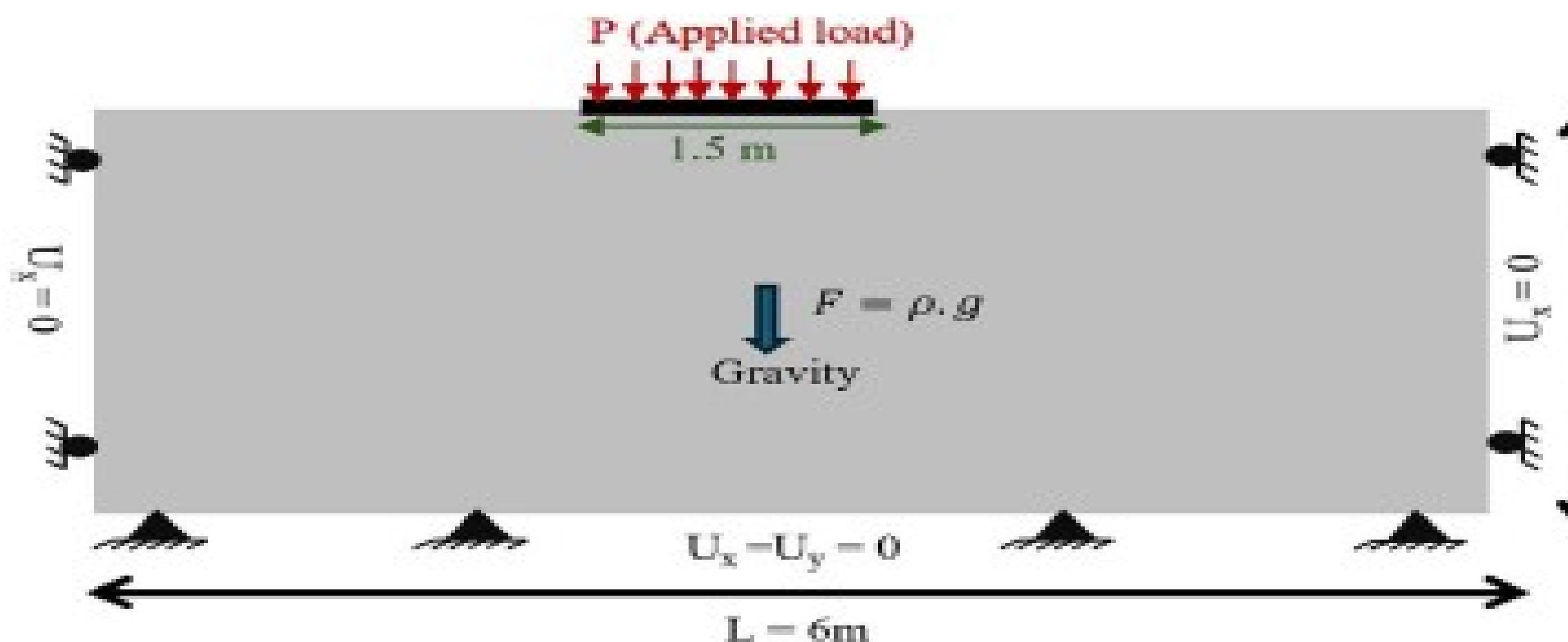
Tassement différentiel (arbre)



Conclusions :

- Une approche considérant l'interaction “sol-végétation-atmosphère” a été développée.
- L'approche numérique a été utilisée pour calculer le retrait/gonflement de site de Roaillan.
- Le tassement différentiel du site a été obtenu en considérant l'interaction “sol-végétation-atmosphère”.

Perspective :



Effondrement hydro-mécanique

