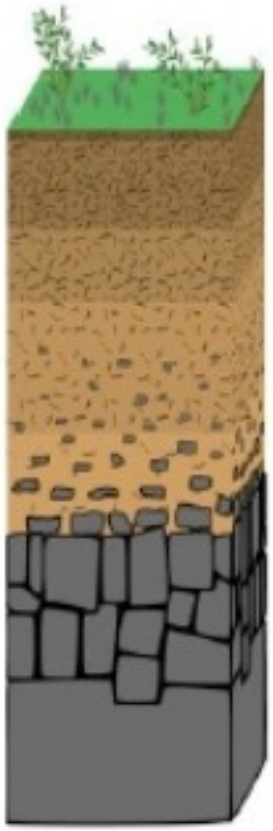
SPATIALIZATION OF SOIL MOISTURE FROM THE INVERSION OF DISTRIBUTED TEMPERATURE OBSERVATIONS STUDY SITE : DRAIX-BLÉONE

Kusnahadi Susanto[1,2], Jean-Phillipe Malet[1], Julien Gance[3], Vincent Marc[4]

[1]Institute de Physics du Globe de Strasbourg, CNRS UMR 7516/EOST – Université de Strasbourg, France
[2]Universitas Padjadjaran, Bandung, Indonesia
[3]IRIS-Instrument, Orléans, France
[4]Université d' Avignon et des Pays de Vaucluse, UFR-ip Sciences Technologies, Santé, France

BACKGROUND

The ability to monitor water infiltration and soil water content in the vadose zone of soils is a great importance for various hydrological, agronomical, ecological and environmental studies.



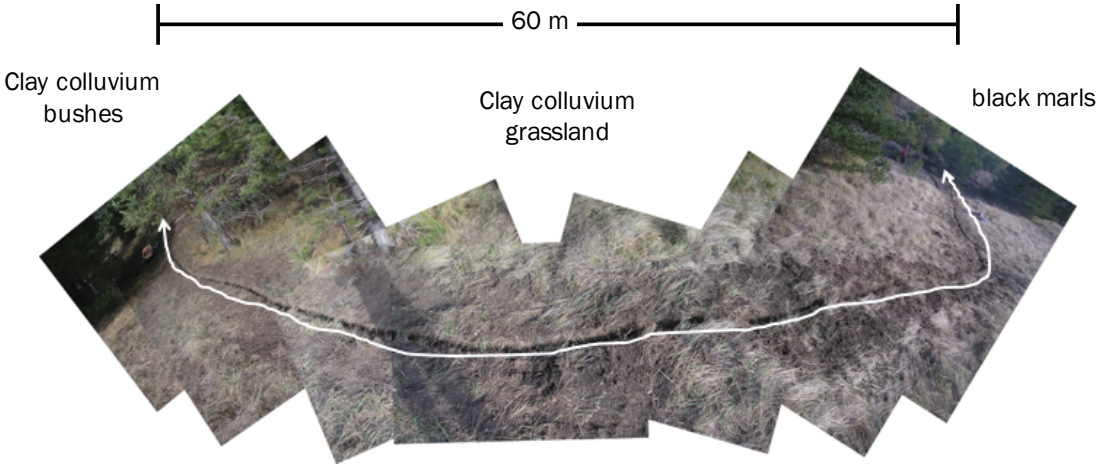
Water stocks are importance for a large range of topics : water resources, global hydrology and meteorology, natural hazard, erosion, pollutants transfers. They are generally more difficult to assess in clayey soils, where the hydrological response can be highly non-linear.

By using soil temperature measurements with Fiber-Optic Distributed Temperature Sensing (FO-DTS), we can indirectly estimate soil water changes at high spatial and temporal frequency

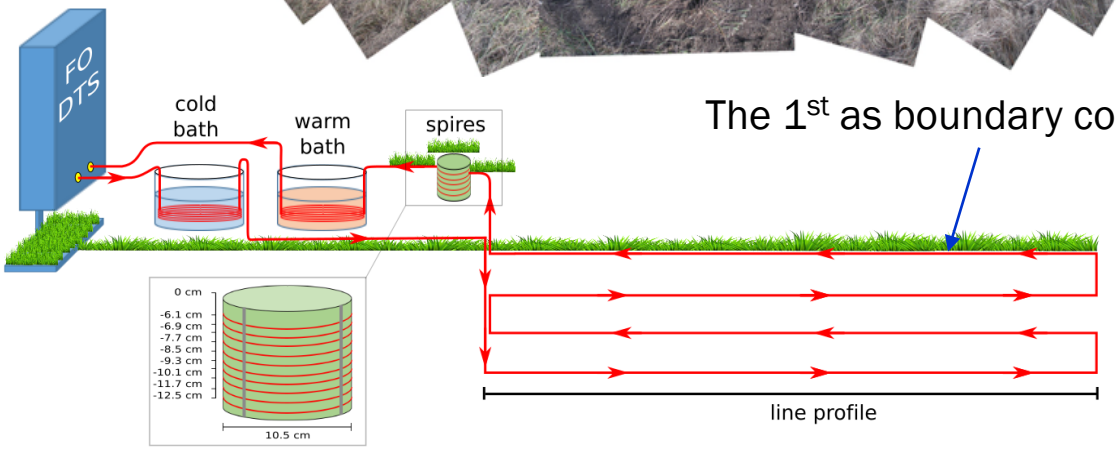
THE STUDY SITE

Draix-Bléone catchment, South French Alps

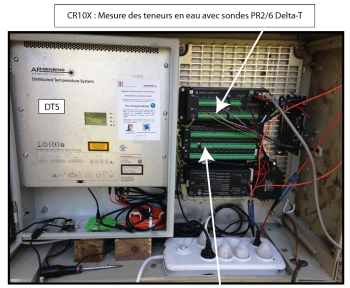
MEASUREMENT SETUP 1



6' collection

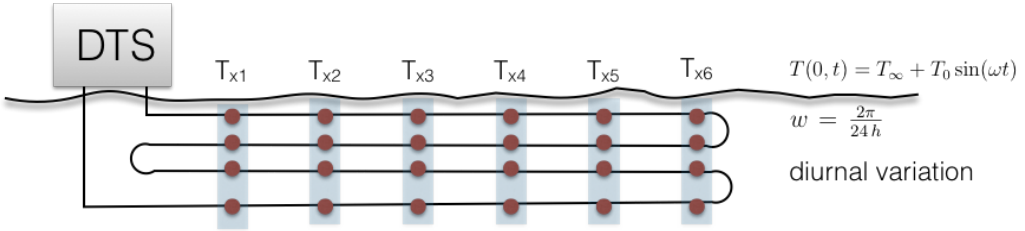


The 1st as boundary condition



Installation of FO cable: 60 m
- crossing 3 soil types
- 4 installation depths

- The instrument was installed on December 2015
- The instrument is still acquiring the data until now

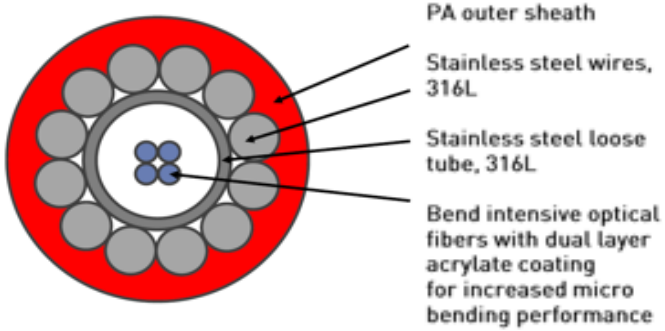


FIBER OPTIC INSTRUMENTATION

Digitizer :
AP Sensing linear ProSeries

Main technical characteristics :

- Single or double ended measurements
- Instrumental accuracy : 0.1°C
- Spatial resolution : 0.5 m
- Remote transfer and configuration
- Laser power 17 mW



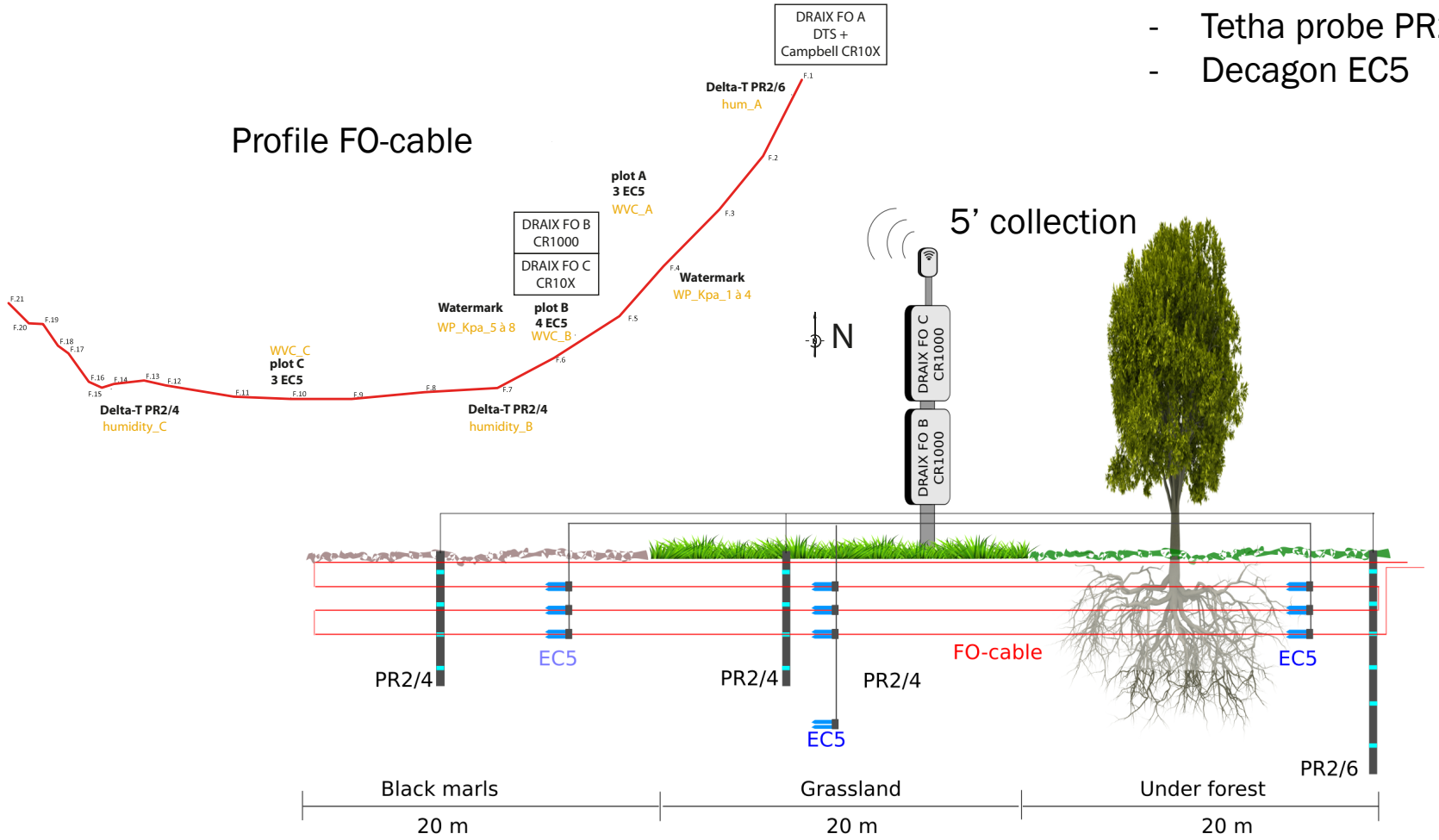
Fiber optic characteristics :

- S2015A : Sensor cable steel PA
- Ø fiber optics (2 mm)
- Very resistant fiber optic

MEASUREMENT SETUP 2

To measure soil moisture directly, some sensor were installed permanently for each soil type.

- Tetha probe PR2
- Decagon EC5

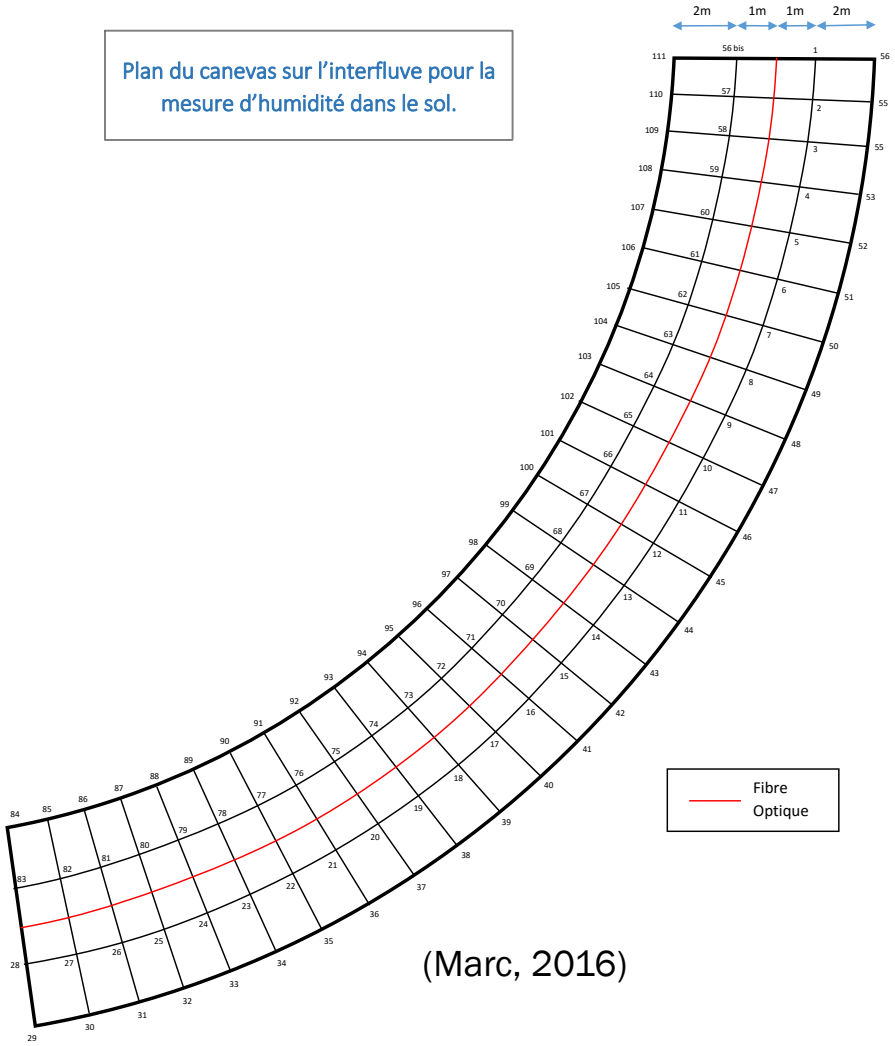


CAMPAIGN OBSERVATION

Avignon le 23/05/2016

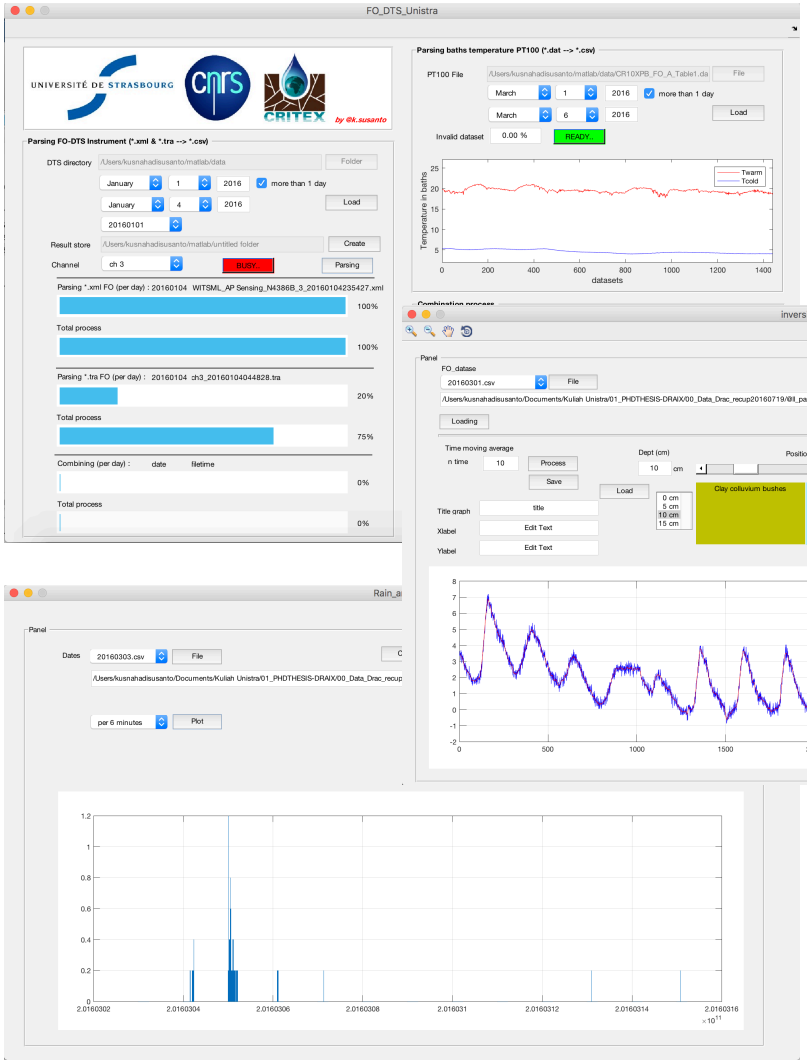
The other hand, direct humidity observation was measured by ML3 probe around fiber optic by colleague from Avignon (Martin, 2016)

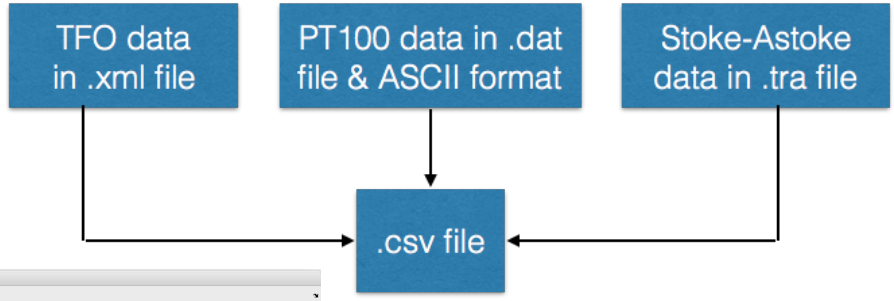
Plan du canevas sur l'interfluve pour la mesure d'humidité dans le sol.



(Marc, 2016)

SOFTWARE DEVELOPMENT





File format information:

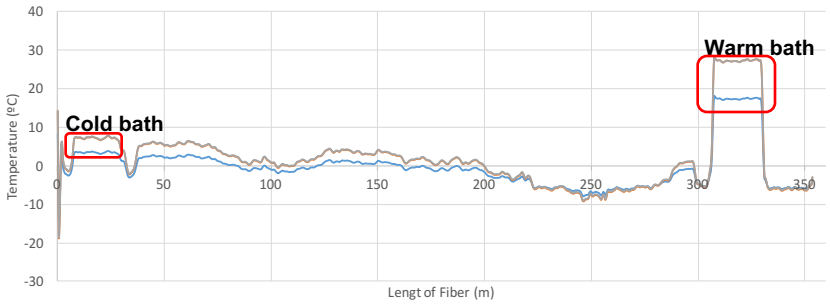
- The .xml files contain the uncorrected temperature The .dat files contain the temperature in baths as references expressed in ascii
- The .tra files contain the stoke-astoke to calculate ratio and γ in the correction steps.

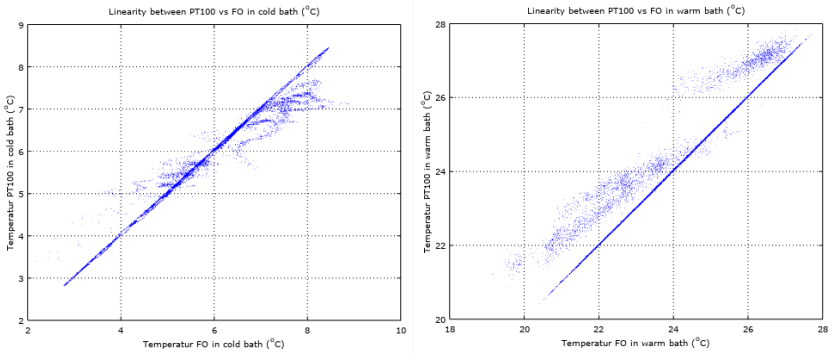
OBSERVATION & CORRECTION

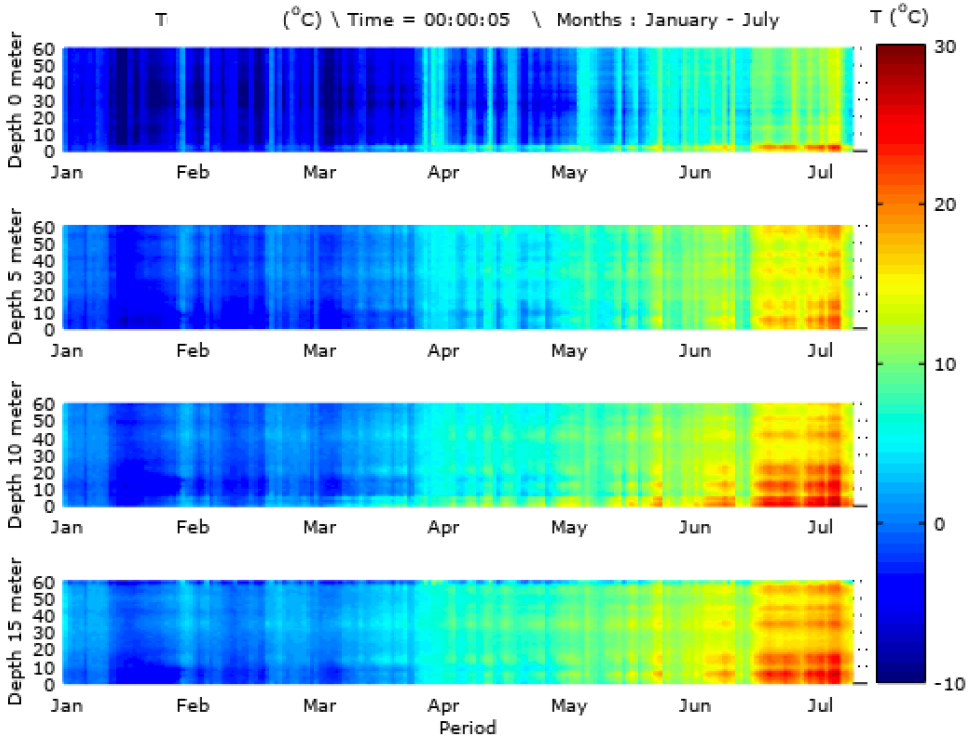
Temperature correction uses the reference baths as calibration and raw data (stoke-antistoke to calculate C(t) coefficient that changes over time (dynamic correction) (De Jong, 2015)

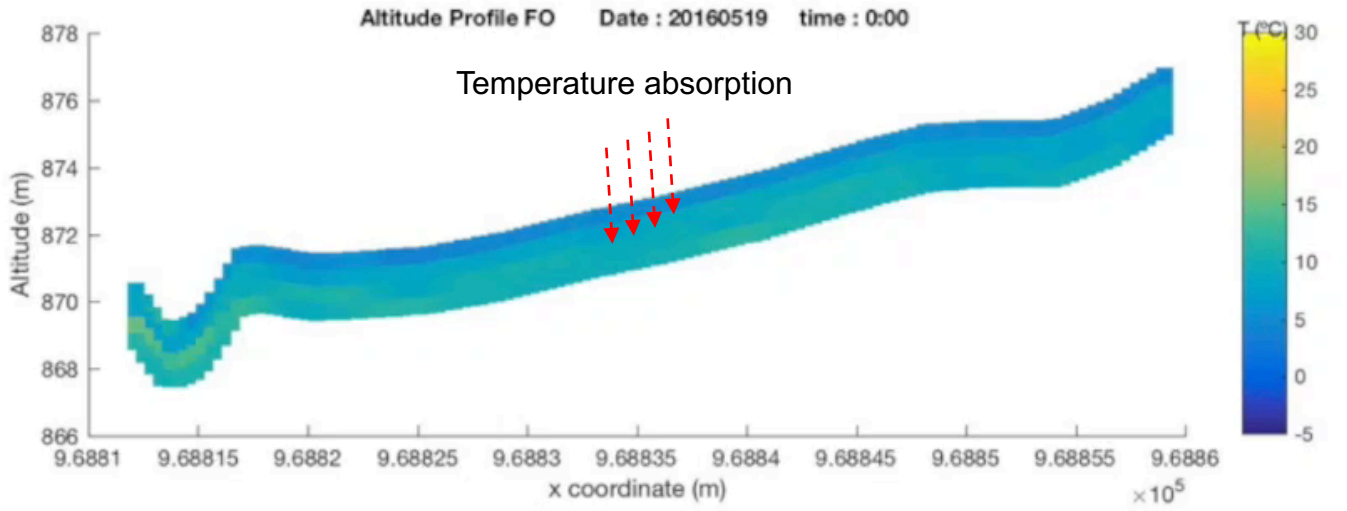
$$T(z,t) = \frac{\gamma}{\ln\left(\frac{P_S(z,t)}{P_{aS}(z,t)}\right) + C(t) - \int_0^z \Delta\alpha(z')dz'}$$ (Giesen 2012)

Data processing is started from Jan – Jul 2016



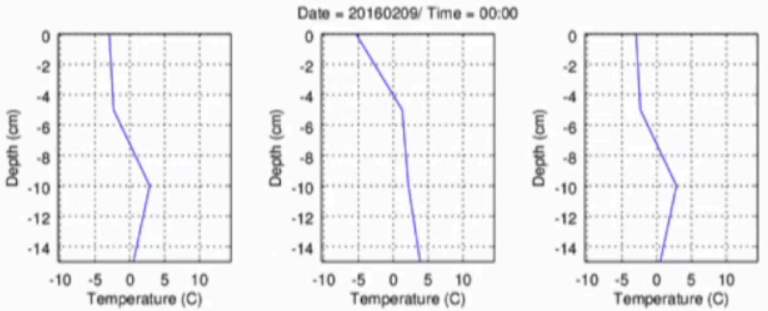


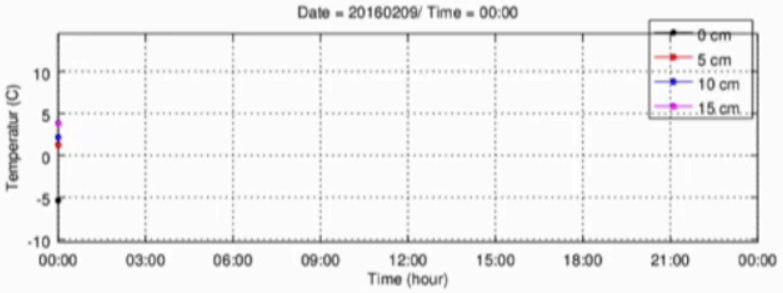




May 2016

Bushes grassland Balck marls

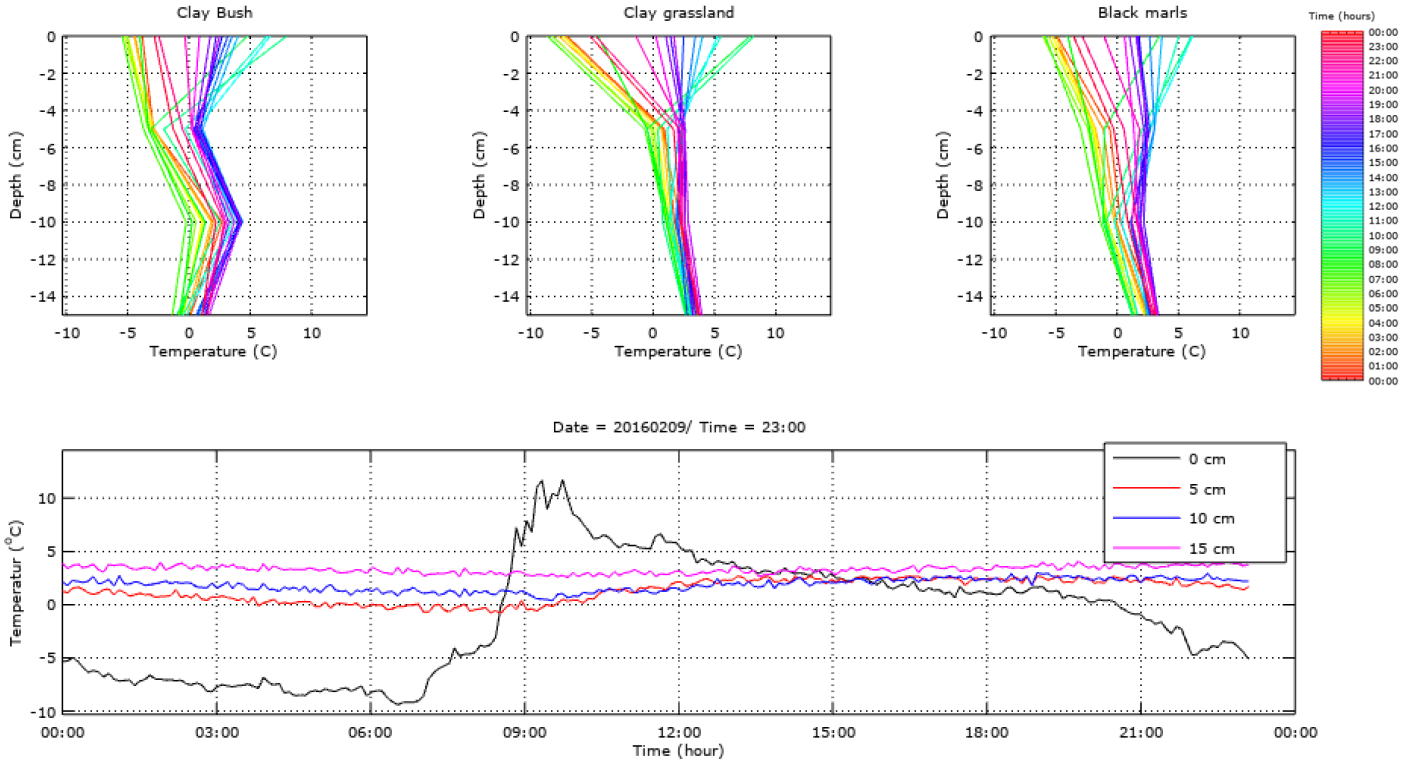




Whole day : February, 9 2016

EACH SOIL TEMPERATURE

The variability of temperature for whole day



DIFFUSIVITY & SATURATION CALCULATION STRATEGIES

The Strategies for estimating the diffusivity are :

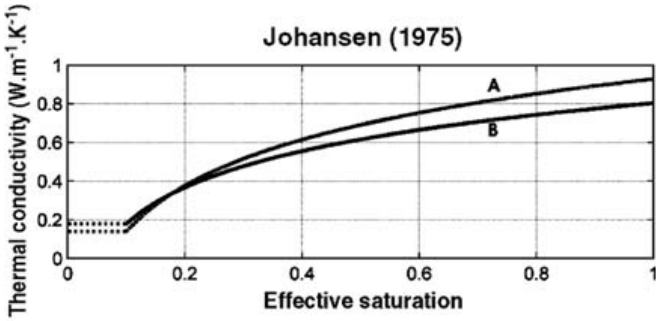
- Amplitude analysis (Krzeminska 2011, Durigon 2012)

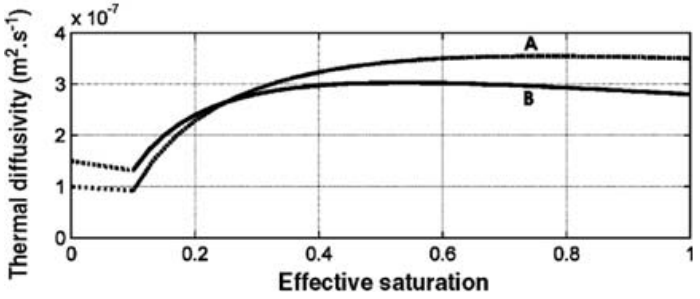
$$D = \frac{\pi}{\tau}\left(\frac{z_2 - z_1}{\ln\left(A_1 / A_2\right)}\right)^2$$

- 1D inversion by Finite Difference calculation (Ukrainczyk, N., 2009)

$$\frac{\partial T}{\partial t} = \kappa \frac{\partial^2 T}{\partial z^2} \qquad \frac{(T_{t+1} - T_t)}{\Delta t} = \kappa \frac{(T_{z-1,t} - 2T_{z,t} + T_{z+1,t})}{\Delta z^2}$$

Johansen model (1975) & Kersten coefficient is used to estimate soil water content (Behagael 2007, Steel dunne 2010, Krzeminska 2011)



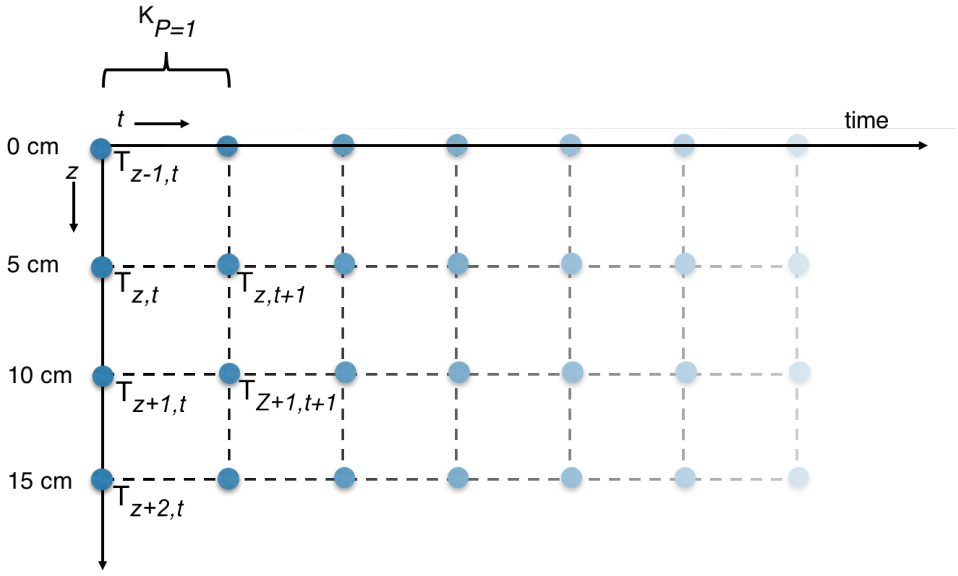


ESTIMATING DIFFUSIVITY BY FINITE DIFFERENCE

1D Finite difference to estimate the diffusivity

$$\begin{bmatrix} \frac{(T_{z,t+1}-T_{z,t})}{\Delta t} \\ \frac{(T_{z+1,t+1}-T_{z+1,t})}{\Delta t} \\ \vdots \\ \frac{(T_{n-1,t+1}-T_{n-1,t})}{\Delta t} \end{bmatrix}_p = \kappa_p \begin{bmatrix} \frac{(T_{z-1,t}-2T_{z,t}+T_{z+1,t})}{\Delta z^2} \\ \frac{(T_{z,t}-2T_{z+1,t}+T_{z+2,t})}{\Delta z^2} \\ \vdots \\ \frac{(T_{n-2,t}-2T_{n-1,t}+T_{n,t})}{\Delta z^2} \end{bmatrix}_p$$

$p=1,2,3...n$ p is time step



Heat equation

$$\frac{\partial T}{\partial t} = \kappa \frac{\partial^2 T}{\partial z^2}$$

$$\frac{(T_{t+1}-T_t)}{\Delta t} = \kappa \frac{(T_{z-1,t}-2T_{z,t}+T_{z+1,t})}{\Delta z^2}$$

Initial condition

$$T(z,0)=T_0(z)$$

Boundary condition

$$T(0,t)=T_0(0,t)+T\sin(\omega t+\phi)$$

Heat parameters

$$\kappa = \lambda / C$$

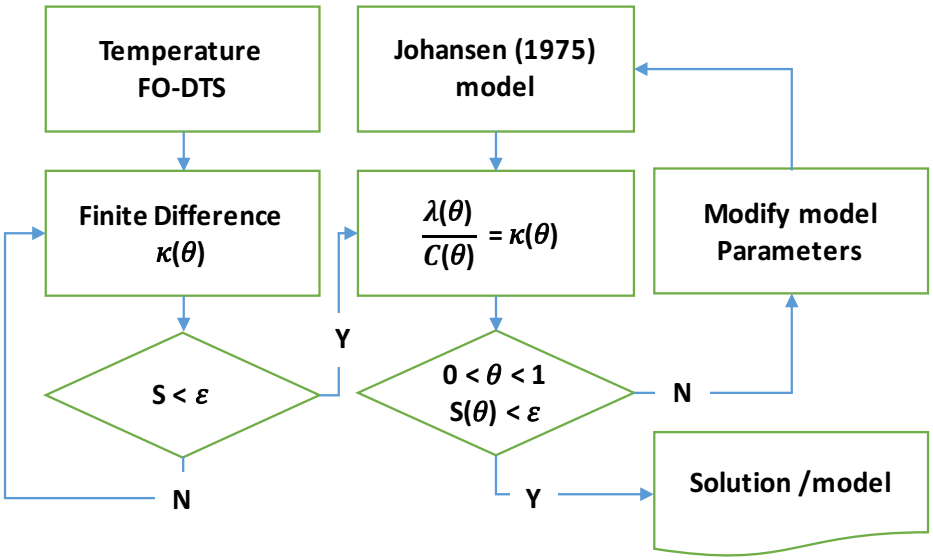
$$C = (1-n).C_{\text{solid}} + \theta.C_{\text{w}}$$

Johansen model (1975) & Kersten coefficient :

$$\lambda = Ke(\lambda_s-\lambda_{\text{d}}) + \lambda_{\text{s}}$$

$$Ke = \log_{10}S_{\text{r}} + 1 \quad \text{for } S_{\text{r}}>0.1$$

PROCESSING

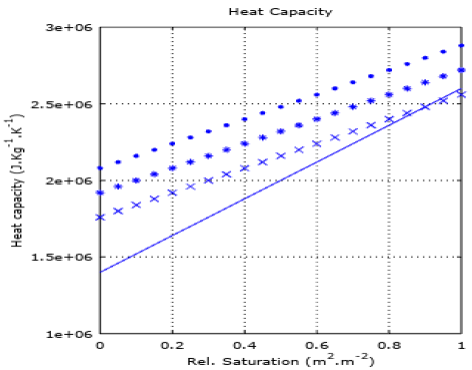


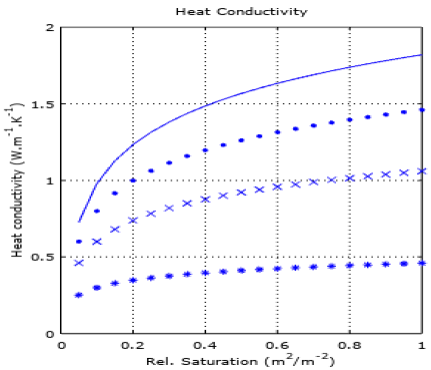
The parameters of model are modified based on thermal properties of clay (dry and saturated). The site is dominated by clay.

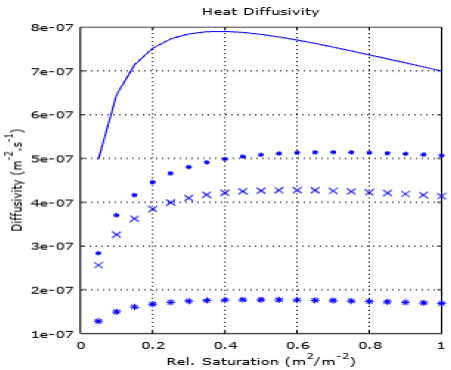
The parameters of model are:

- Ø = 20 – 35 %
- Hc = 1.4 – 2.7 $MJ.m^{-3}.K^{-1}$
- Cd = 0.6 – 0.8 $W.m^{-1}.K^{-1}$
- Cs = 1.6 – 1.98 $W.m^{-1}.K^{-1}$

(Krzeminska, 2011)

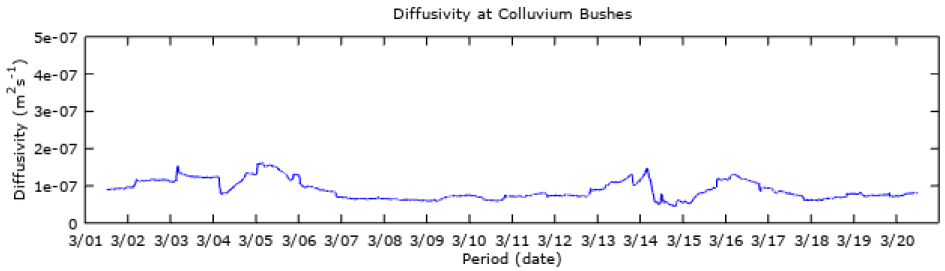


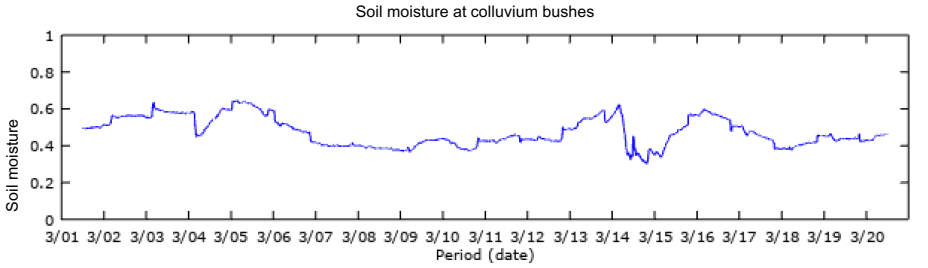


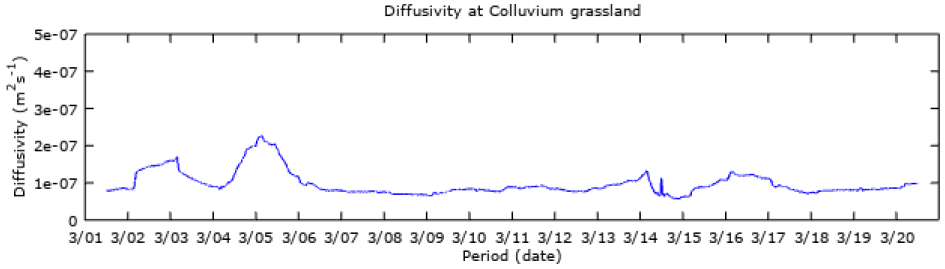


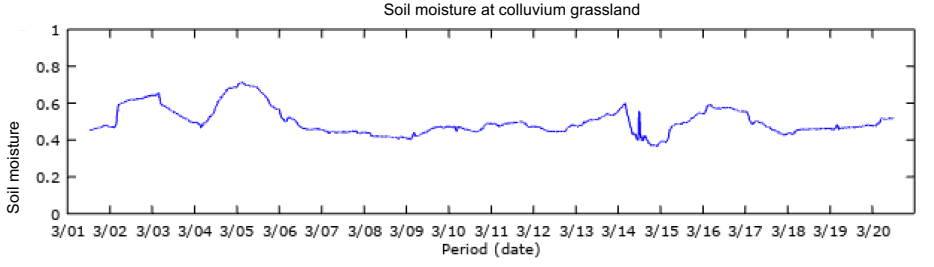
DIFFUSIVITY & SOIL MOISTURE

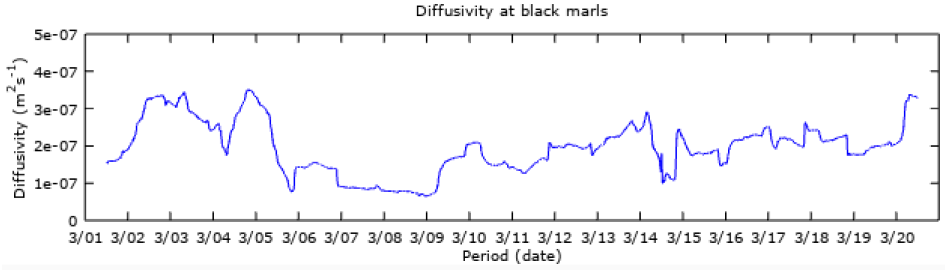
Diffusivity & soil moisture for each soil type over time

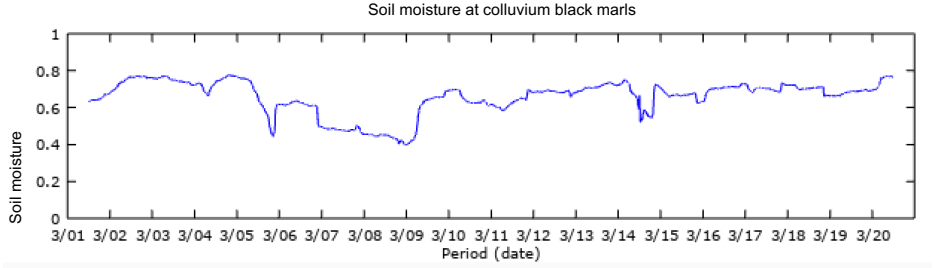




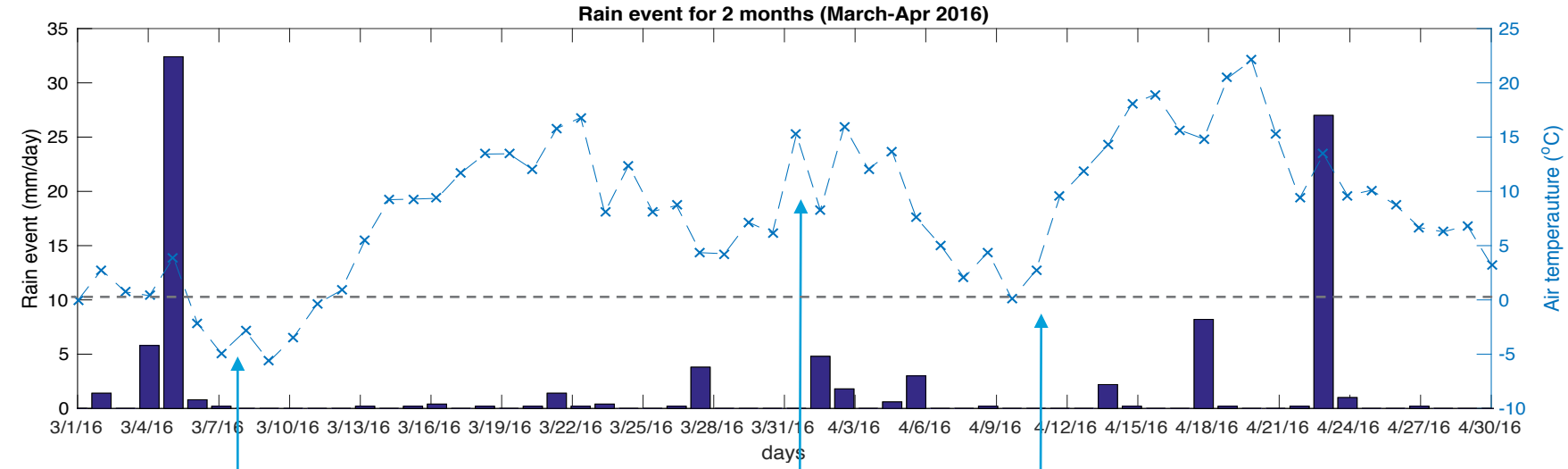


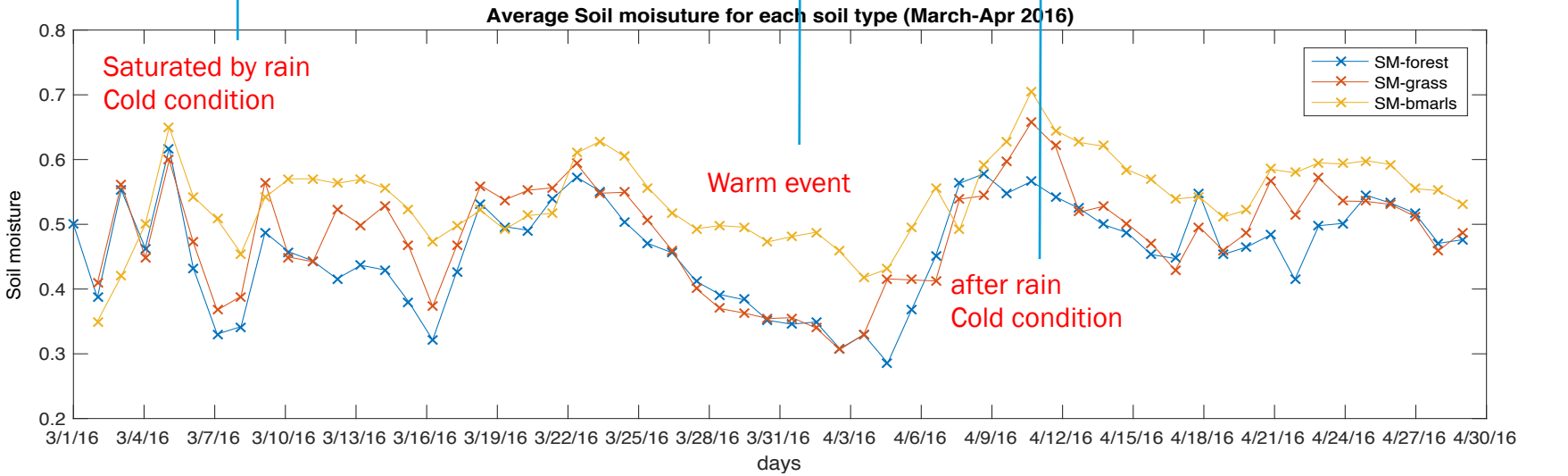






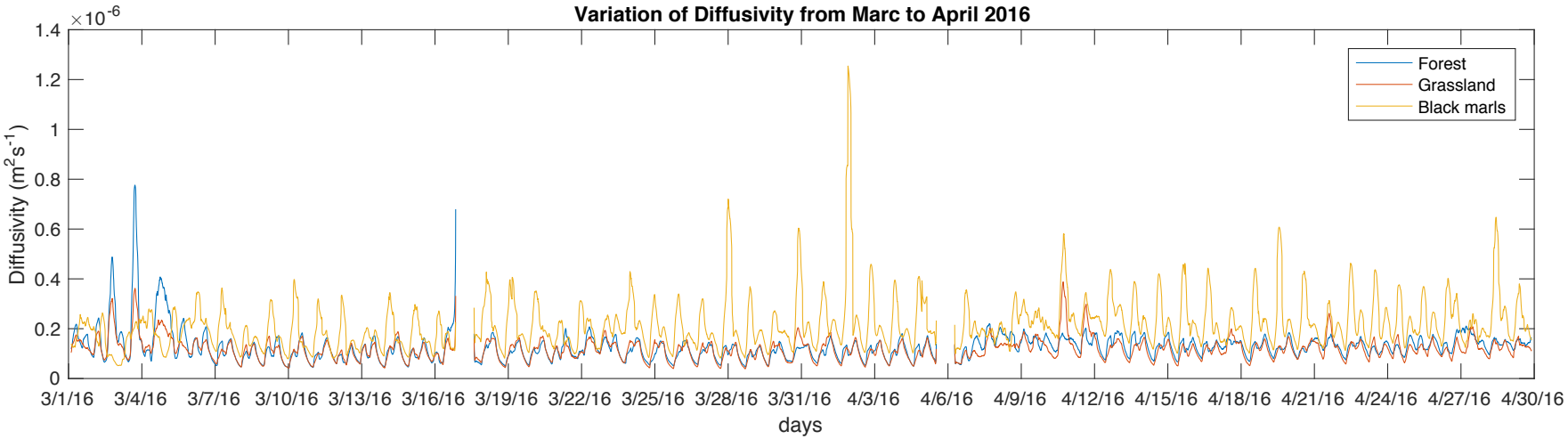
RAIN EVENT, AIR TEMPERATURE & SOIL MOISTURE CALCULATION



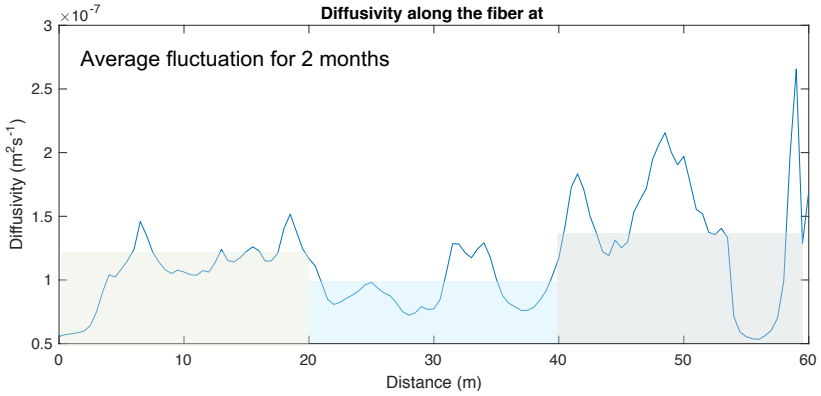


VARIATION OF DIFFUSIVITY

The variation of diffusivity and range from March to April 2016 for each soil type



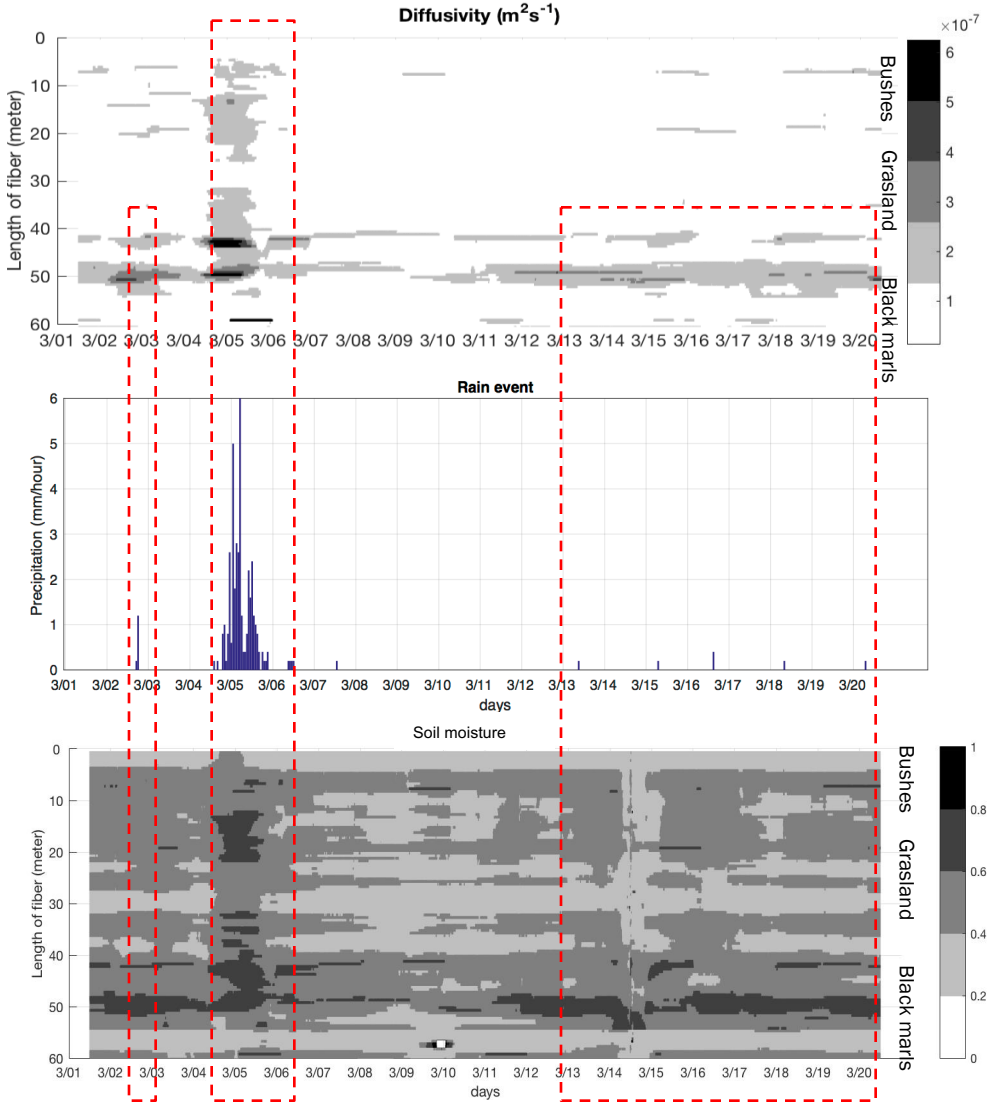
- The average of diffusivity for each soil type is calculated to obtain the range of value.

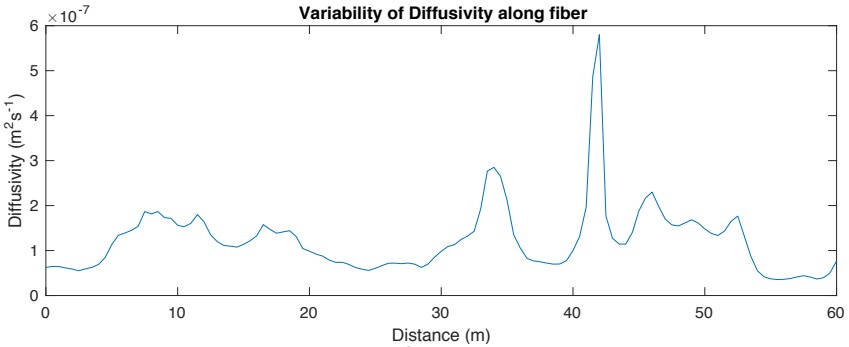


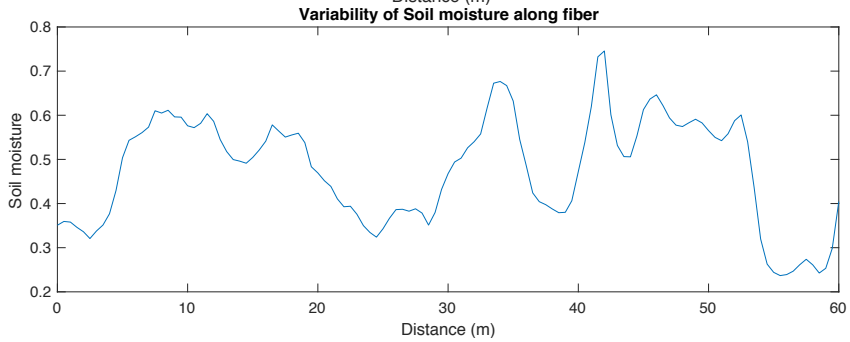
Range of Diffusivity for each soil type (m^2s^{-1})

	Max	Min	σ
Forest	7.76×10^{-7}	4.23×10^{-8}	6.17×10^{-8}
Grassland	3.88×10^{-7}	3.89×10^{-8}	4.61×10^{-8}
Black marls	1.25×10^{-6}	5.15×10^{-8}	2.48×10^{-7}

DIFFUSIVITY, SOIL MOISTURE & RAIN EVENT

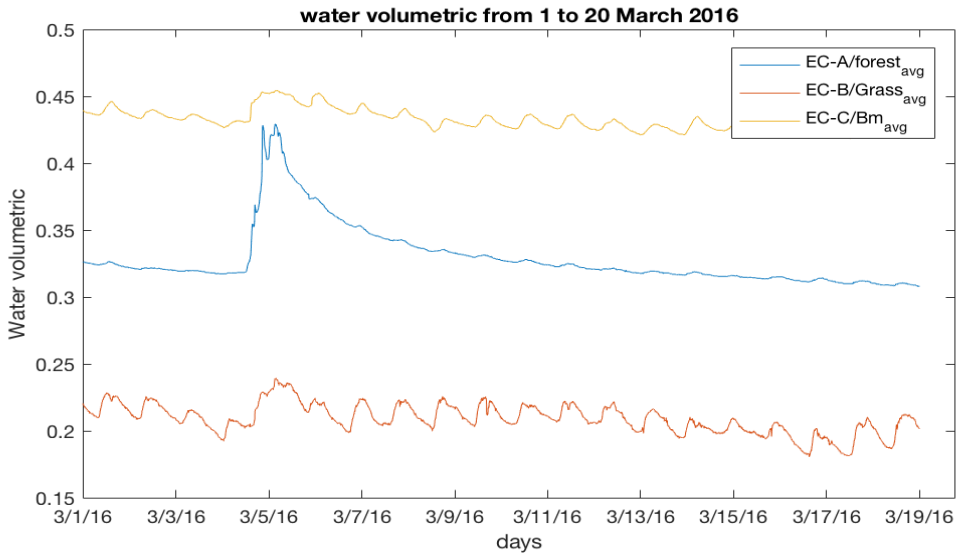


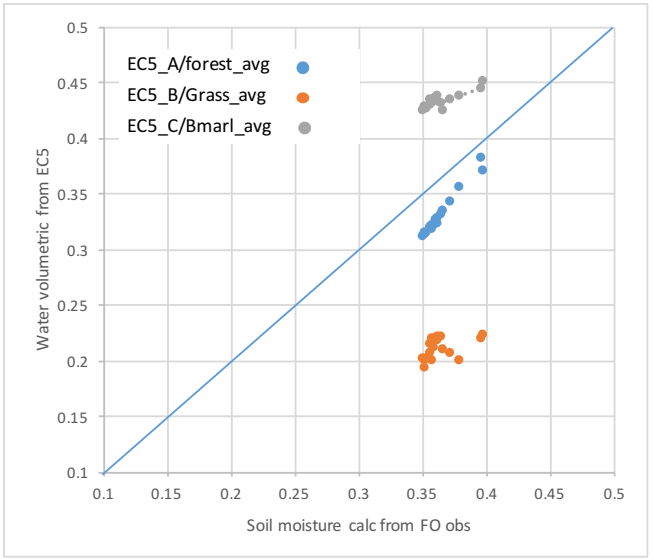


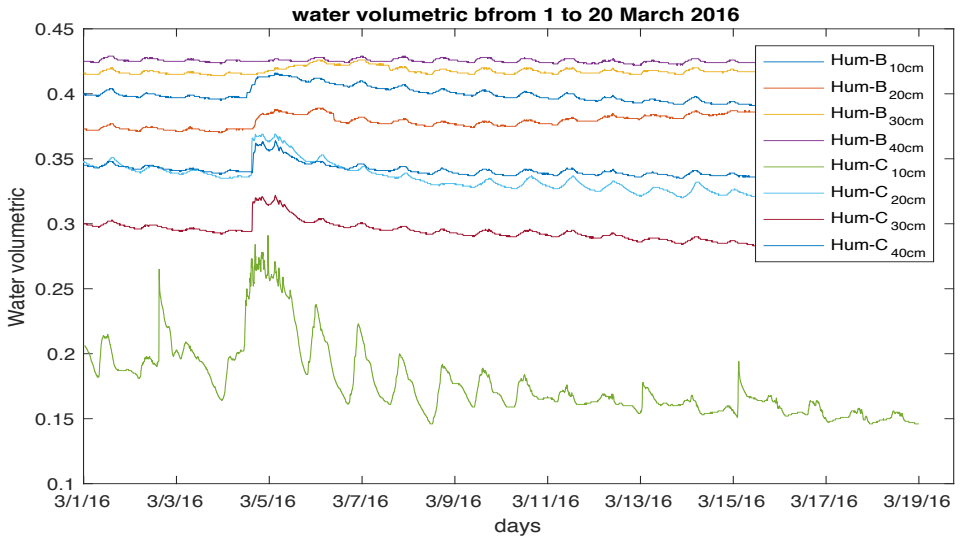


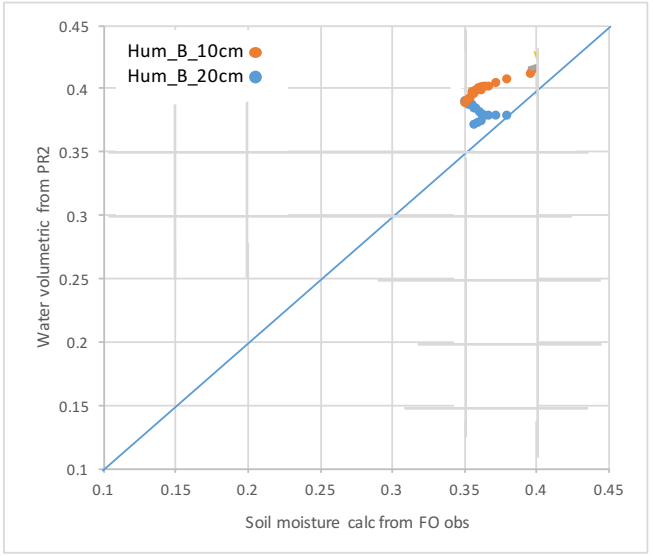
Analysis parameters	value
Moving average	window = 5 hour
RMSE	0.05 ^{o}K
Mean Relative error	3.3 %

COMPARISON OF SENSORS AND CALCULATION



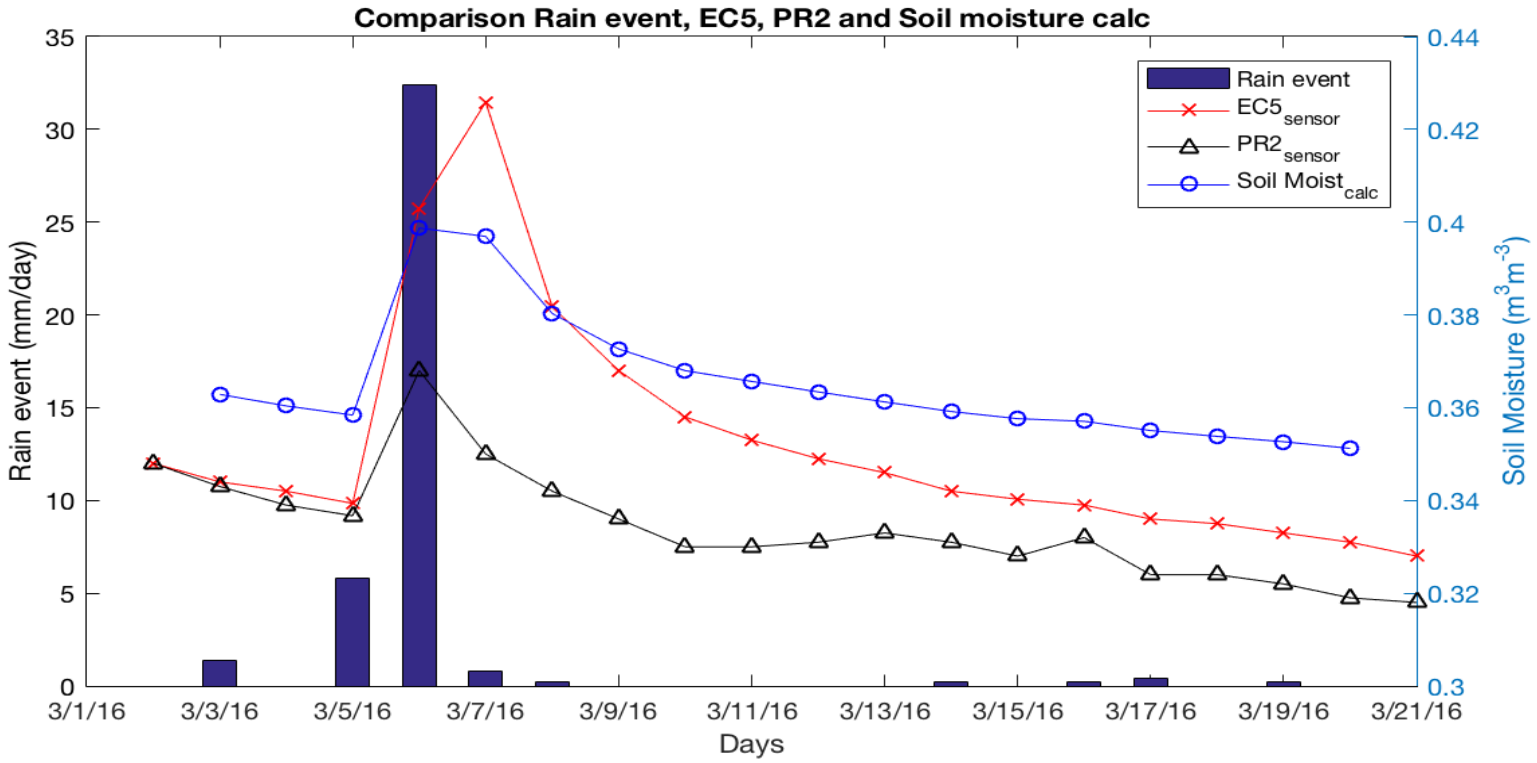






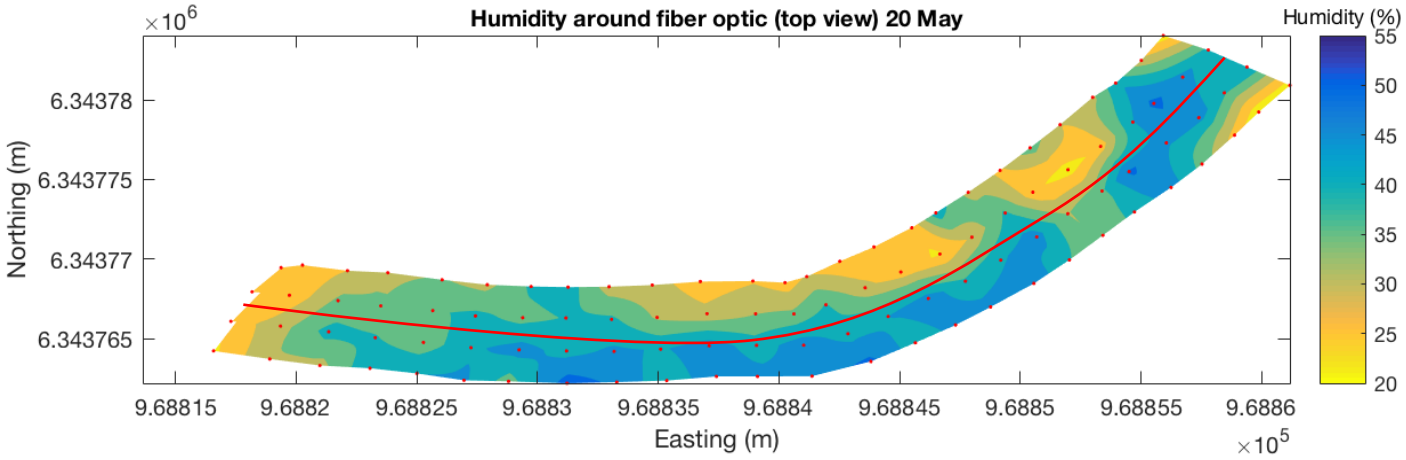
COMPARISON OF CALCULATION AND DIRECT OBSERVATION

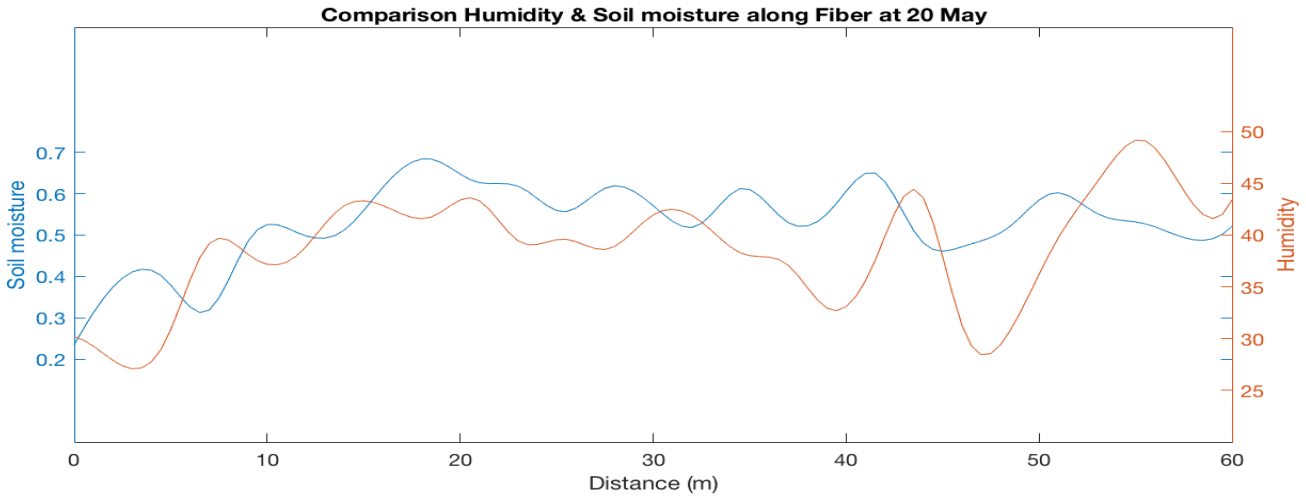
The changes of soil moisture has same patterns that observed by several sensor and calculation for 20 days period.



HUMIDITY AROUND THE FIBER OPTIC

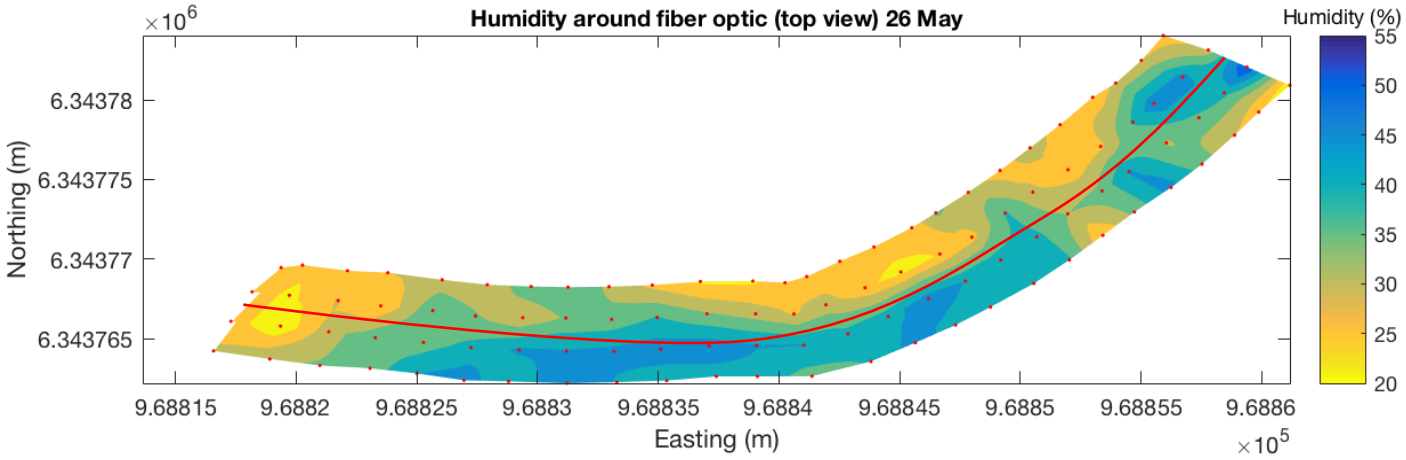
Humidity was measured by ML3 probe, and average soil moisture at whole of the day.

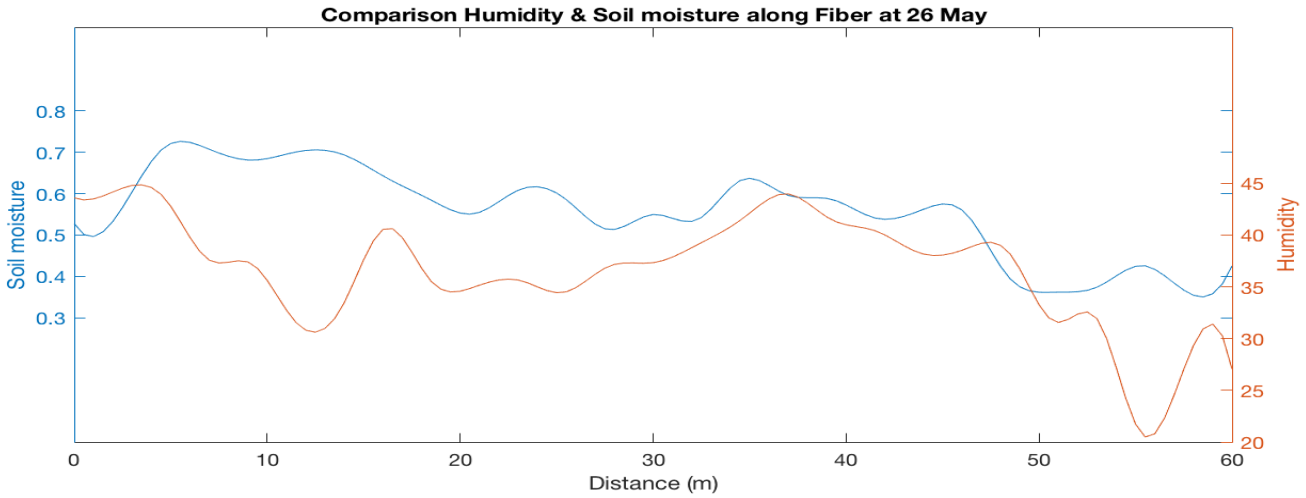




HUMIDITY AROUND THE FIBER OPTIC

Humidity was measured by ML3 probe, and average soil moisture at whole of the day.





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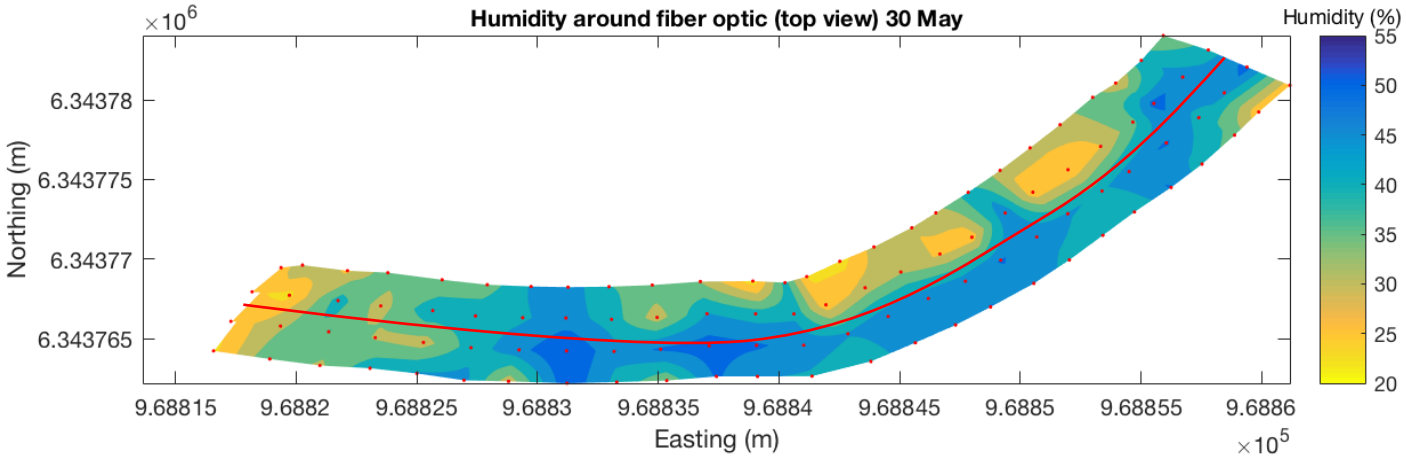

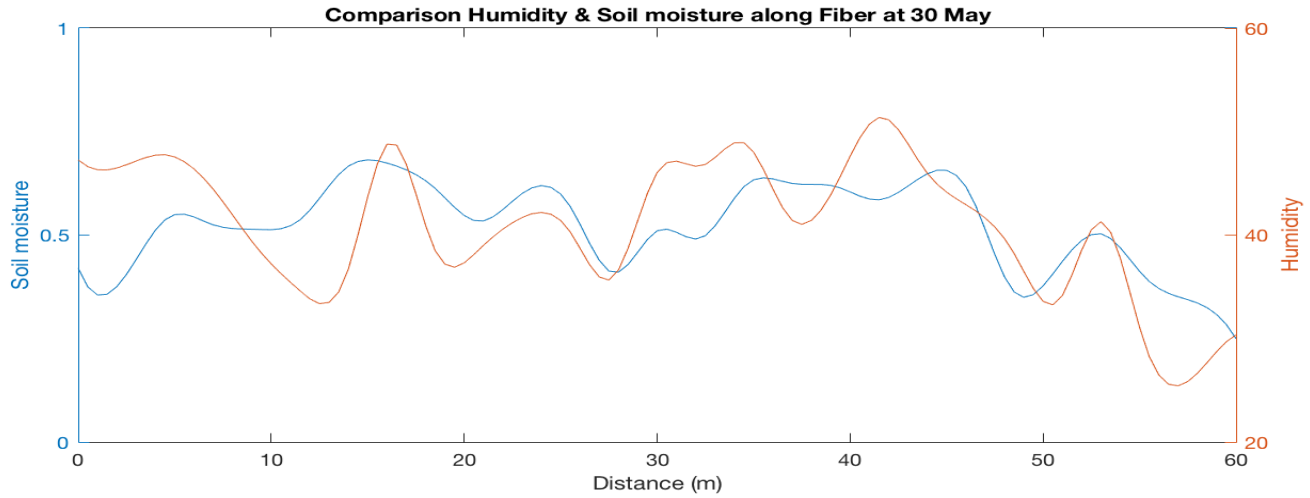

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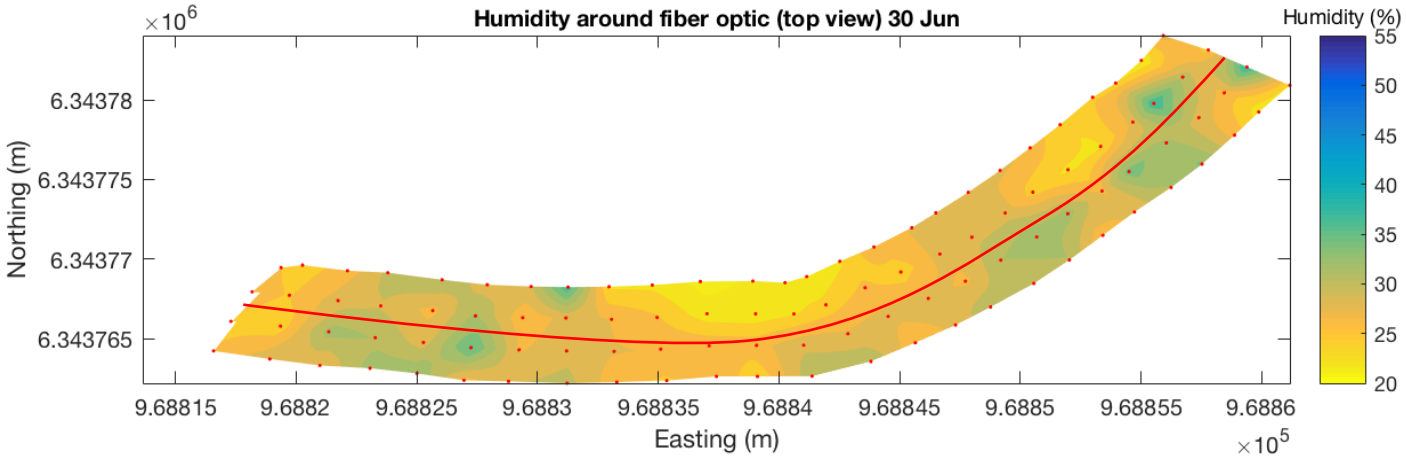
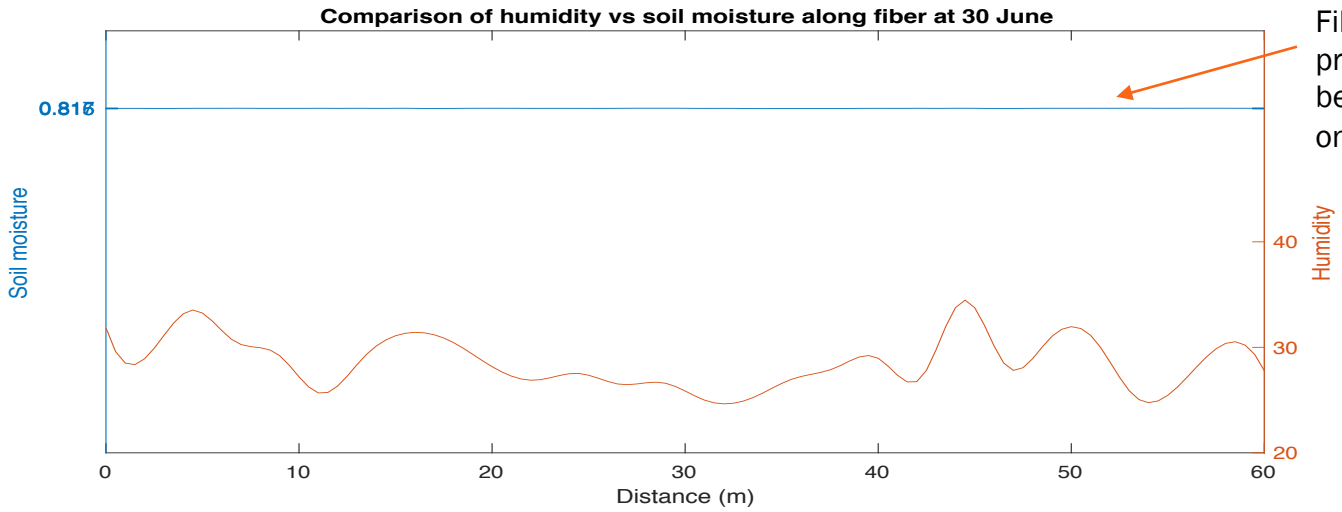
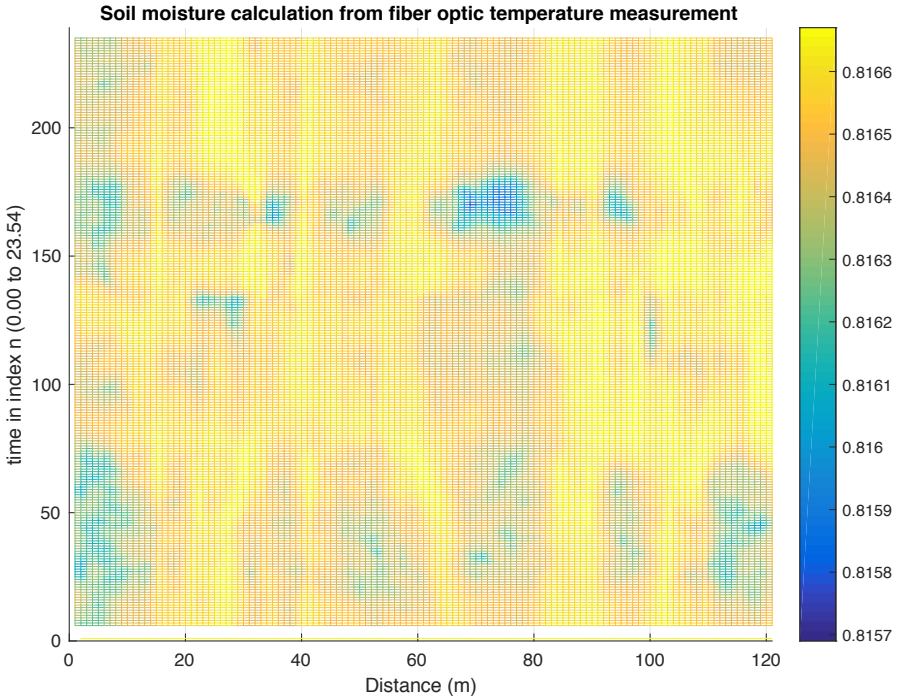


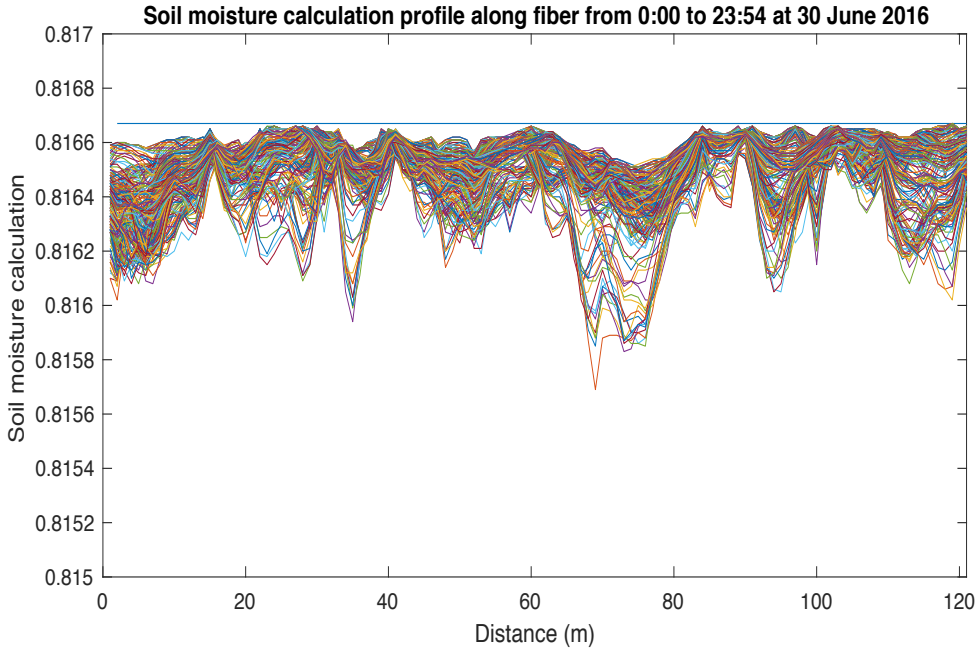


Fiber optic did not work properly, maybe because of drying bath on June & July 2016

SOIL MOISTURE ON DRY BATH CONDITION

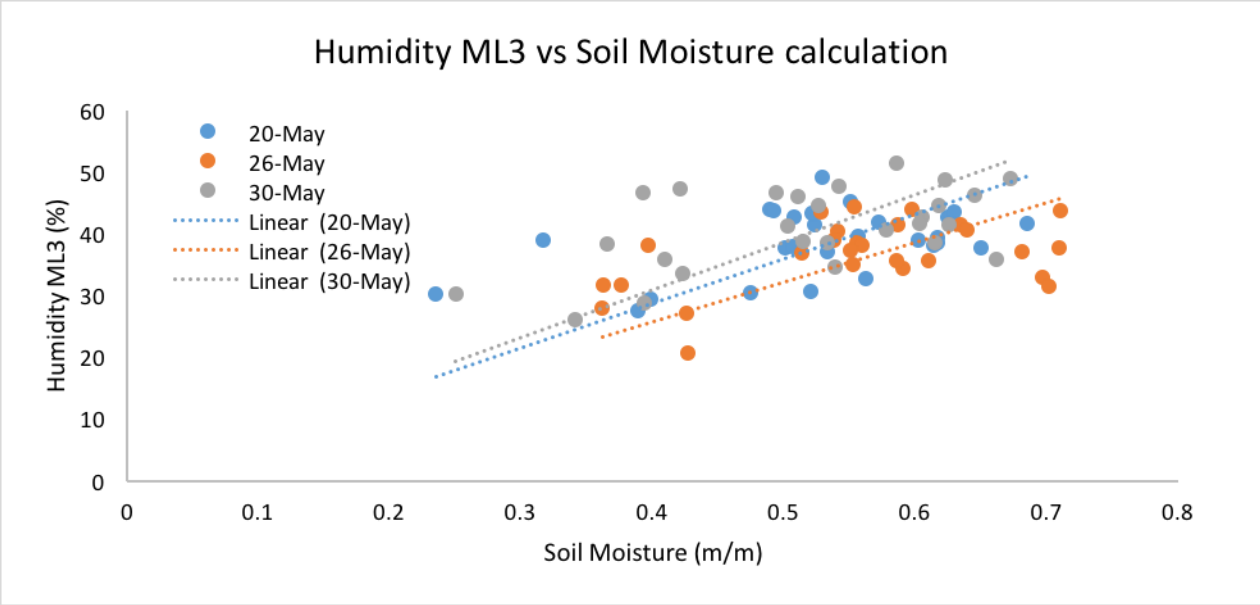
The bath reference was dry that started from mid of June 2016 to mid of July 2016.





HUMIDITY SENSOR VS SOIL MOISTURE CALCULATION

Relation of data observation from ML3 and Soil moisture calculation



Linearity of calculated soil moisture versus humidity from ML3 probe.

	20-May	26-May	30-May
RMSE	4.7	4.9	5.4

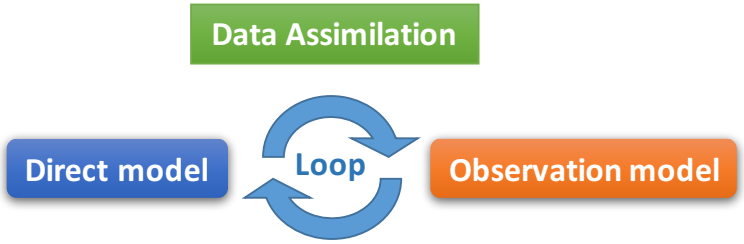
CONCLUSION

This work presents diffusivity calculation using the finite difference method and inversion process from temperature observations measured by FO-DTS.
The result are:

- Fiber optic DTS works properly from Dec 2015 until now.
- FO DTS was not properly on July 2016 because bath references were dry.
- Diffusivity and soil moisture is qualitatively coherent with rain events.
- The variability of diffusivity and soil moisture presents the water changes over the time.
- Comparison of calculation and observation (EC5, PR2 and ML3 probe as soil moisture and humidity sensor).

THE NEXT STEP

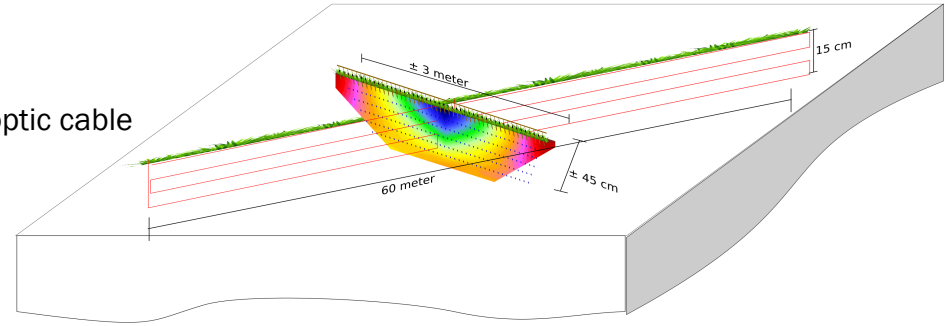
- Analysis of soil thermal properties on active heated fiber optic configuration.
- Running electrical resistivity tomography (ERT) around the fiber to determine variability of electrical resistivity. The electrical resistivity is affected by soil water content.
- Controlling water infiltration system to validate the the soil moisture calculation without any disturbance.
- Future research will also explore The diffusivity calculation by data assimilation. Kalman filter will be used for estimating the soil water changes.



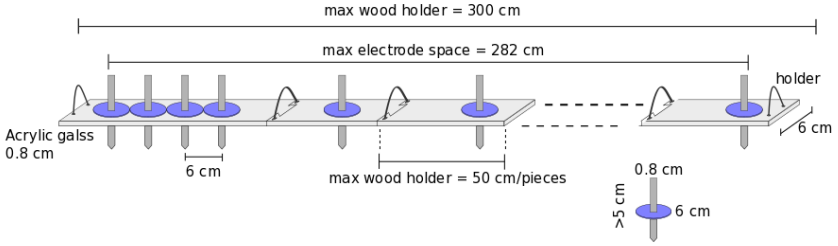
ERT PLANNING SETUP

2D survey installation

Electrode material	: Stainless steel (for long time burial purposes)
Dimension of elect	: Ø = ± 8 mm, L = >5 cm (±3 cm buried and 2.5 contact to cable)
Configuration	: Wenner
Number of electrode	: 48
Electrode spacing	: 0.06 m
Total distance	: 2.82 m
Installation line	: 3 lines perpendicular with fiber optic cable
Lateral resolution	: 0.06 m
Vertical resolution	: ± 0.03 m
Measurement depth	: ± 0.45 m
Profile distance	: ± 2.5 m (maximum)
Measurement time	: ± 30 minutes per line (depend on main unit instrument)
Electrode pad	: wood as current insulation

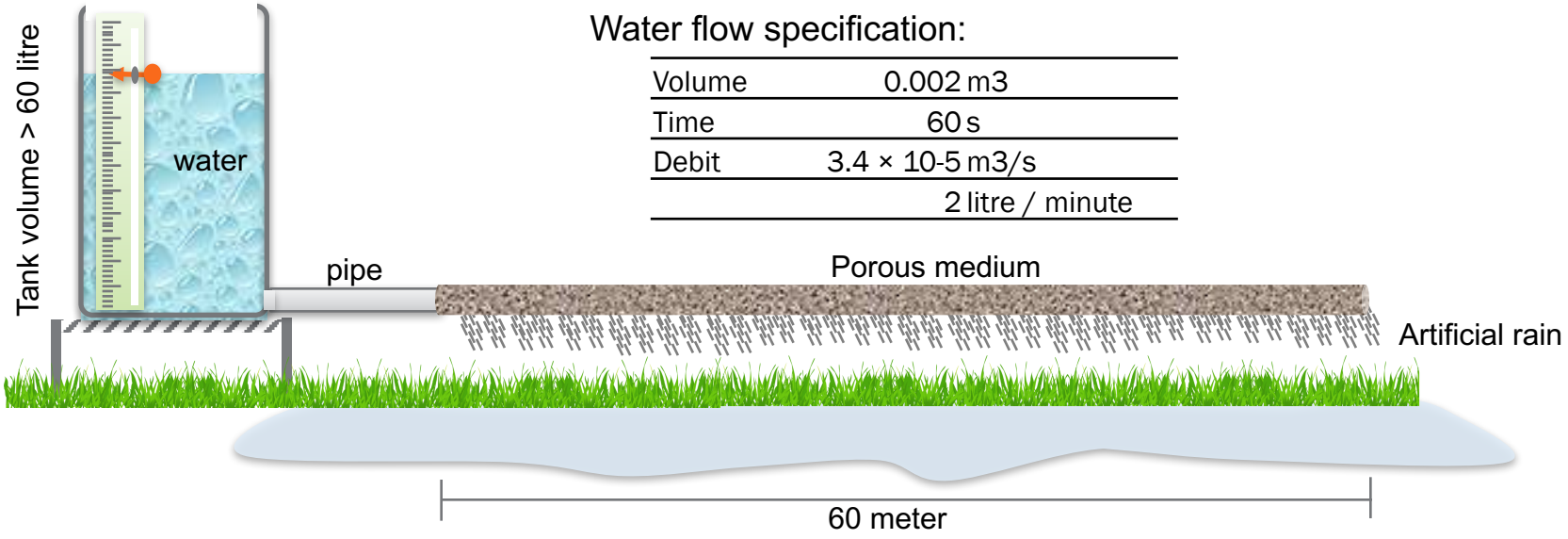


- The wood is used to make easier electrode movement setup
- It will be better if plywood is covered by plastic. So The wood keeps dry even rainy. Wet wood will be a conductor and that is a bad insulator between electrode.



WATER INFILTRATION CONTROL SYSTEM

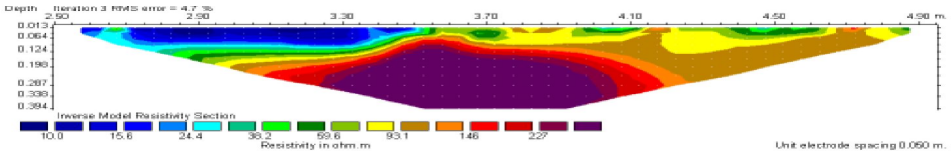
Water level sensor



Water flow specification:

Volume	0.002 m3
Time	60 s
Debit	3.4 × 10-5 m3/s
	2 litre / minute

(Oliver sass, 2010)



ACKNOWLEDGEMENTS

The work is supported by the research project HYDROSLIDE and the large infrastructure project CRITEX funded by the French Research Agency (ANR).

The first author was financially supported by Indonesia Endowment Fund for Education (LPDP) from the Republic of Indonesia.

Thank you..