USE OF PRECISION LYSIMETERS IN SCIENCE

Investigations of the water balance and solute transport

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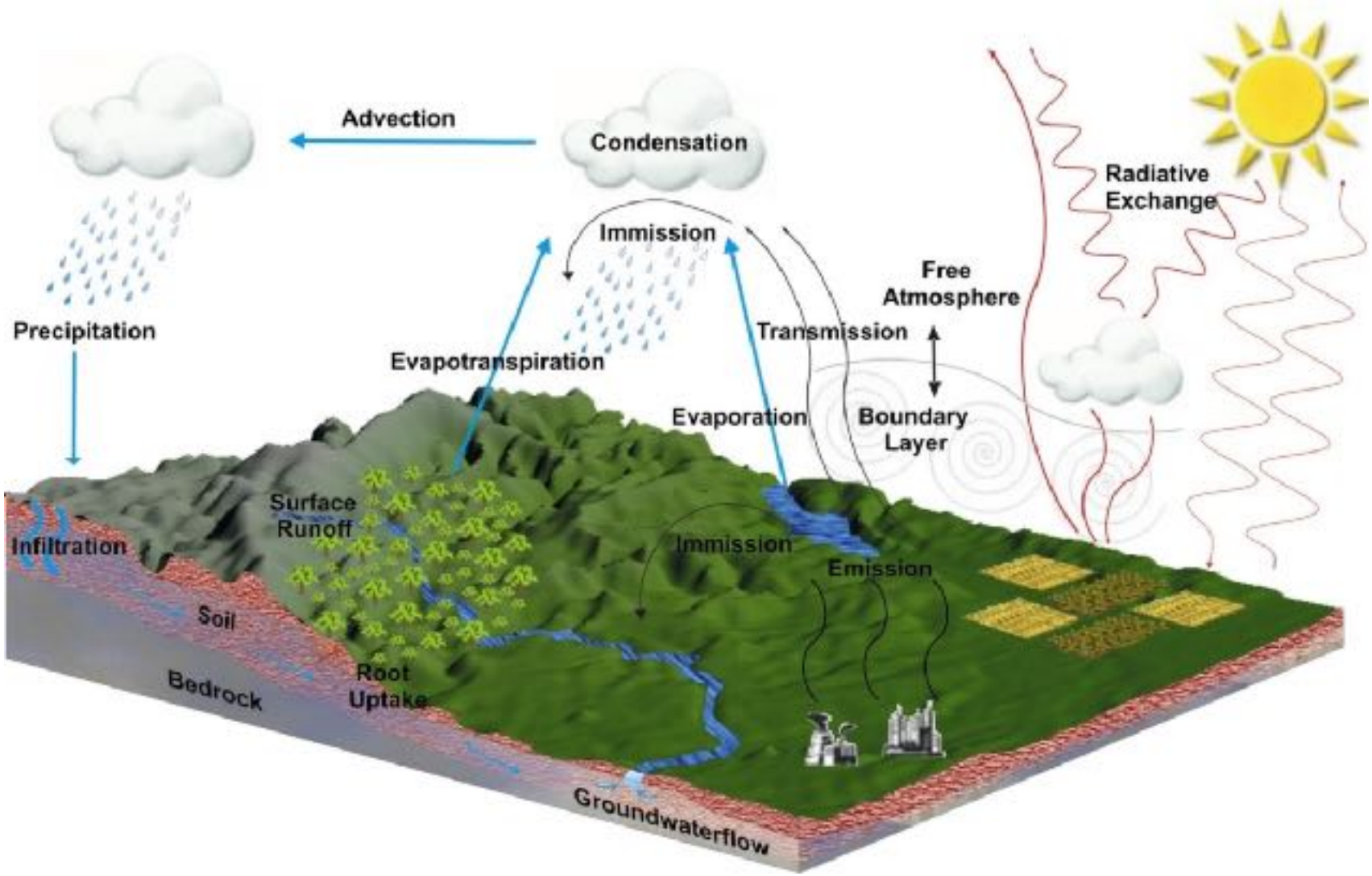
Soil-plant-atmosphere interactions



Definition of a lysimeter

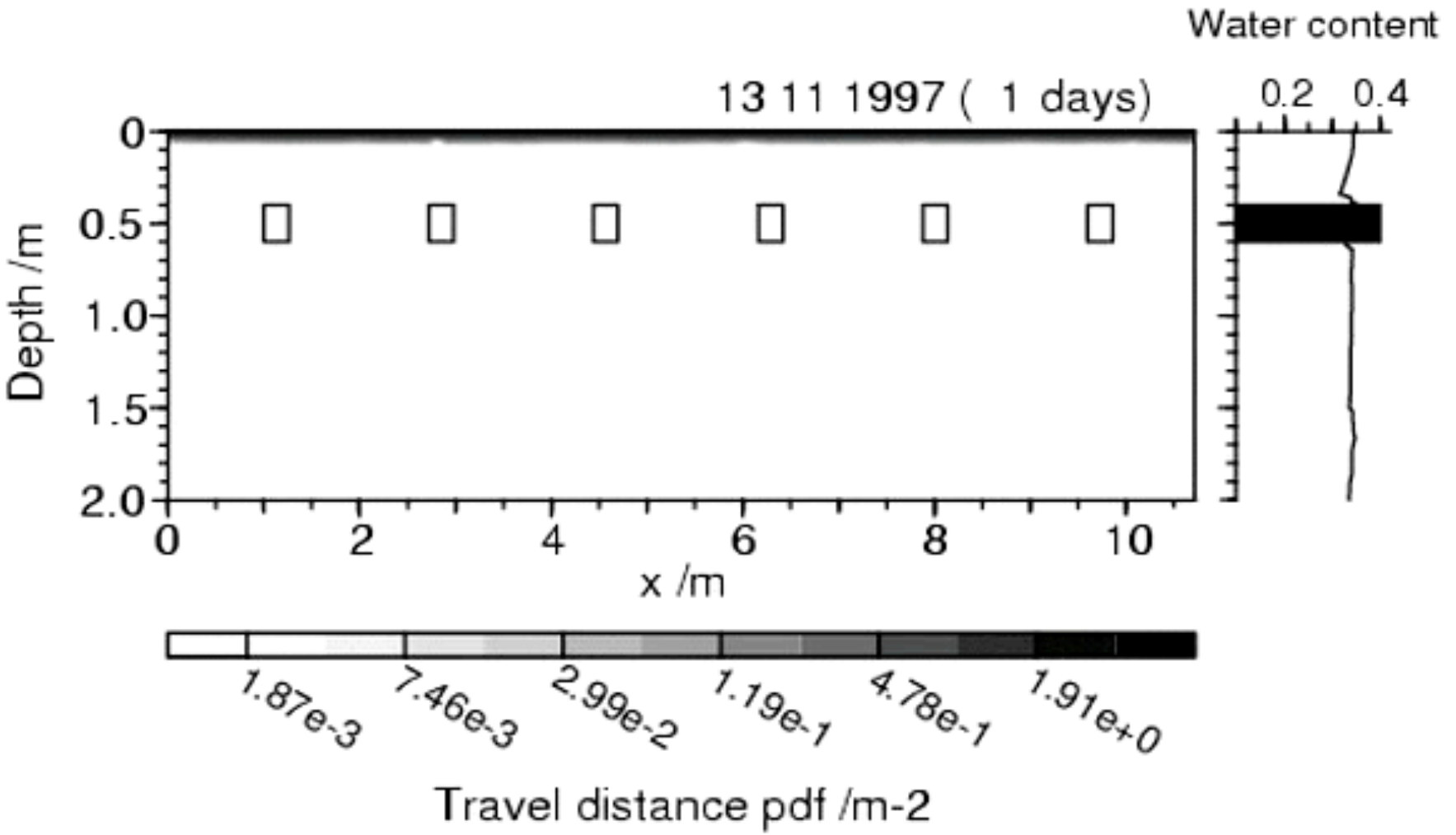
As general definition, **a lysimeter consists of a vessel filled with soil.** The lysimeter vessel can be placed above ground or inserted into the ground. If larger weighable lysimeters are used, the lysimeters at field sites must be placed in a container to allow the installation of load cells. The different lysimeter types can be classified according to the following criteria:

- Size
- Filling procedure
- Design
- Bottom boundary condition of the lysimeter

Why do we need Lysimeter?
Lysimeter = bridge between field and laboratory

Laboratory	Lysimeter	Field
Advantages: defined conditions reproduible mass balace cheap radioactive isotopes	Advantages: undisturbed soil agricultural practice mass balance repetitions radioactive isotopes	Advantages: real situation
Disadvantages: artificial false estimation	Disadvantages: (disturbed drainage) restricted dimensions expensive	Disadvantages: no mass balance soil heterogeneity no control expensive

Bromide-tracer-application on an Orthic Luvisol



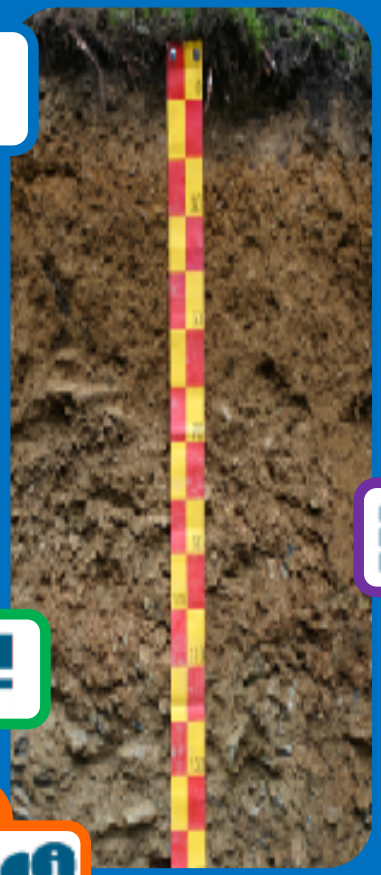
Research topics of our network

Quantification and prediction of non-rainfall water and its ecological relevance for ecosystem

Quantification and prediction of rainfall, drainage water, … and groundwater recharge for grassland eco-systems

Dynamic bottom boundary control

High precision lysimeter



Quantification and prediction of nighttime evapotranspiration for eco-systems

Quantification and prediction of solute fluxes and fate of xenobiotics in eco-systems

Estimating soil hydraulic properties and dispersities under realistic boundary conditions

Water- and matter balance

Water balance:

$$\Delta W = P + I + T - (A + D + ET)$$

precipitation (P), irrigation (I) and dew (T) are balanced with the surface losses. Run off (A), drainage (D) and Evapotranspiration (ET) measured over a certain period of time; changes in the water content (ΔW)

Solute balance:

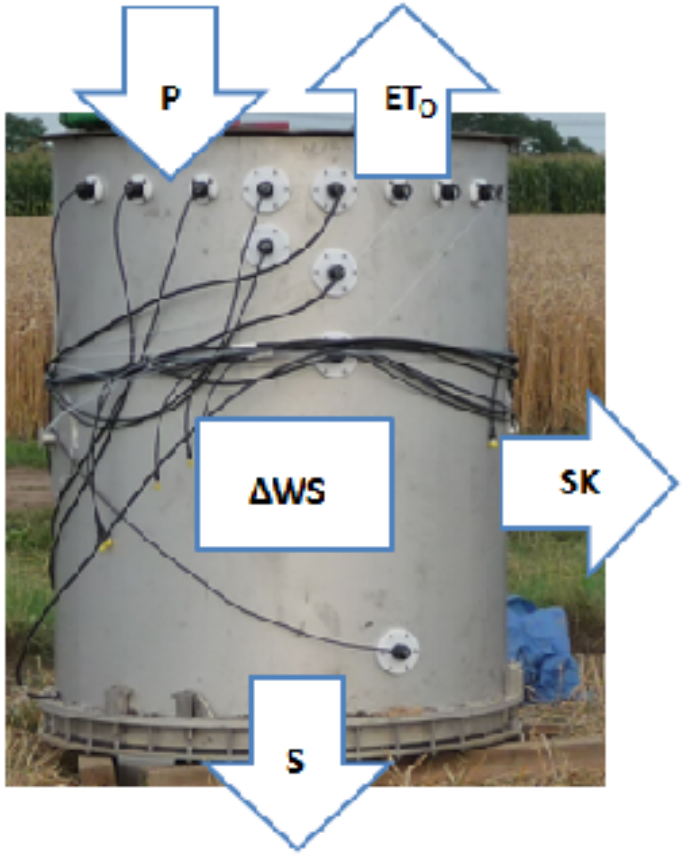
$$L = C_s * D$$

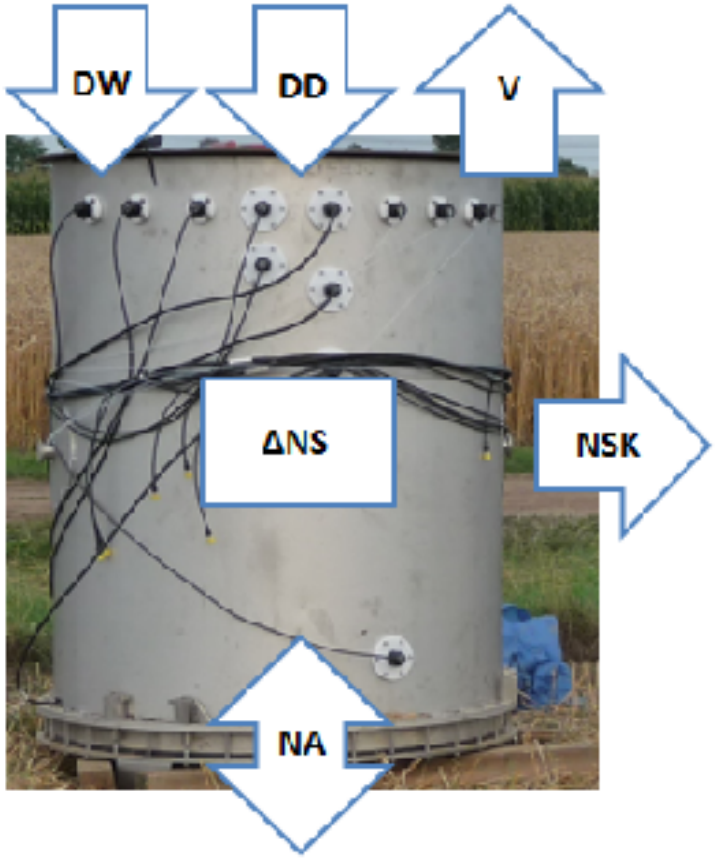
Dissolved amount of solute **(L)** (mg m^{-2})

solute concentration of the drainage (C_s) (mg L^{-1})

volume of rainage (D) (L m^{-2} = mm)

Different terms of the solute and water balance





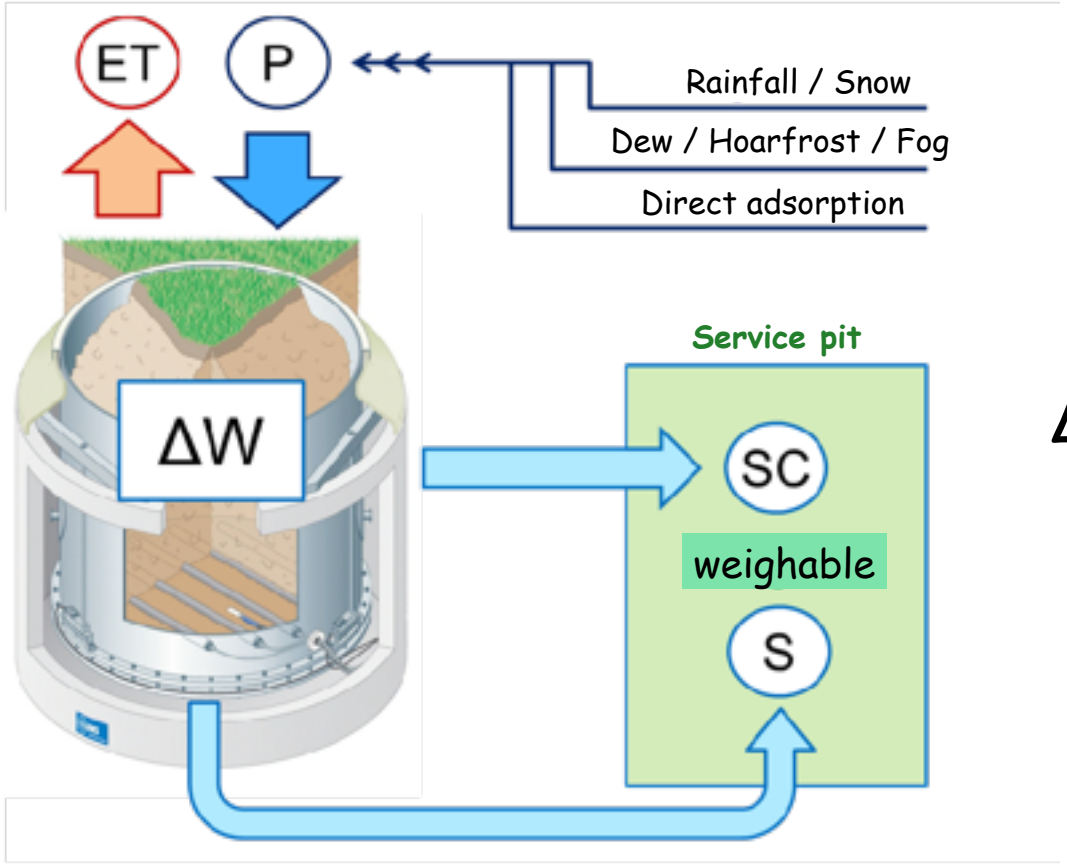
P	=	precipitation/dew/hoar frost
ET_O	=	evapotranspiration/evaporation
S	=	seepage water
SK	=	soil solution
ΔWS	=	changes water storage

DW	=	nitrogen deposition, wet
DD	=	nitrogen deposition, dry
V	=	volatilisation
NSK	=	sum soil solution
NA	=	nitrogen discharge or input

„Non-Rainfall-Water“

- Non-rainfall → dew / hoar frost
- Water vapour adsorption → „fog-droplet-deposition“

$$\Delta W = (P+I+D)-ET-S-SC+CR$$

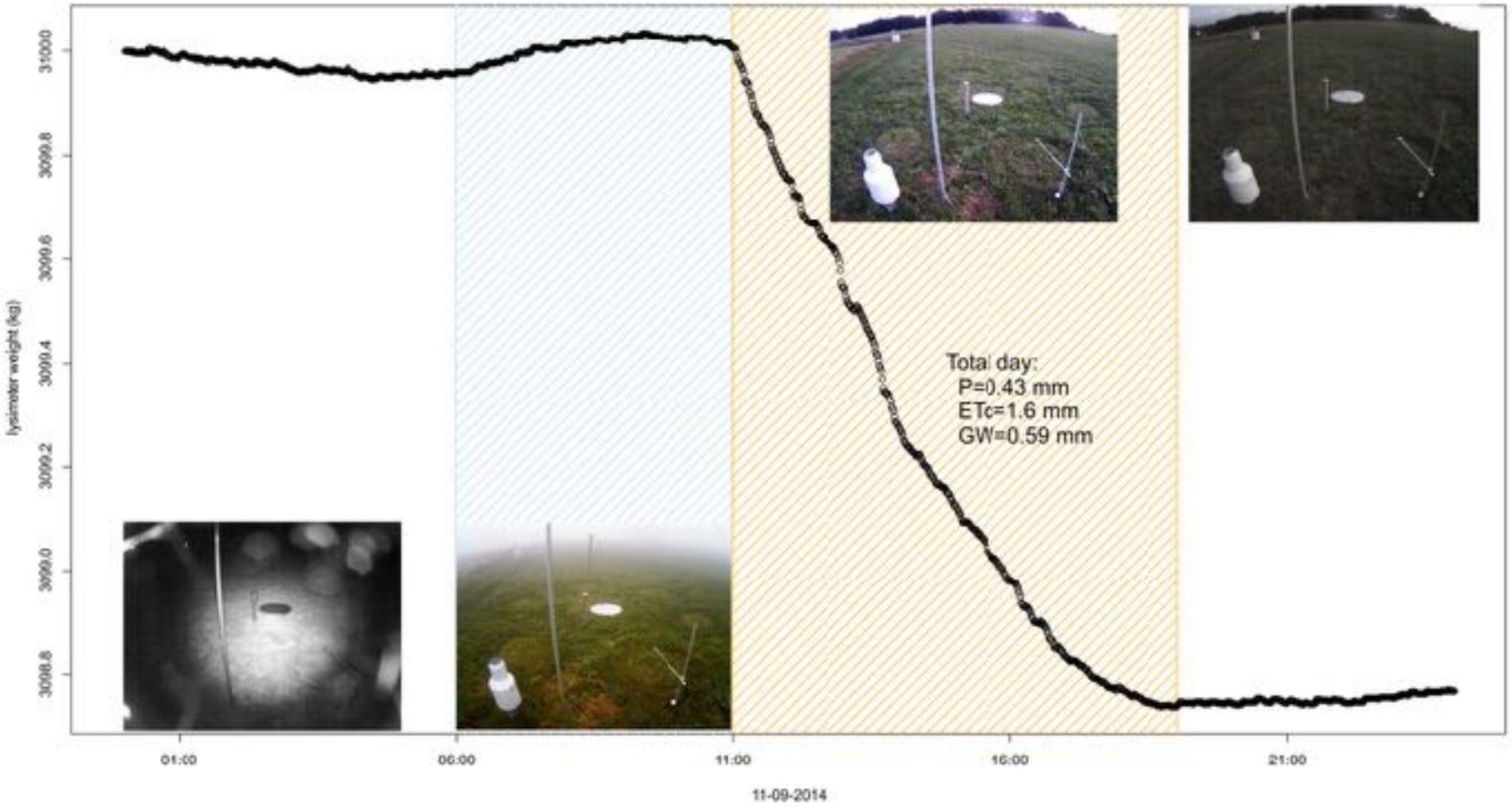


$$\Delta W = \Delta W_{lys} + \Delta W_{drain}$$

$$\Delta P = \begin{cases} \Delta W, & \Delta W > 0 \\ 0, & \Delta W \leq 0 \end{cases}$$

$$\Delta ET = \begin{cases} 0, & \Delta W \geq 0 \\ \Delta W, & \Delta W < 0 \end{cases}$$

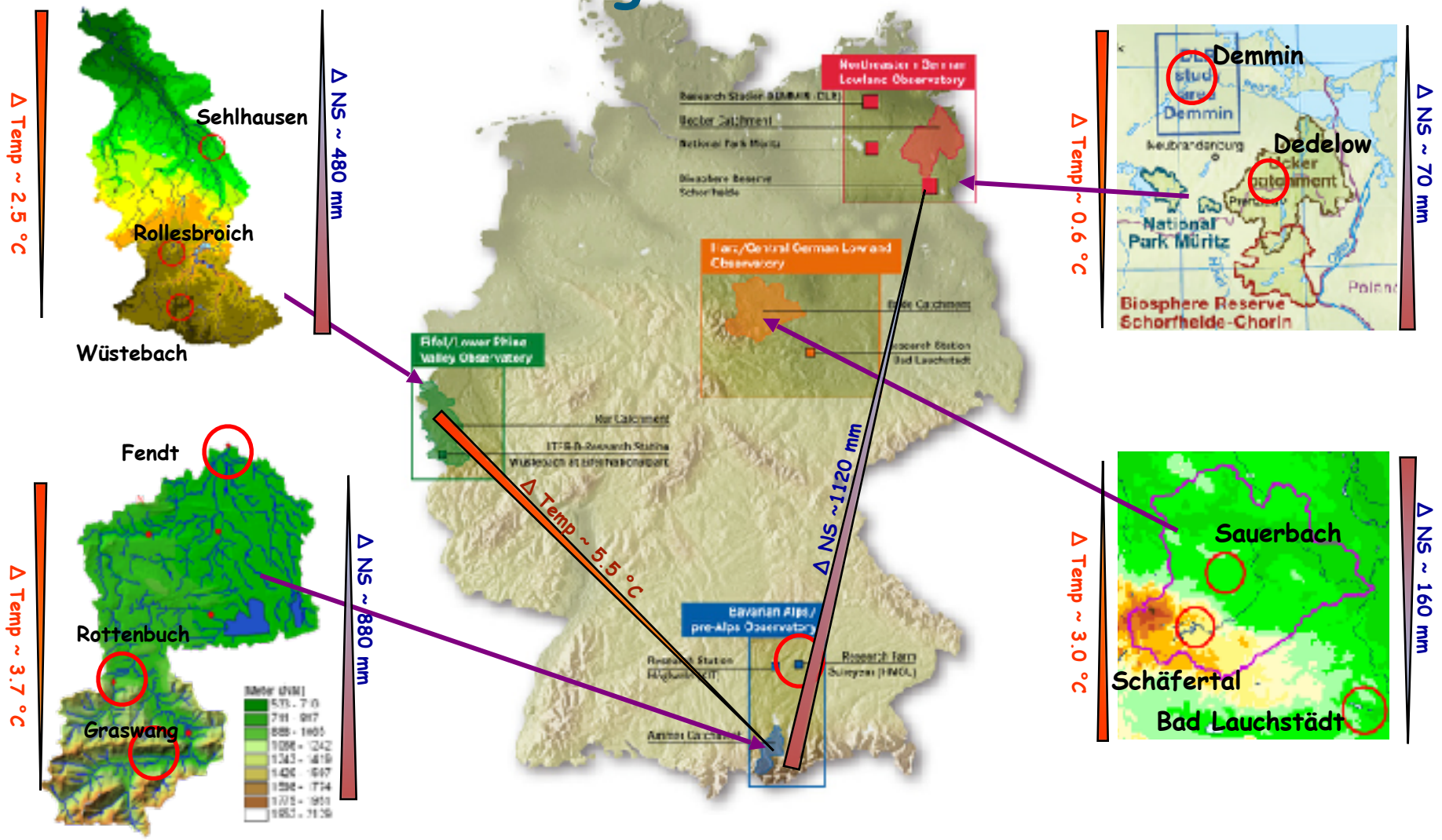
Typical water balance at a grassland site



TERENO ➞ SOILCan

- bring together scientists from different scientific communities and **integrate disciplines**
- exploit the availability of **novel technologies and high performance computing** for terrestrial research
- establish **common measurement platforms** as the basis for **long term data sets**
- combine **observation and experimentation**
- **foster synergies** between Helmholtz-centers and national and international research organizations

TERENO-SOILCan lysimeter network
- Climate gradient -



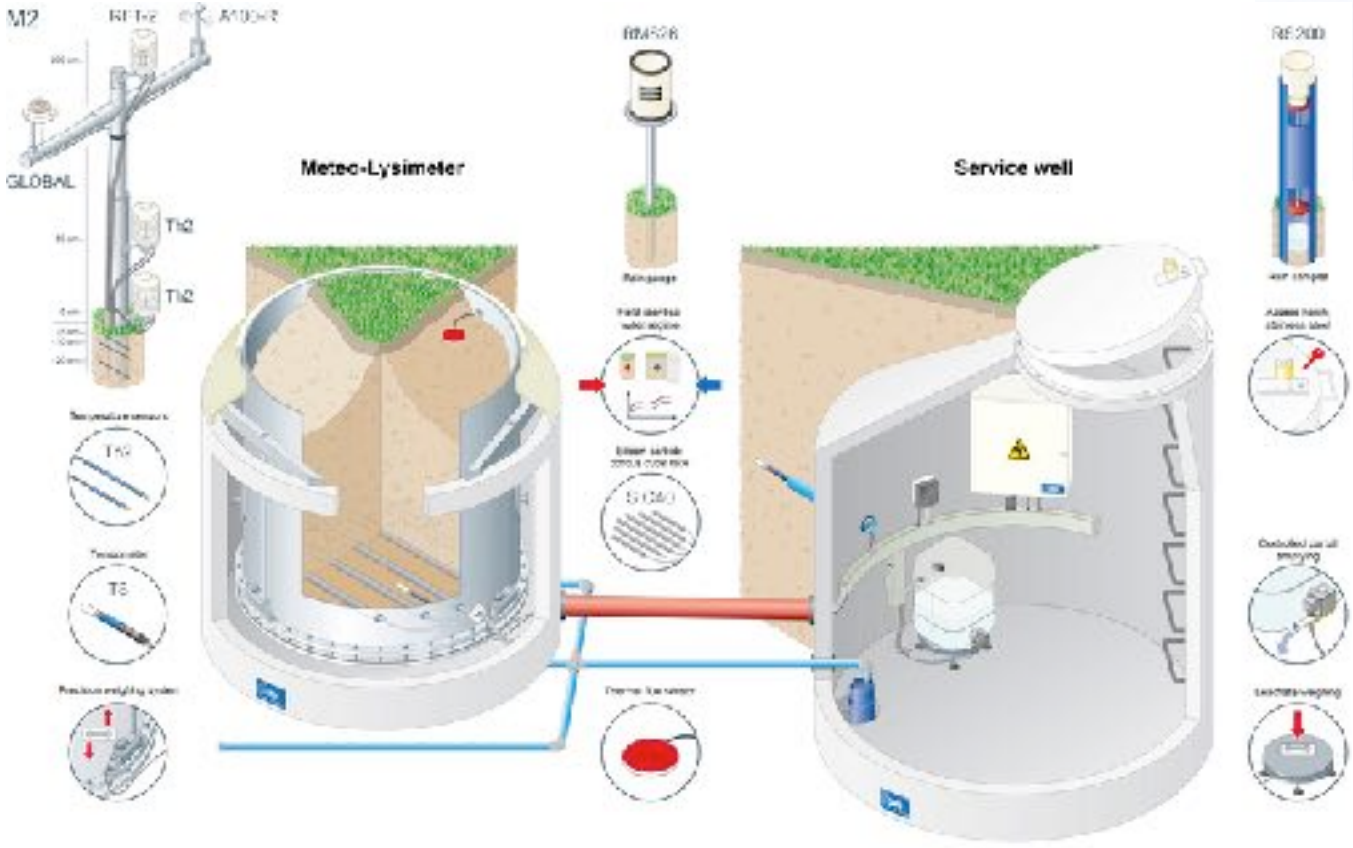
SOILCan - Lysimeter Setup

Lysimeter specification:

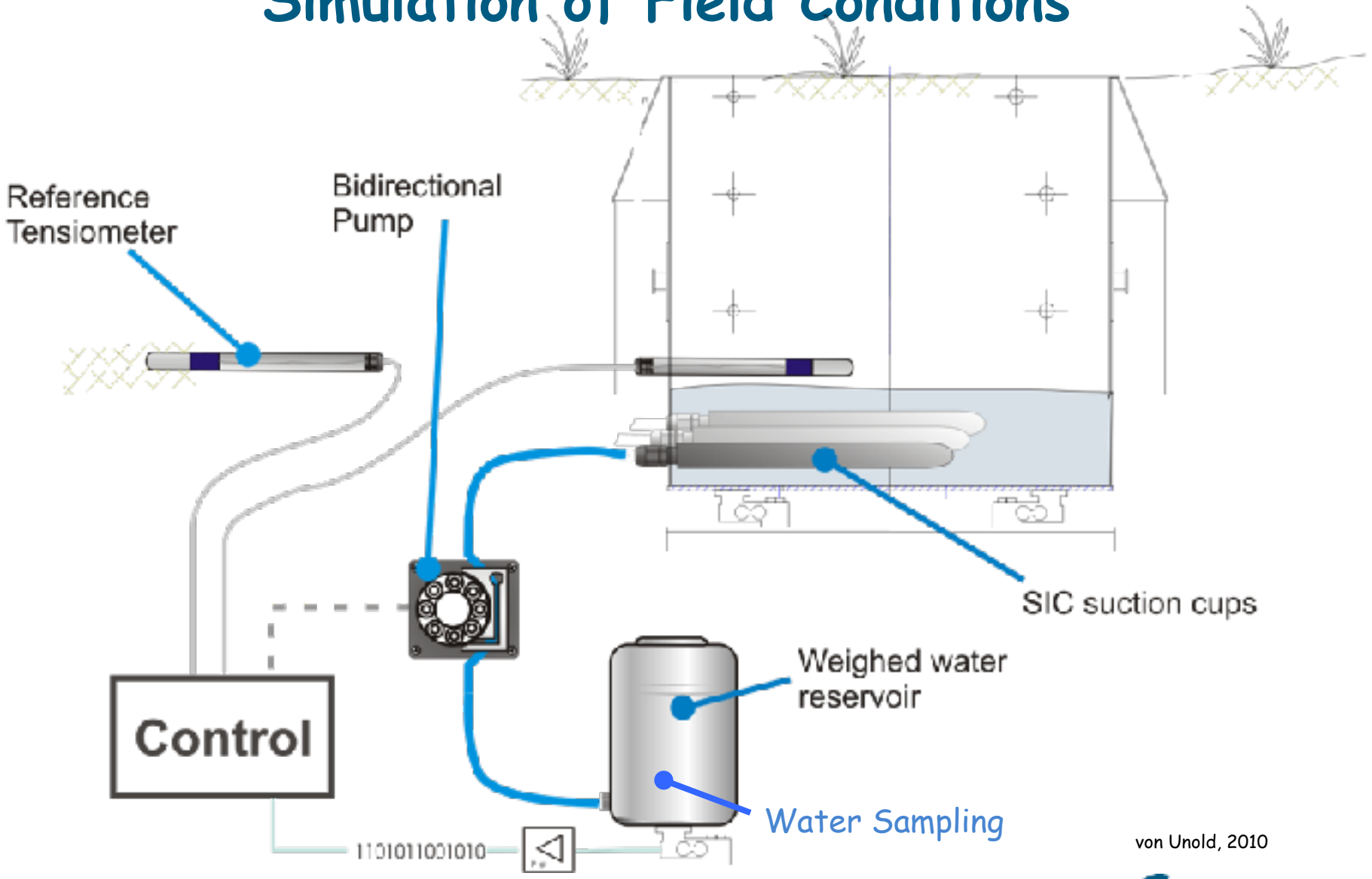
surface area: 1 m²

depth: 1.5 m

resolution lysimeter balance: 0.01 mm or 10 g



Controlled Lower Boundary Condition
Simulation of Field Conditions



von Unold, 2010

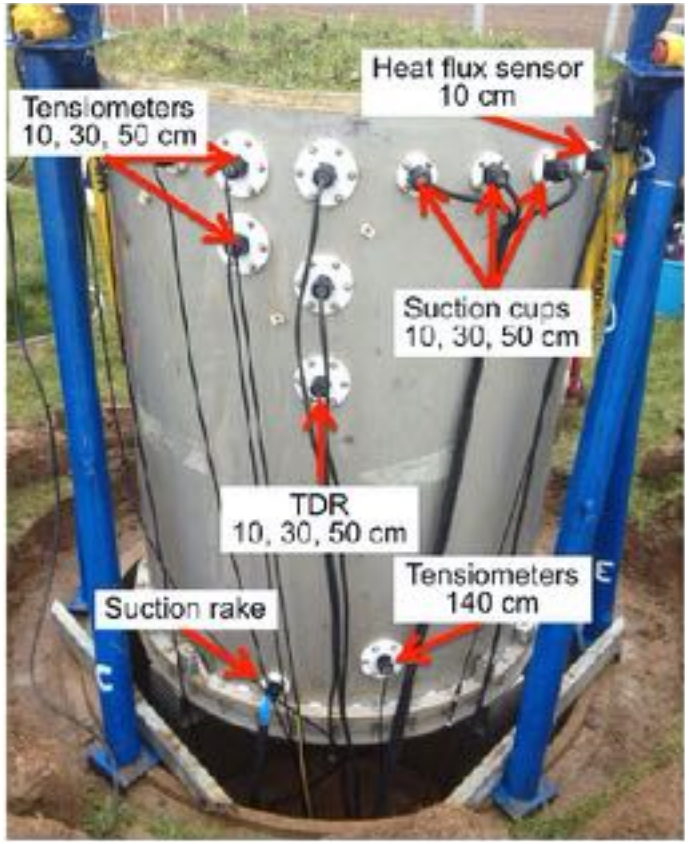
Filling A Lysimeter: Pressing Technique






Installation of a suction rake

Probes and sensors of SOILCan lysimeters



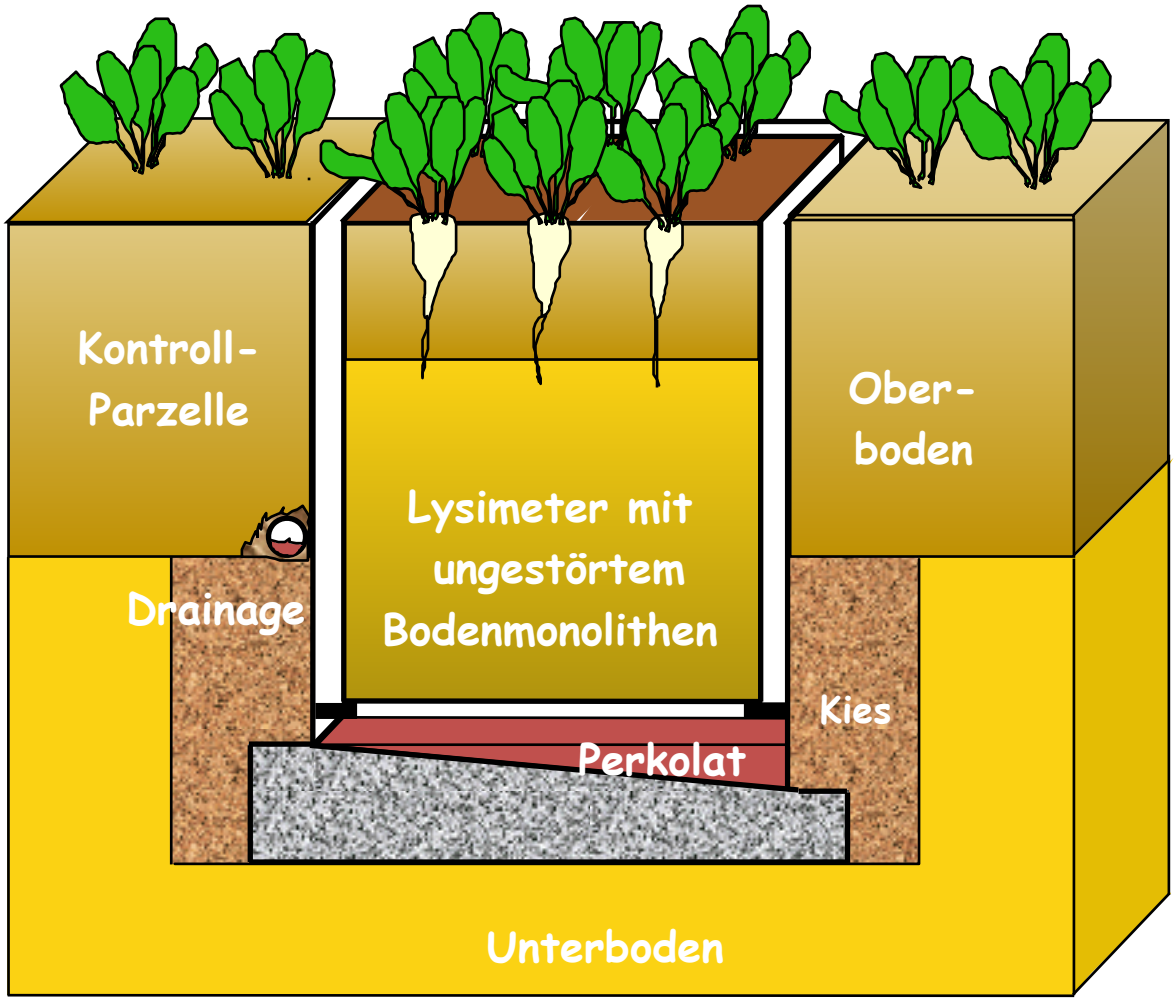
- 3 suction cups (10, 30, 50 cm)
- 3 (to 4) tensiometers (10, 30, 50, 140 cm)
- 3 Campbell Scientific TDR-probes (10, 30, 50cm)
- 1 Matrix potential sensor (10 cm)
- 1 Heat flux sensor (10 cm)
- 4 temperature sensors (10, 30, 50, 140 cm)
- 2 balances (lysimeter, leachate)

Suction rack for lower boundary condition

Filling A Lysimeter: Pressing Technique

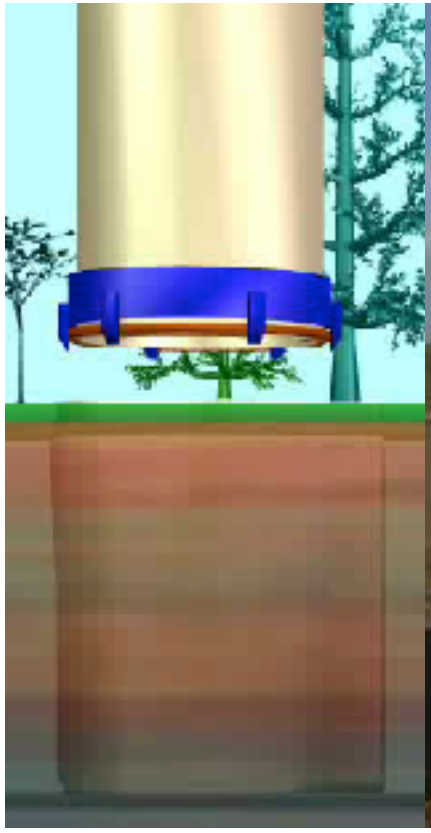
Filling A Lysimeter: Bottom Plate

Lysimeter-System in Jülich



Filling A Lysimeter: Circular Cutting Technique

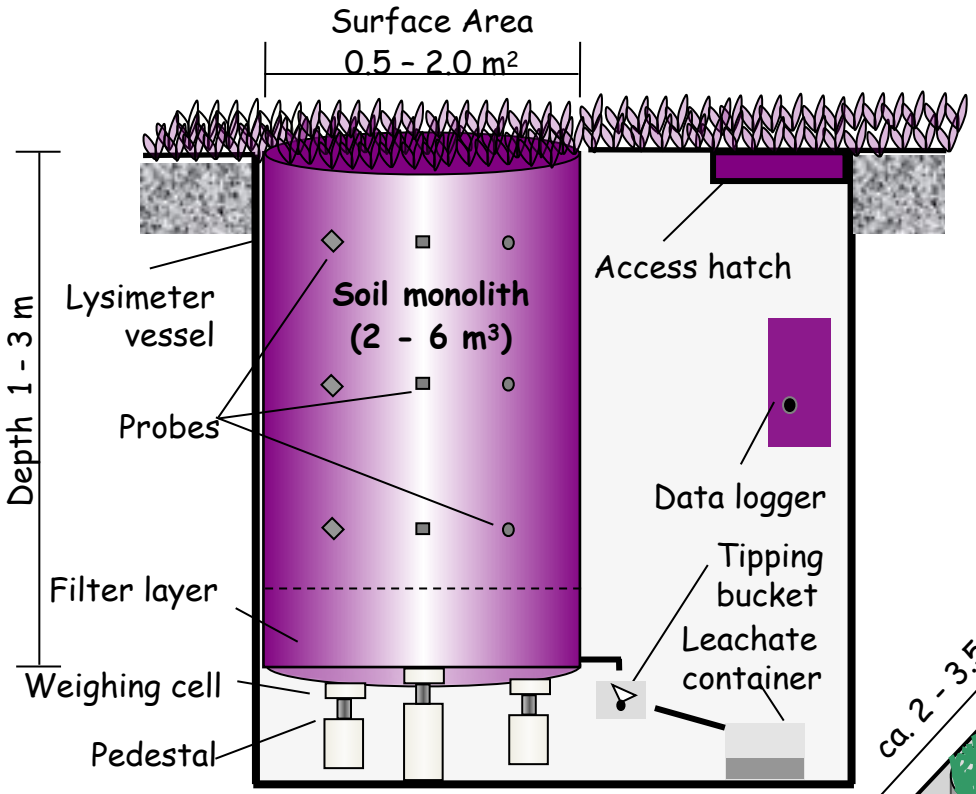
- Cutting of a soil monolith
- Bottom plate

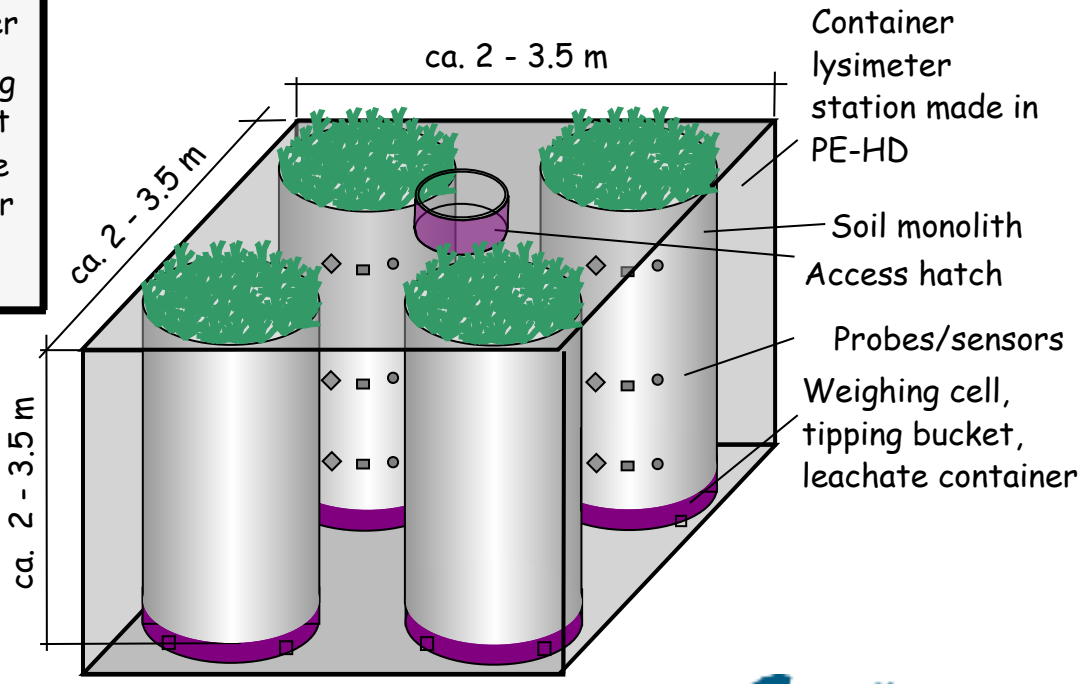


- Chisel mill
- Filling a lysimeter with a soil monolith

Filling A Lysimeter: Circular Cutting Technique

Container/basement lysimeter station





source: Ralph Meissner (UFZ), 2014, personal communication

Impressions of the lysimeter filling

Impressions of the lysimeter filling

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Impressions of the lysimeter filling

Insertion of lysimeter

Campus lysimeter station of Institute Agrosphere

How a lysimeter site should look like

- No buildings
- No disturbing installations
- Sufficient control area
- Harmonious integration into the natural/agricultural ecosystem
- Lysimeters should not be „visible"

How a lysimeter site should look like

What do lysimeters need?

- Weekly check
- Annual maintenance
- Technical staff with appropriate training/education
- Budget for operation and spare parts
- Desirable: Power connection
- Long-term perspective for performing experiments and measurements

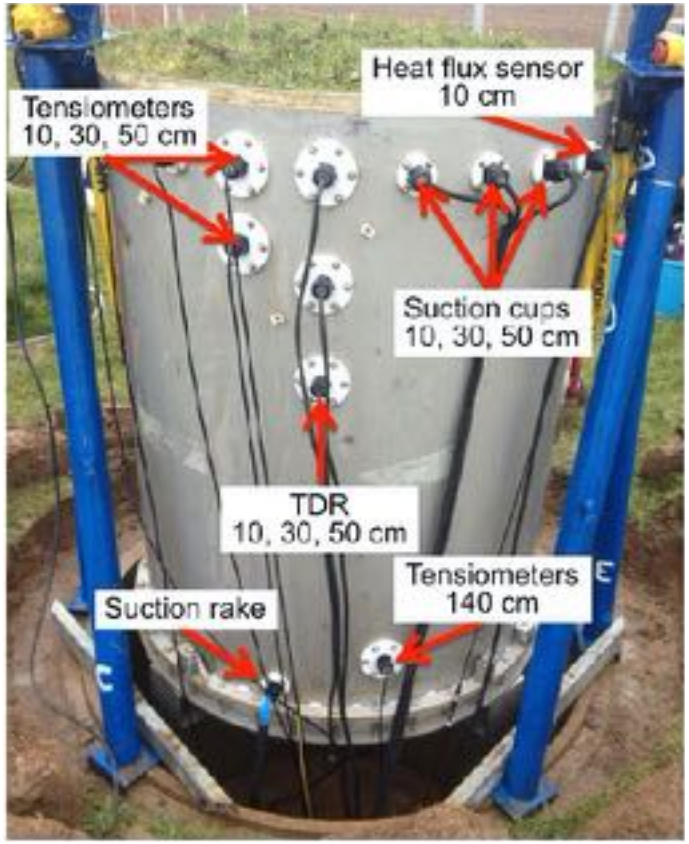
Leachate sampling

- Installation of bottles for leachate sampling
- Control of the lower boundary for lysimeters transferred to other test sites
- Pump intervals of the leachate
- **Very important: continuous plausibility check of the data!!!**

Weekly check

- Control of the sealing lips of the lysimeter
- Sampling leachate, soil solution, etc.
- Measurement of the leaf area index
- Technical control of all systems
- Control of mice, ants, snails, etc.

Annual maintenance of SOILCan lysimeters



- Replacement of malfunctioning sensors/probes
- Testing and adjusting the load cells
- Control of the gaskets of the lysimeter
- Visual inspection of the lysimeters
- Cleaning of the lysimeter container

Suction cups rack for lower boundary condition

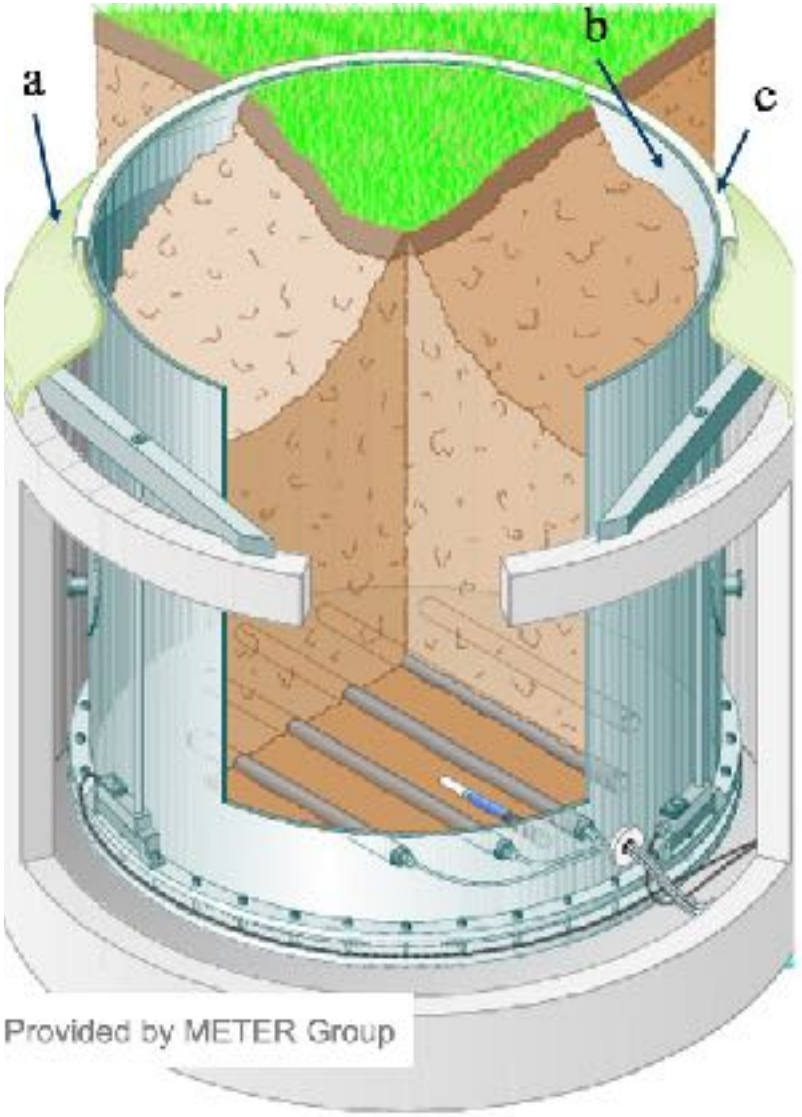
Additional instrumentation beside lysimeter stations

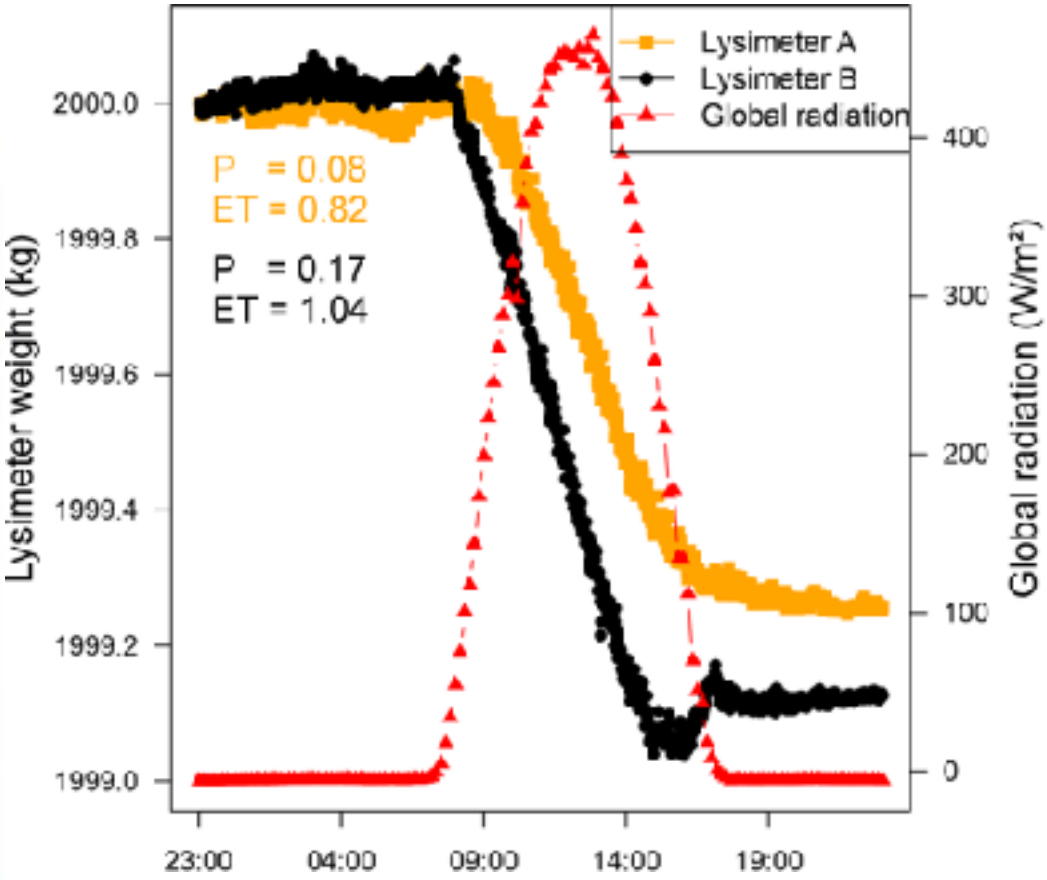
- Weather station
- Eddy covariance station
- Deposition collector
- Soil respiration chamber
- Radiation sensor above lysimeter
- Rain gauge
- Remote access
- **Camera!!!!!**

Not all soil types are suitable for lysimeters depending on the location

- Gap between vessel and soil monolith
- Hydraulic short cut
- Shrinking and swelling of the soil

Impact of sealing lip for high-precision lysimeter weighing

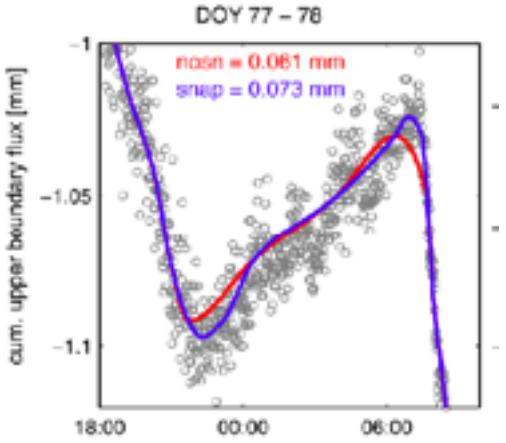




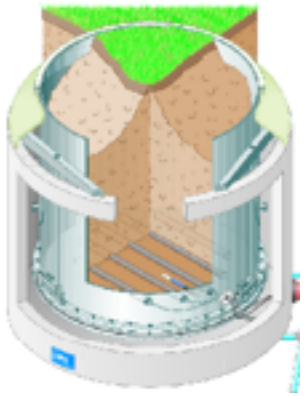
Perfect sealing lip for high precision lysimeter weighing

„Non Rainfall Water" & Evapotranspiration

AWAT-filter (noise reduction)



Peters et al. 2017, J HYDROL



Lysimeter data

Mass change?

(-)

(+) Rainfall at night?

yes

no

Rainfall

Daytime ET

Nighttime ET

Temperature >0°C?

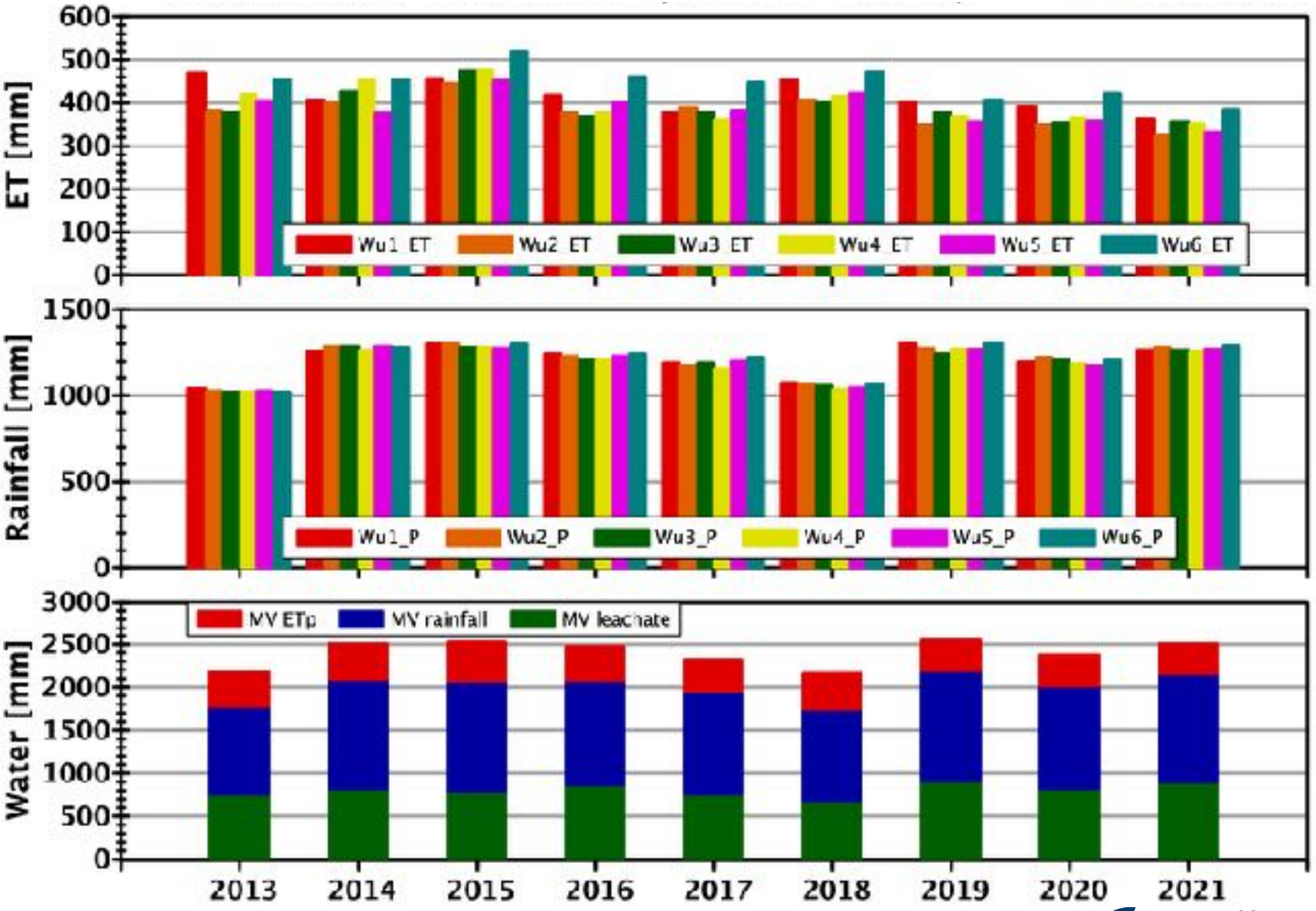
yes

no

Dew

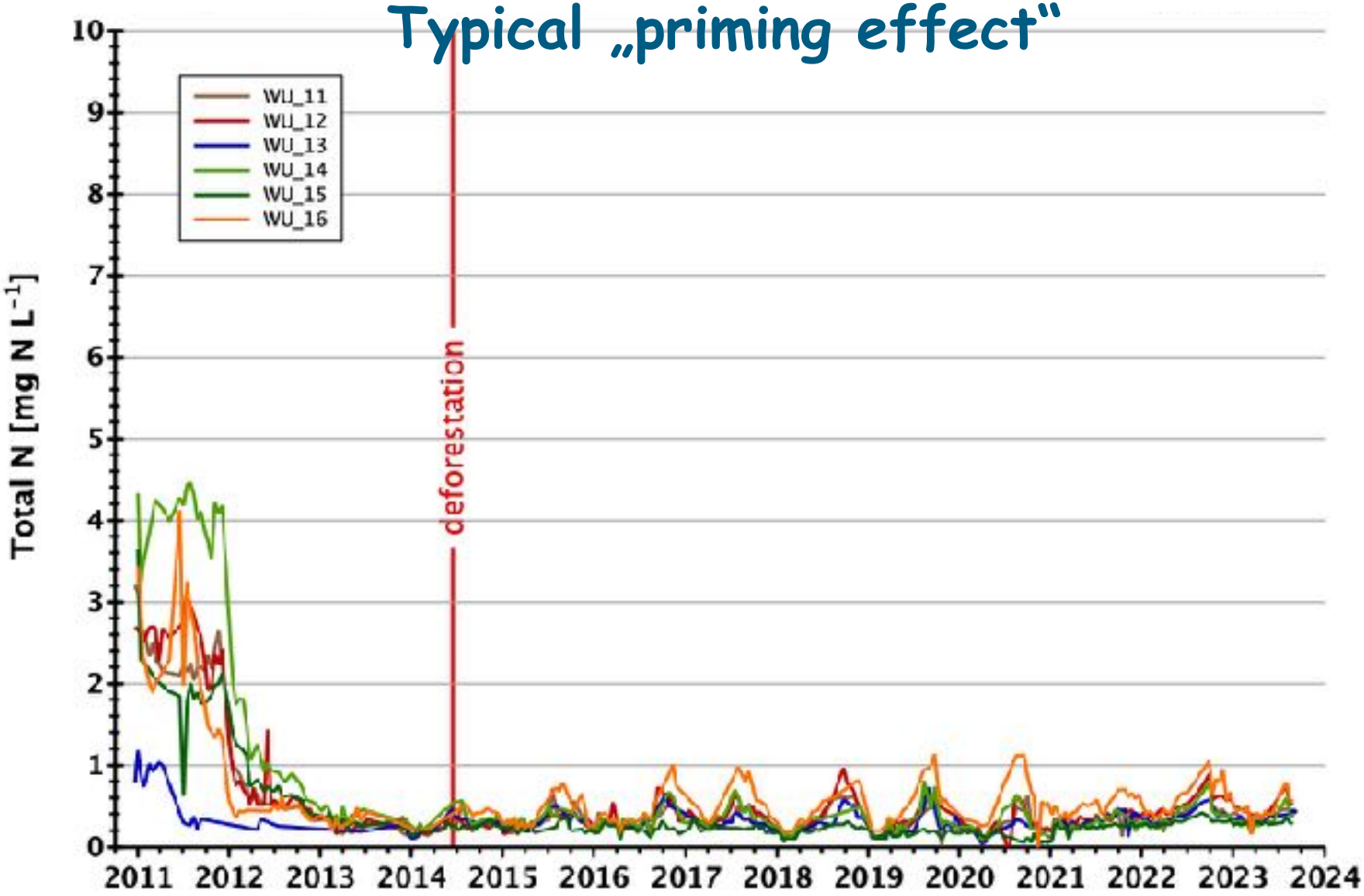
Hoar frost

Water balance of 6 lysimeters (annual values)

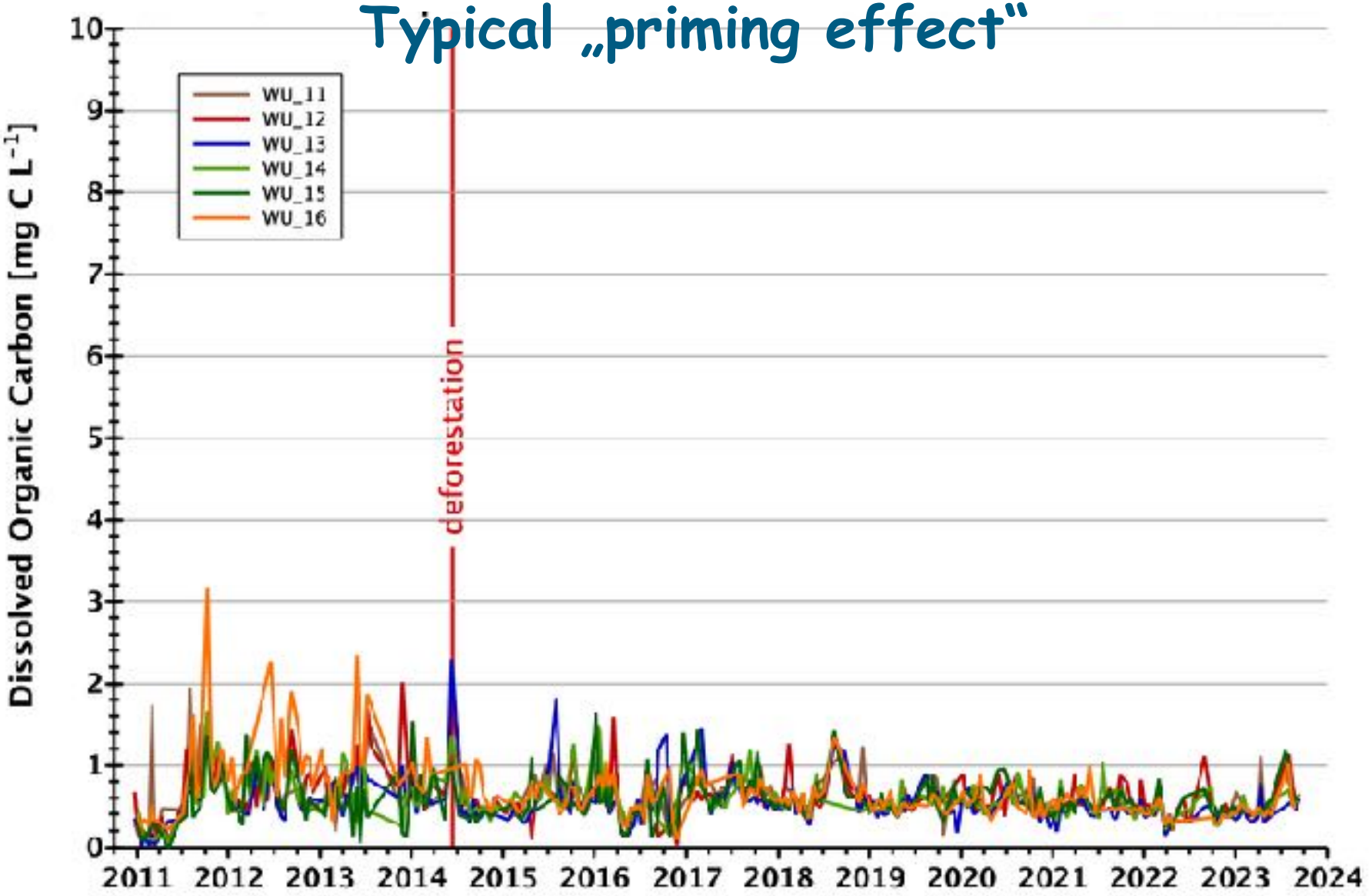


NO_3-concentrations in drainage water

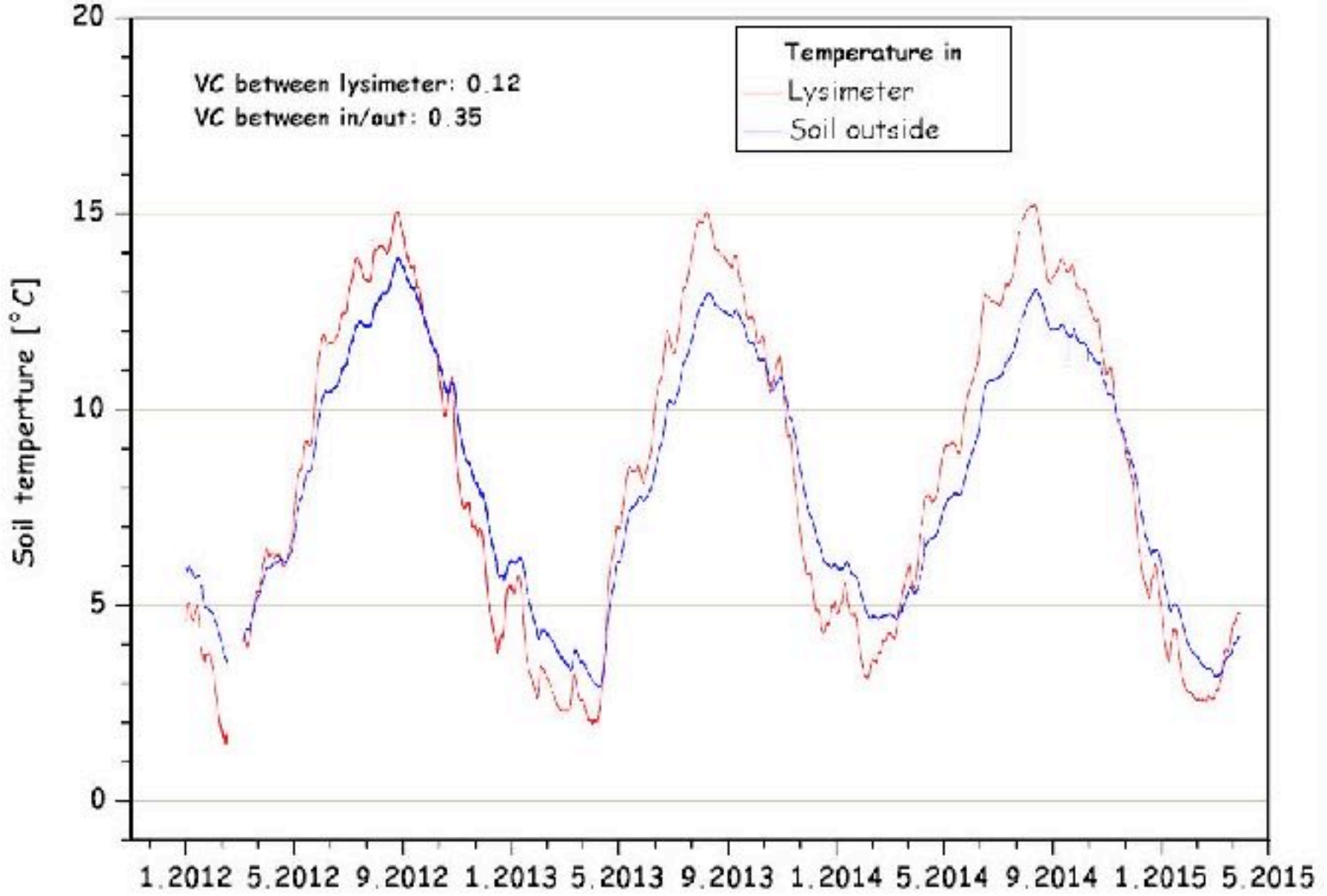
Typical „priming effect“



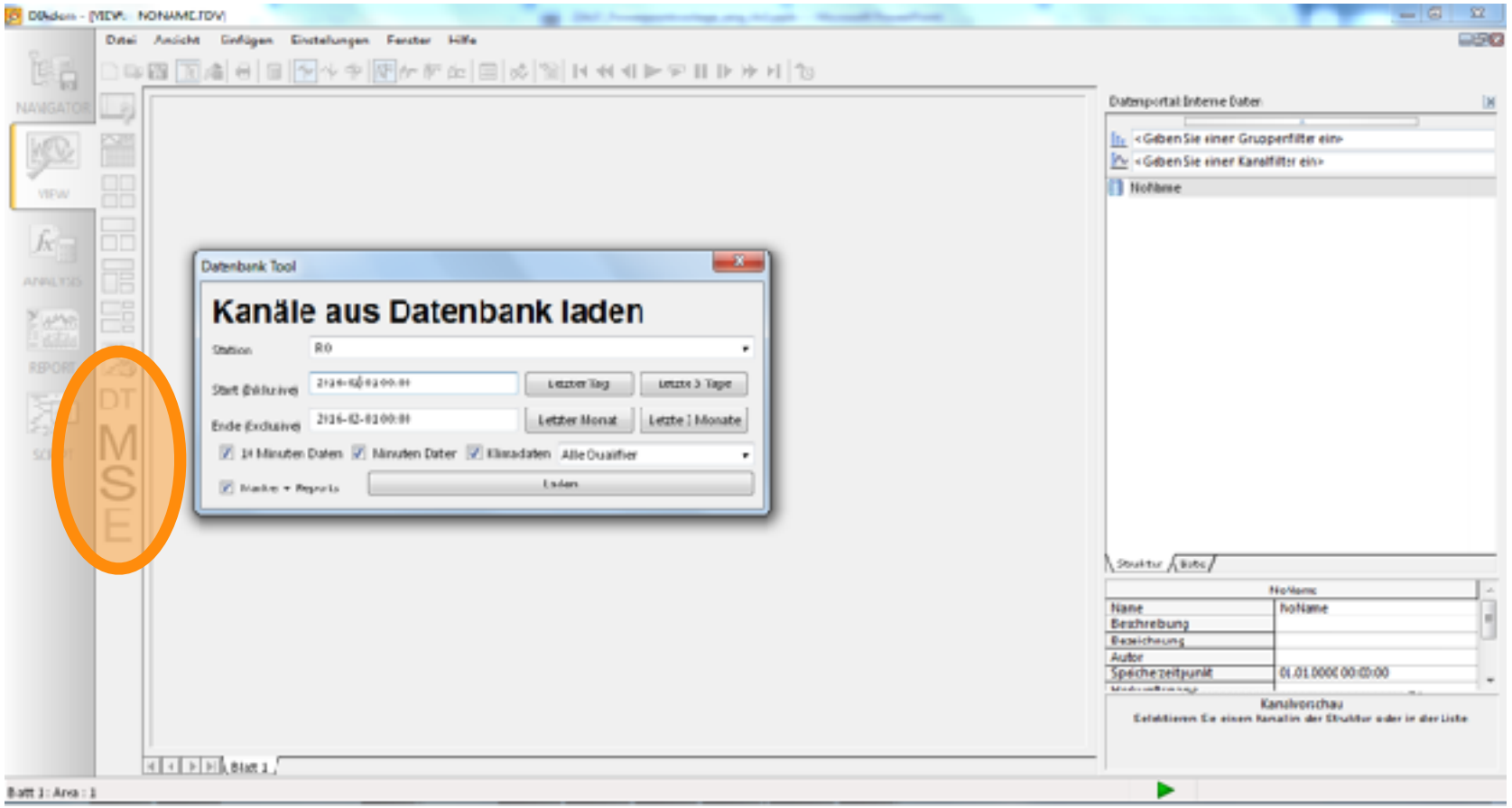
DOC-concentration in drainage water
Typical „priming effect“



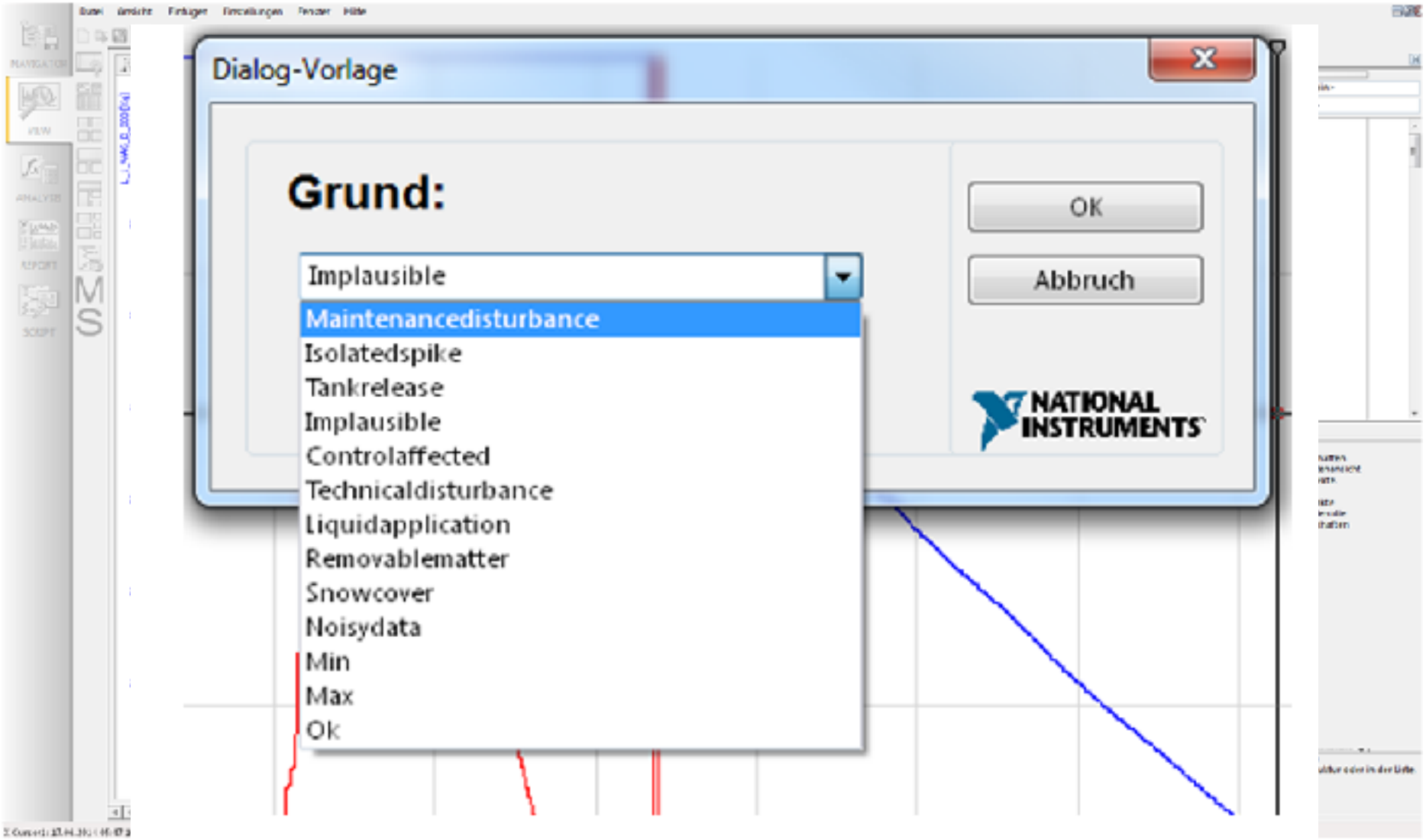
Soil temperature in Rollesbroich lysimeters



Modern data pre-processing

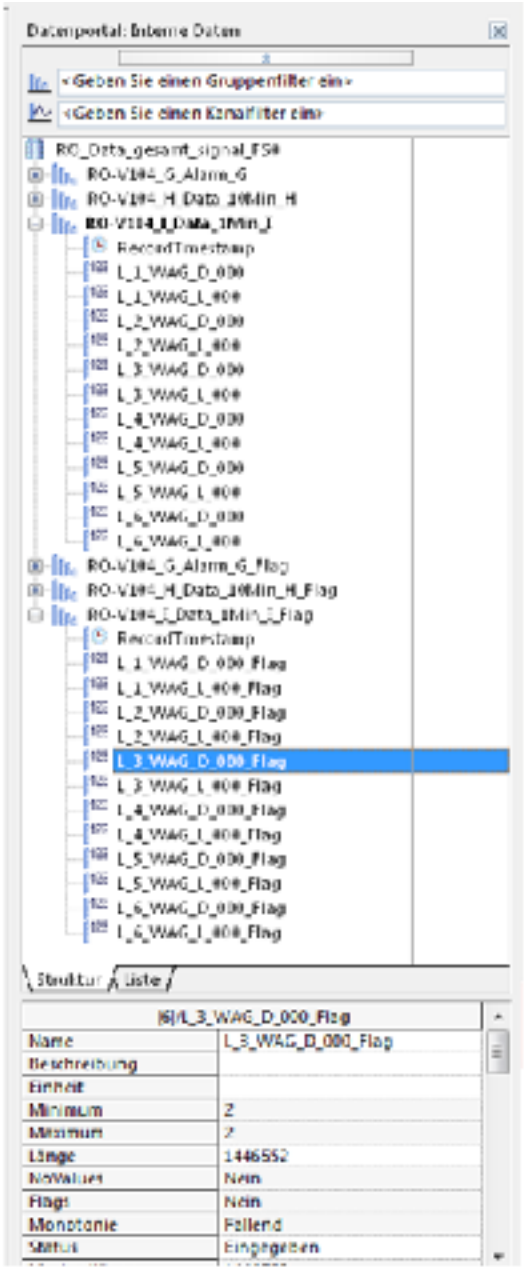


Data Processing - 1st Step: Manual Check/Flagging

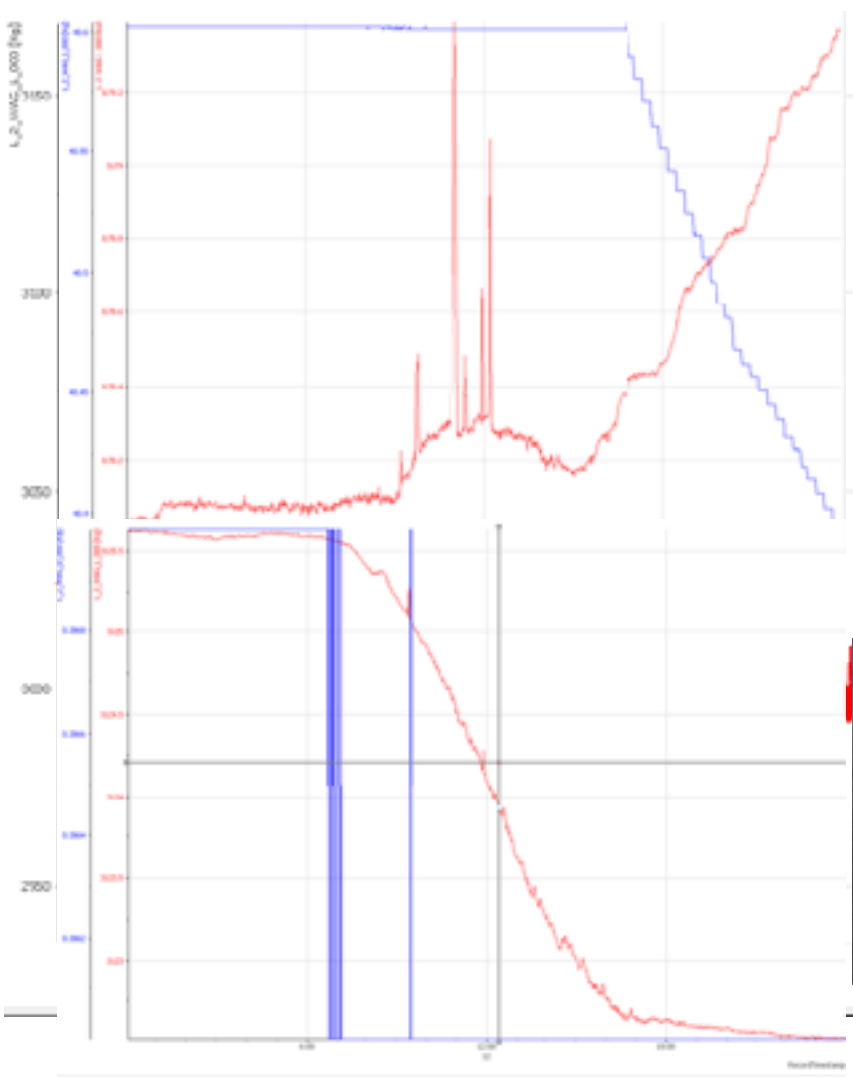


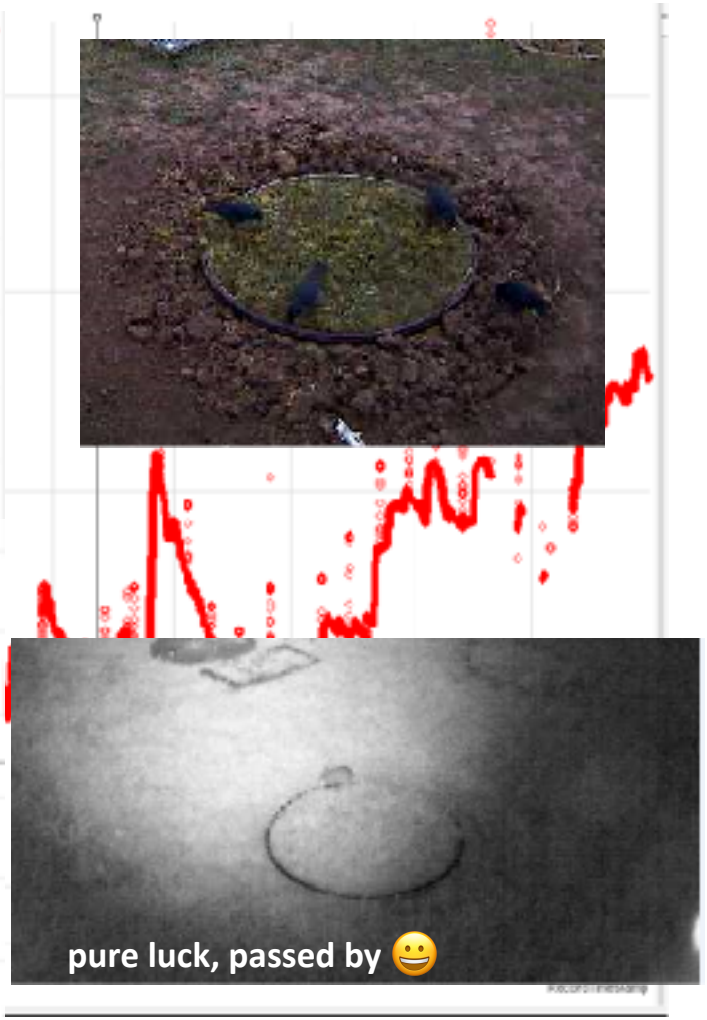
Flag-tool: DIADEM

Error-class	Type	OBJID
Maintenancedisturbance	baddata	37
Isolatedspike	baddata	18
Tankrelease	ok	44
Implausible	baddata	25
Controlaffected	ok	43
Technicaldisturbance	baddata	36
Liquidapplication	ok	42
Removablematter	baddata	41
Snowcover	suspicious	38
Noisydata	suspicious	8
Max	baddata	5
Min	baddata	6
ok	ok	2



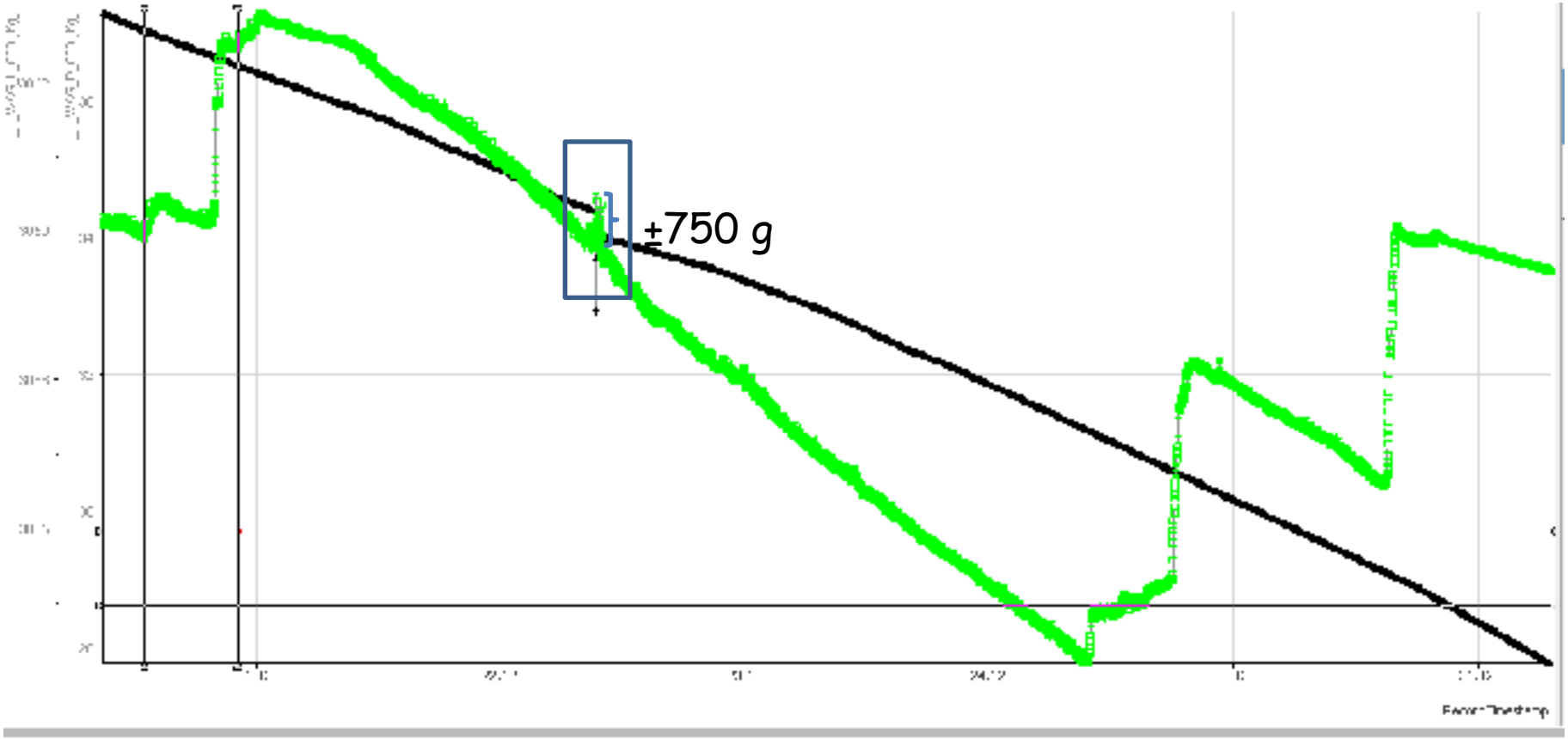
Example Of An Error Class: Outlier = „ Isolatedspike“



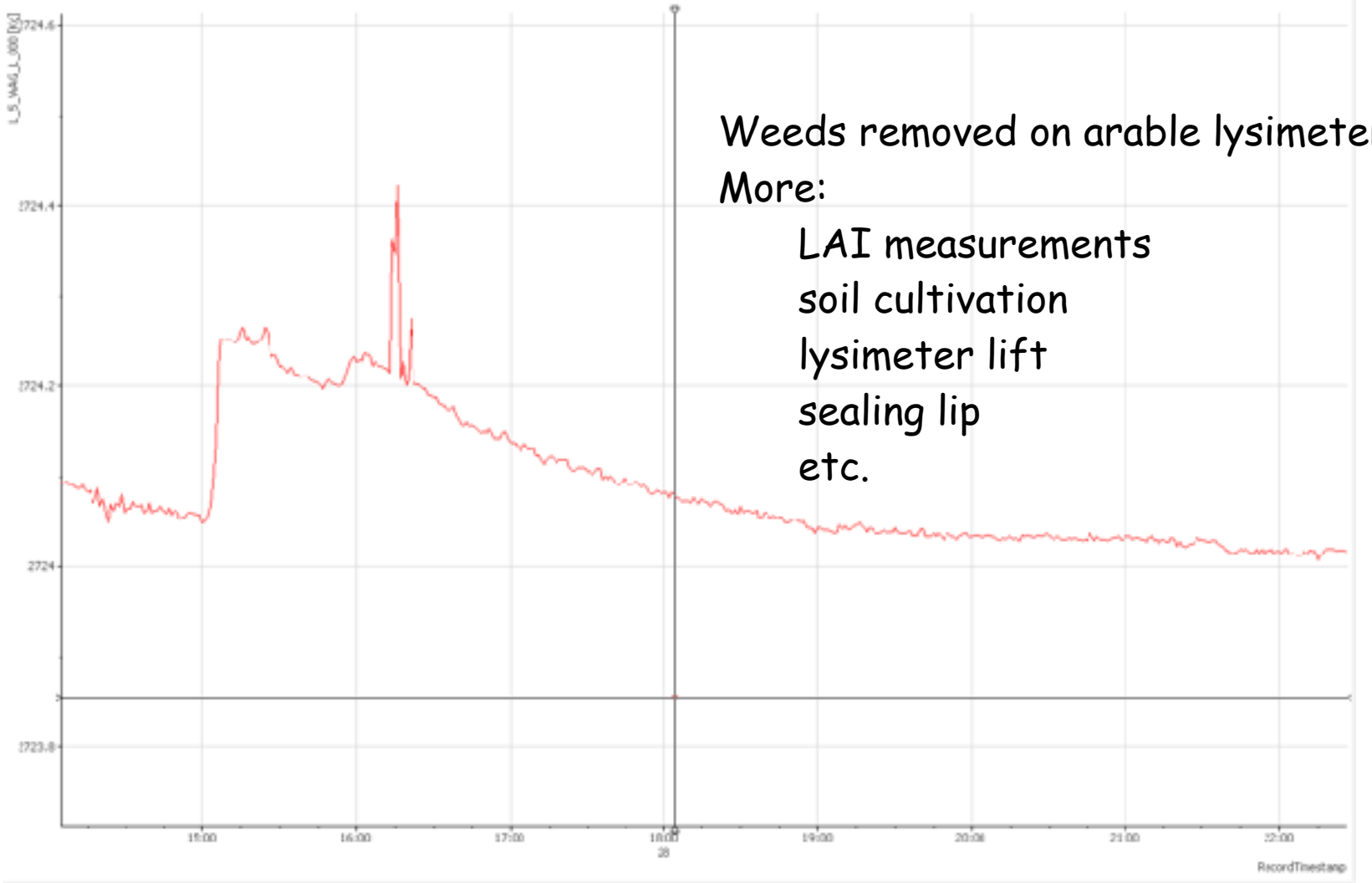


Example Of An Error Class:
Sampling / Repair etc. = "Maintanencedisturbance

Sampling in particular led to frequent errors!
Problem also for GAP-FILLING, because the whole hexagon is affected!



Example Of An Error Class:
Sampling / Repair etc. = „Maintanencedisturbance
More Disturbances



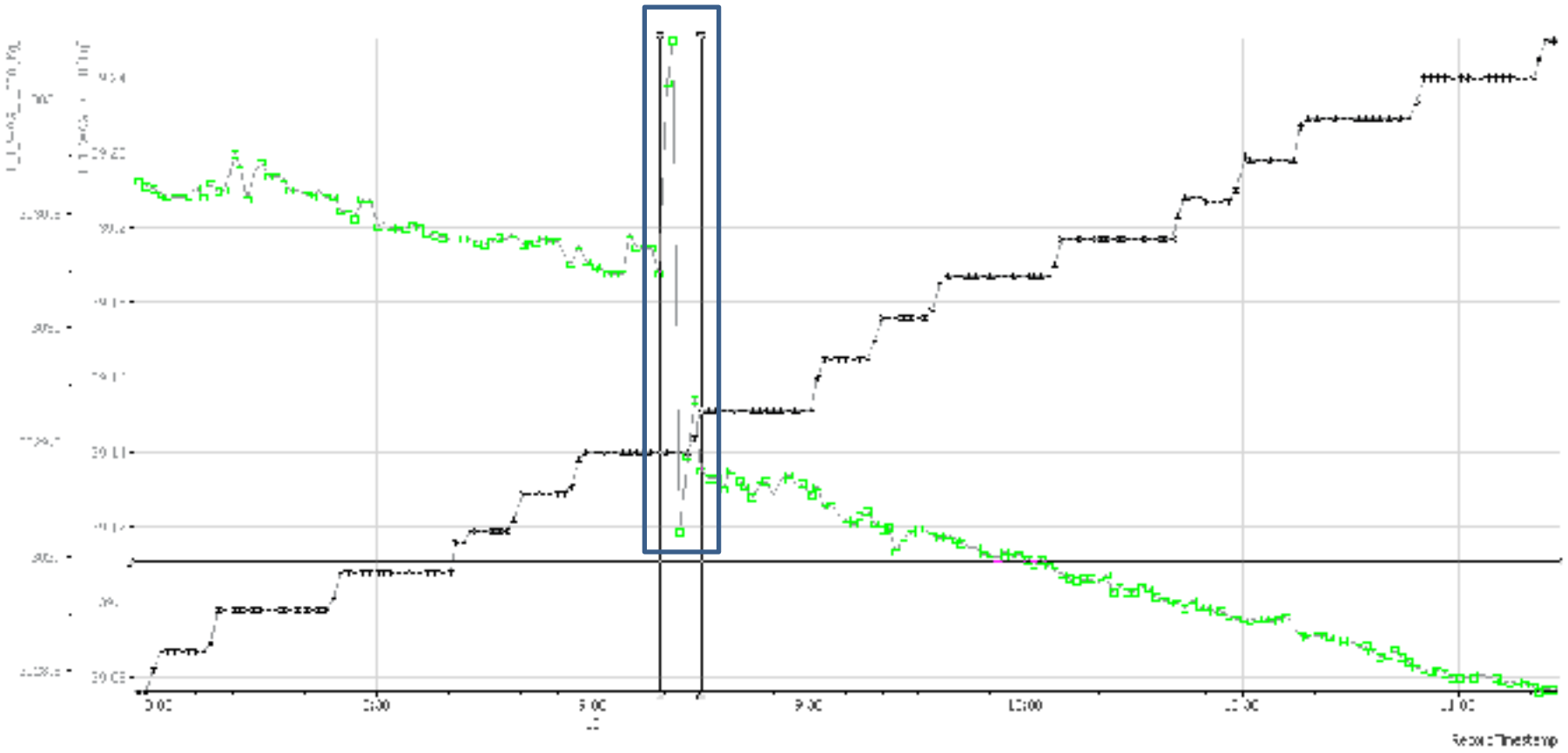
Weeds removed on arable lysimeter!

More:

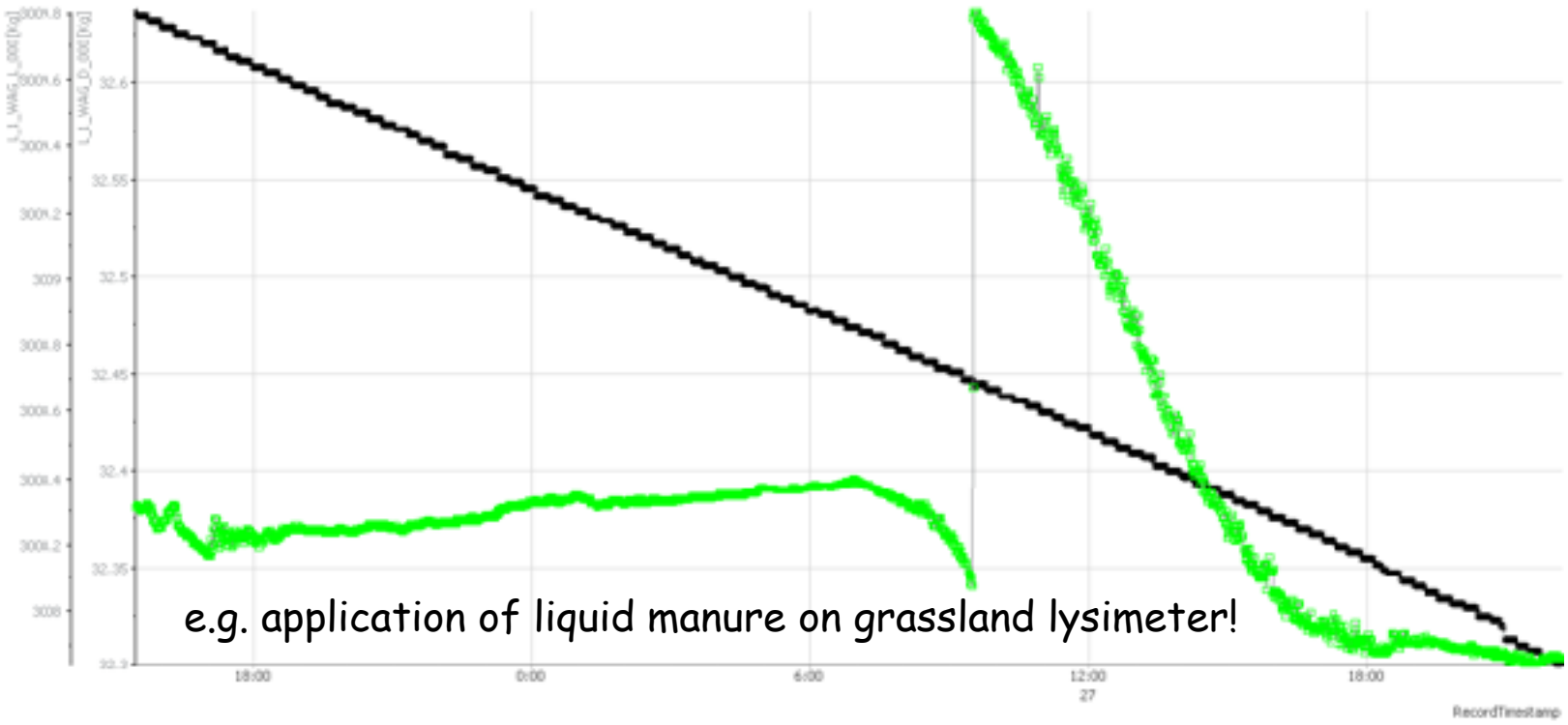
- LAI measurements
- soil cultivation
- lysimeter lift
- sealing lip
- etc.

Example Of An Error Class: Harvest = Removablematter

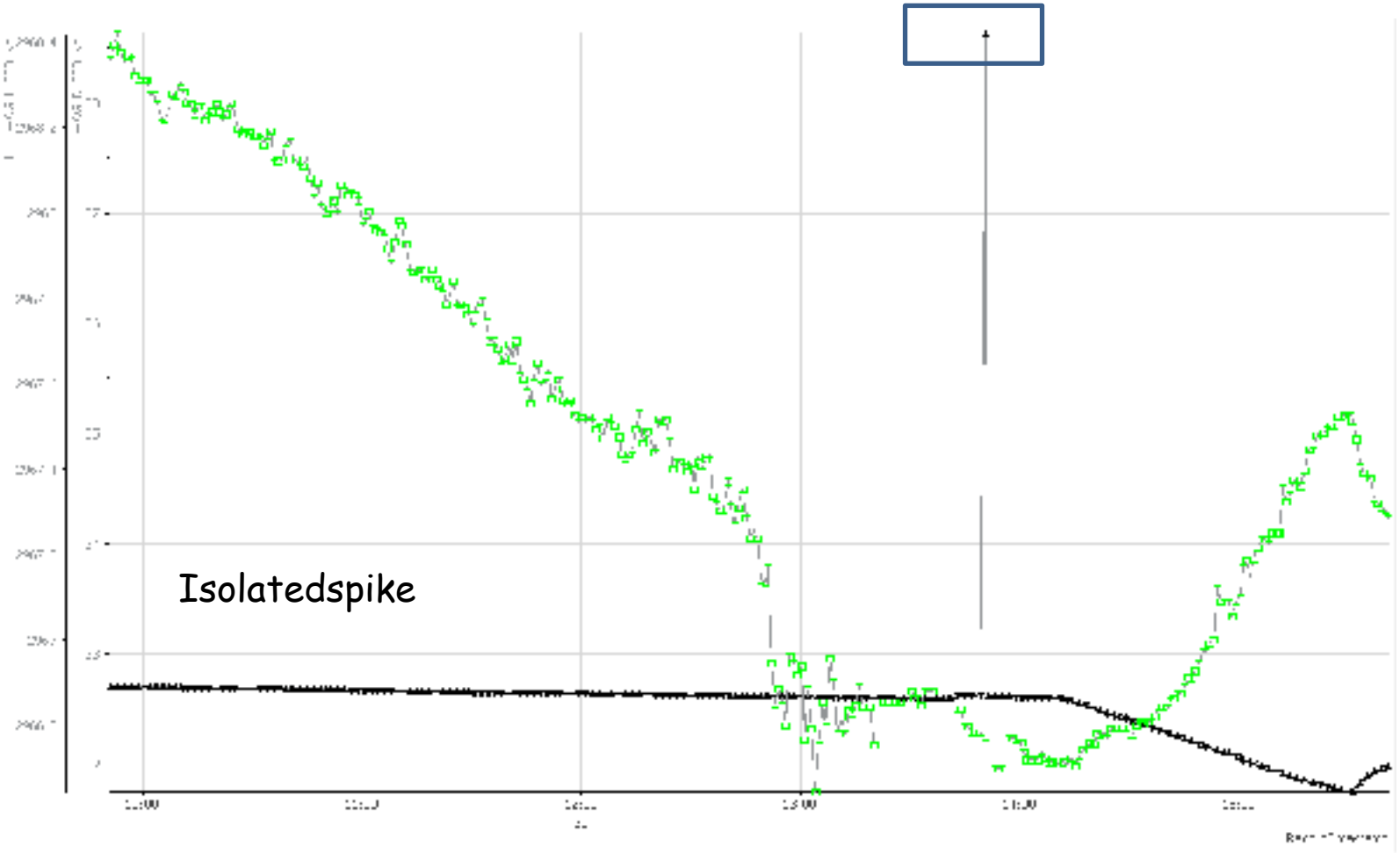
Why? Information for the water balance and it must be calculated correctly!
Otherwise it would have to be marked as an agricultural measure anyway!



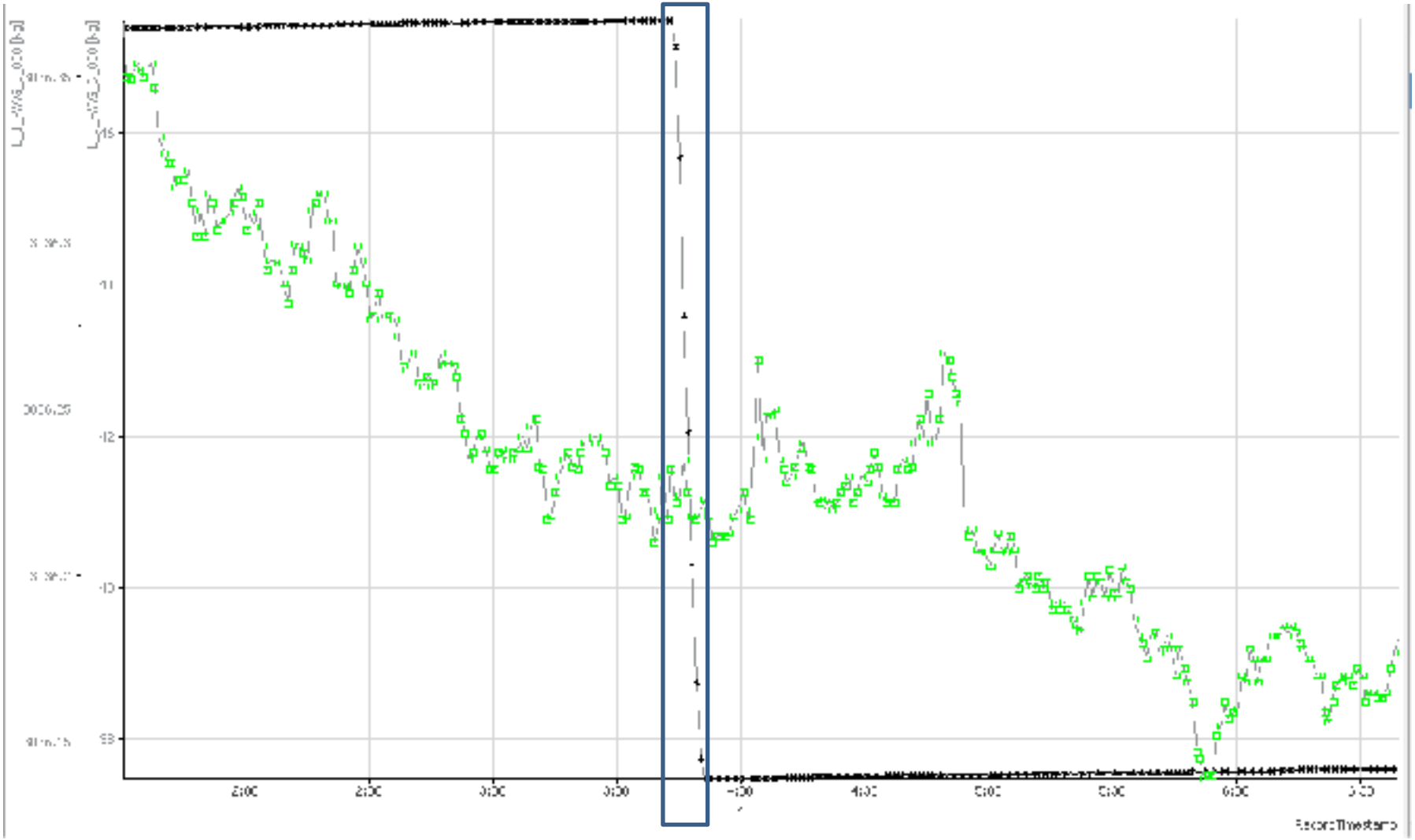
Irrigation/application = Liquidapplication (Data ObID = ok and not Baddata!)
Mark fertiliser (slurry), pesticides or e.g. tracer; prevents influence on the water balance / compare with rain gauges (check plausibility)!



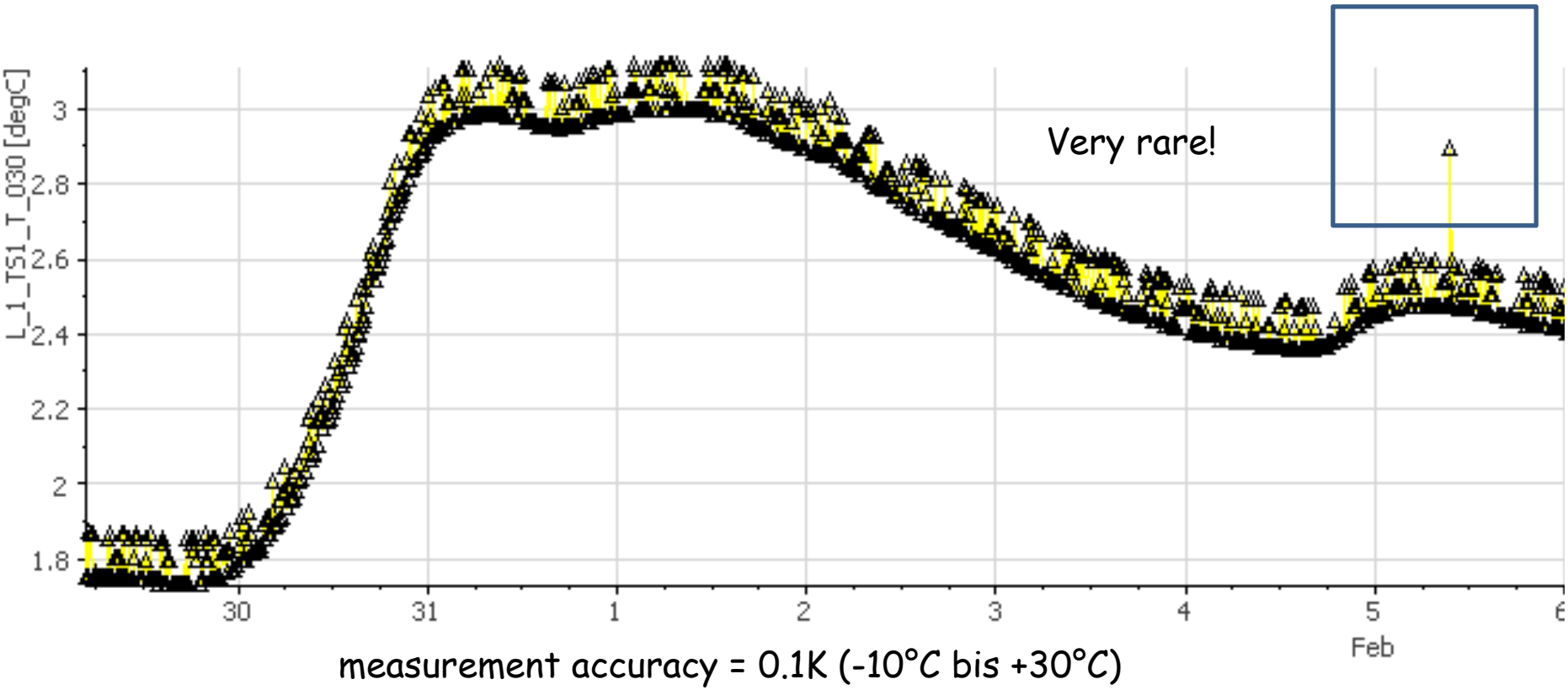
Outlier = „Isolatedspike“



Emergency outlet = Tankrelease (ok)

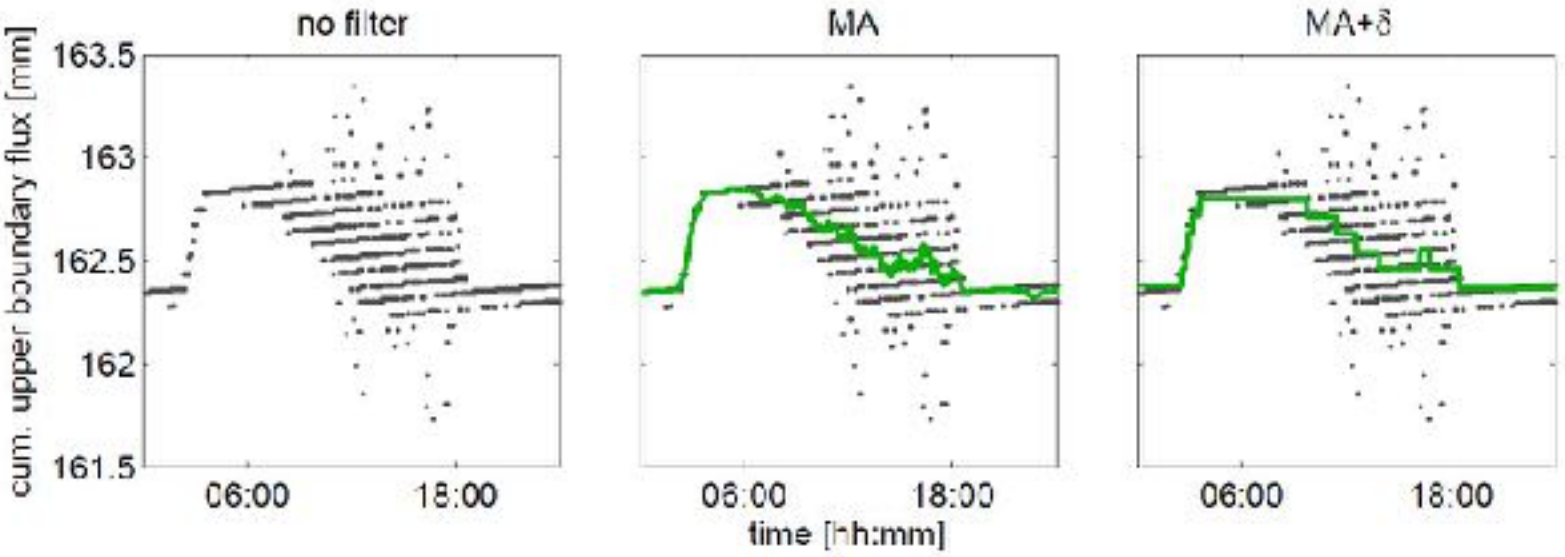


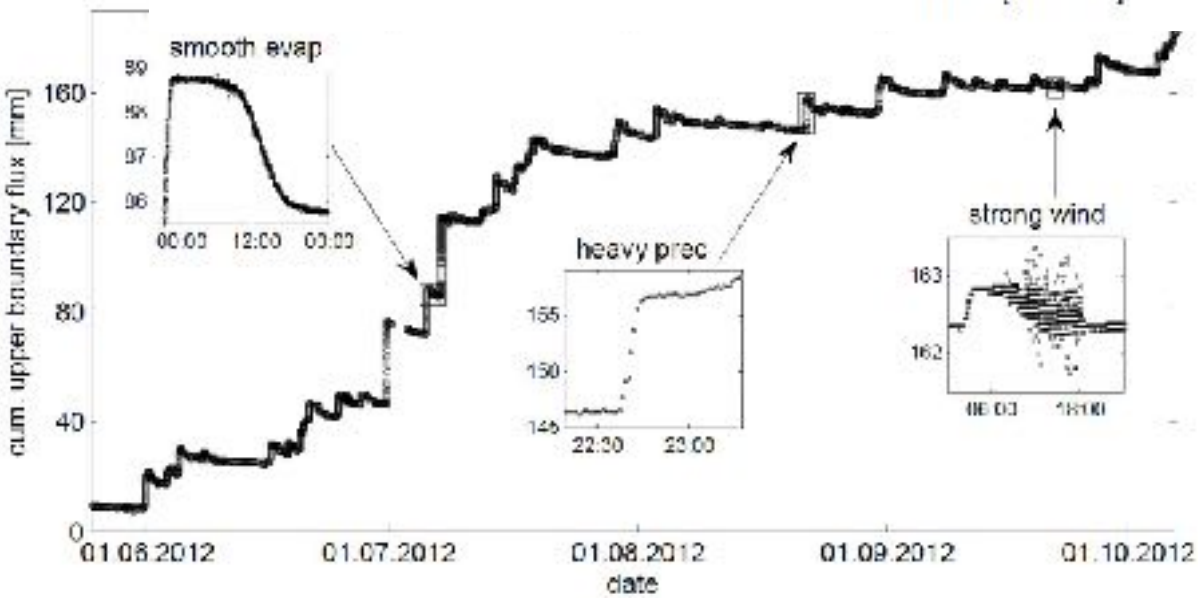
Temperatur (TS1)
1. Outlier = Isolatedspike



measurement accuracy = 0.1K (-10°C bis +30°C)

Data Processing

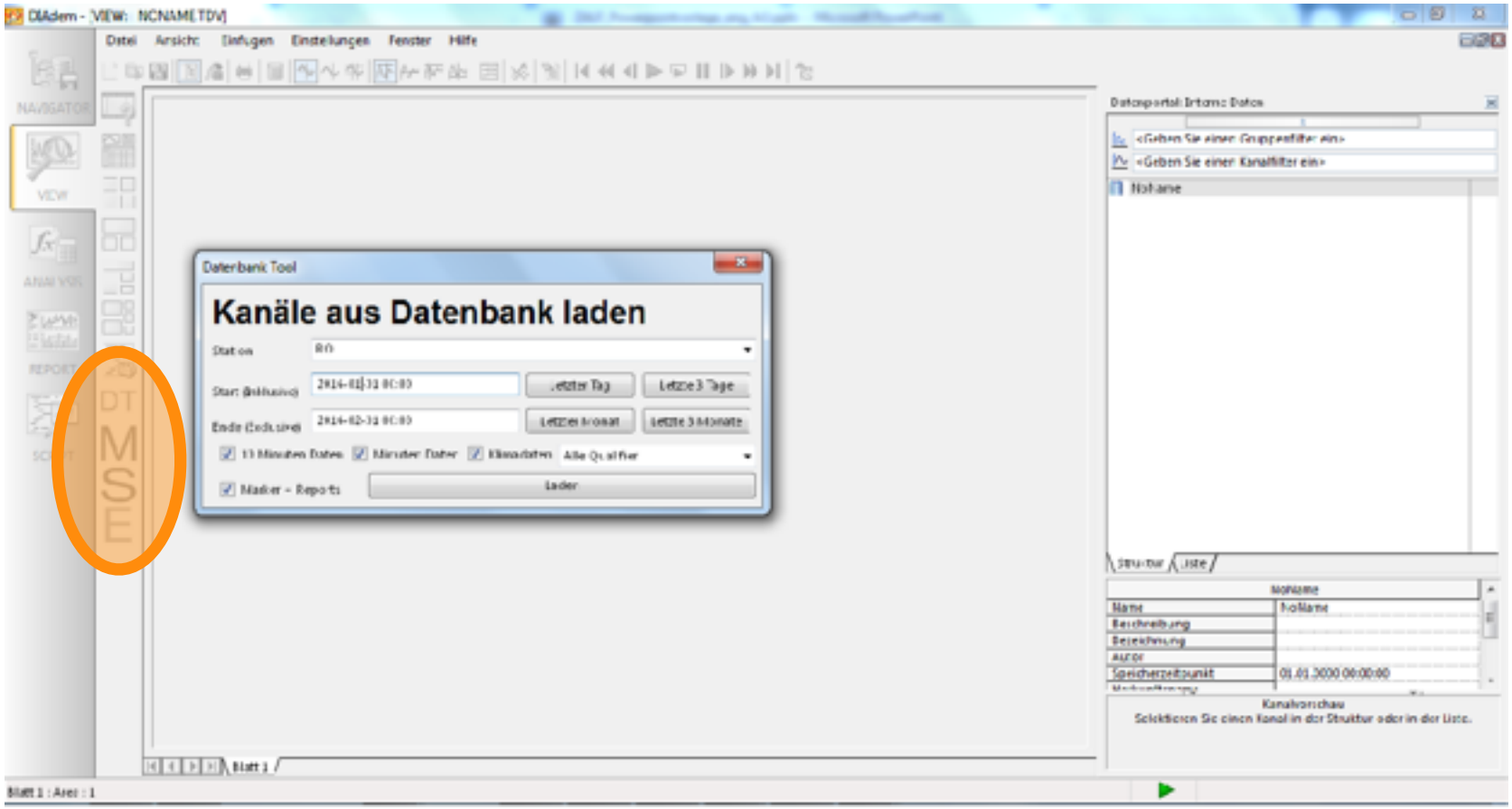




AWAT- filter routine

source: PETERS 2017

Software to handle „big“ data sets



A high-performance lysimeter network

Important prerequisites for a functioning network:

- Regular scientific exchange/conferences/workshops
- Regular meetings of technical staff to exchange experiences!!!
- Know-how transfer
- Mutual data exchange for quality assurance
- Central tools for data processing with continuous support, development and adaptation
- Central database for optimal utilization and use of "expensive" data

Some scientific conclusions

- Dynamic tension controlled bottom boundary of lysimeters is an import asset to observe water flux and solute movements with a minimal disturbance
- Dew formation and nighttime evapotranspiration need to be considered in ecosystem water balance studies
- Observations from high precision weighable lysimeters improved models to predict dew formation and nighttime evapotranspiration
- Using lysimeter observations to define accurately the boundary conditions of the model domain and present an important asset of the measurements system
- Using realistic boundaries and simultaneously multiple in-situ observations types during the inverse modeling improved the description of water flow and solute transport processes in the vadose zone

Thank you for your attention!

Acknowledgements:

Thanks to all my colleagues for their kind support: J. Groh, W. Küpper, F. Engels, R. Harms, P. Meulendick, L. Fürst, M. Krause, A. Ecker, S. Stork, H. Wissel, A. Lücke, J. Sorg, R. Peters, T. Korf, B. Bourgart, R. Kunkel, J. Vanderborght, H. Vereecken,