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Manipulation experiments to infer the age and tracer composition of hydrologic fluxes

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Manipulation experiments can be very useful because one can:

- measure things that cannot be measured/observed in the field

(e.g. water storage, leakage)

- control and stress physical experimental conditions

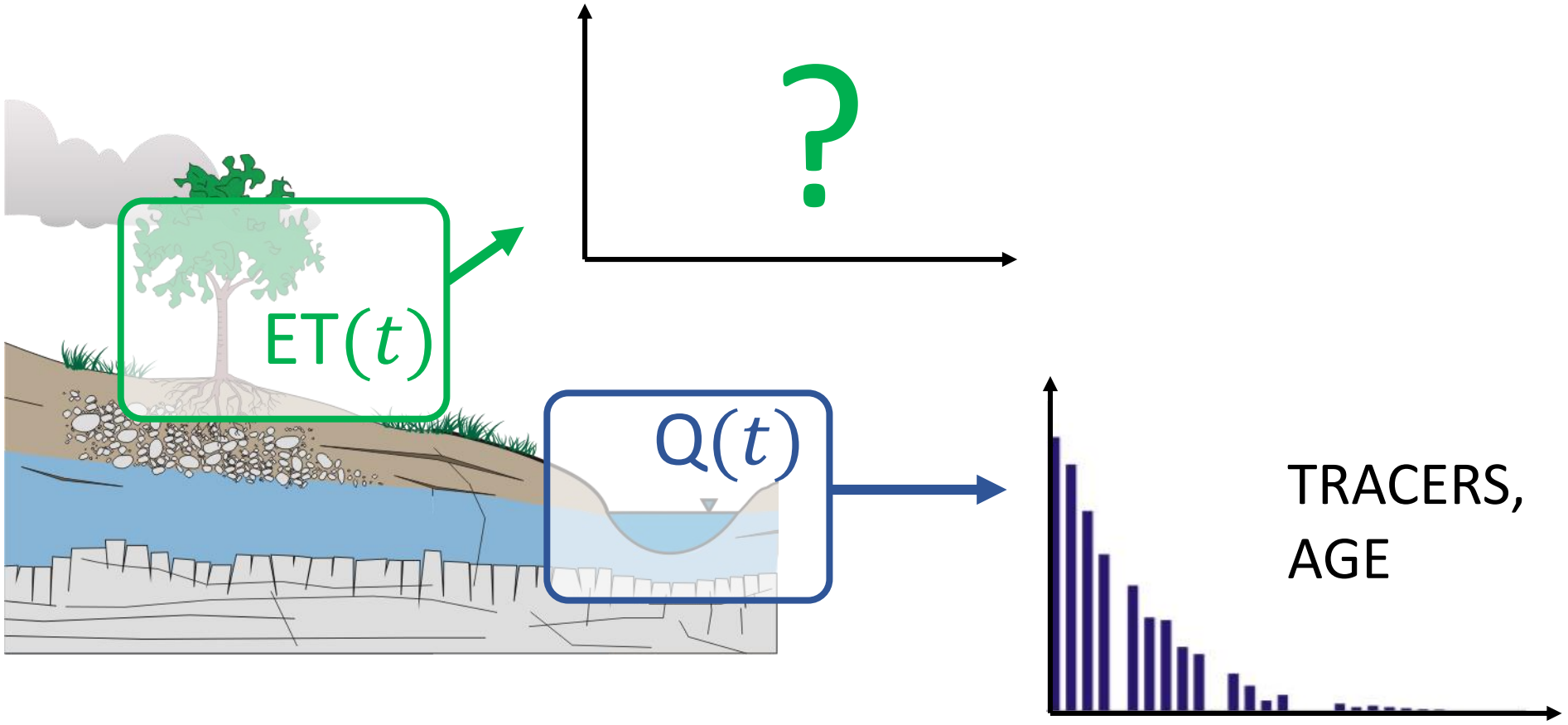
(e.g. wet/dry conditions)

- enhance process detection

(e.g. use of high tracer concentration)

few recent examples of controlled tracer experiments:
Evaristo *et al*., 2019, WRR
LEO, Biosphere 2 (USA), *ongoing*
University of Freiburg (DE), *ongoing*

Do we have the ability to close the hydrologic balance EXPERIMENTALLY?



We often impose the mass balance closure, even when we do not know if we achieved it

There is substantial uncertainty whenever a mass flux is not monitored and we estimate it by difference

SPIKE II: a controlled tracer experiment to

1) attempt the tracer mass balance closure

2) get a high-resolution tracer breakthrough curve for the transpiration flux

3) test models and hypotheses of integrated hydrologic function

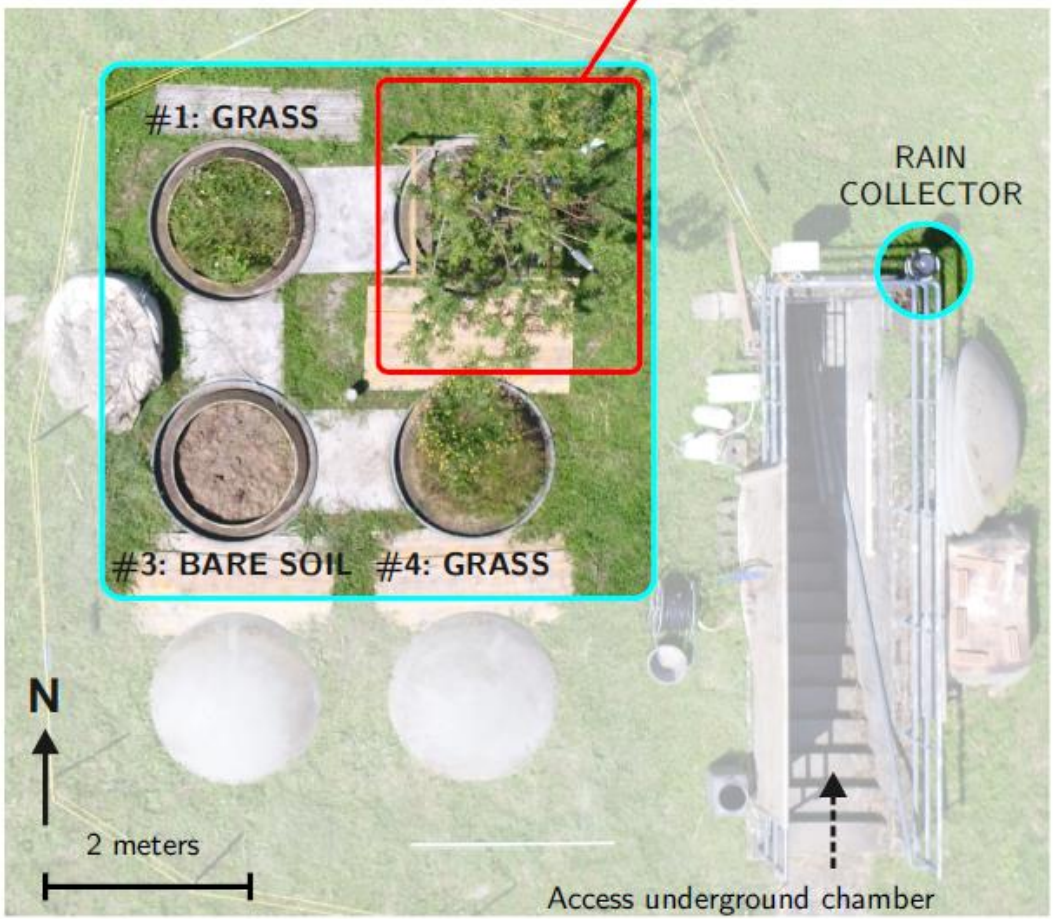
… and much more

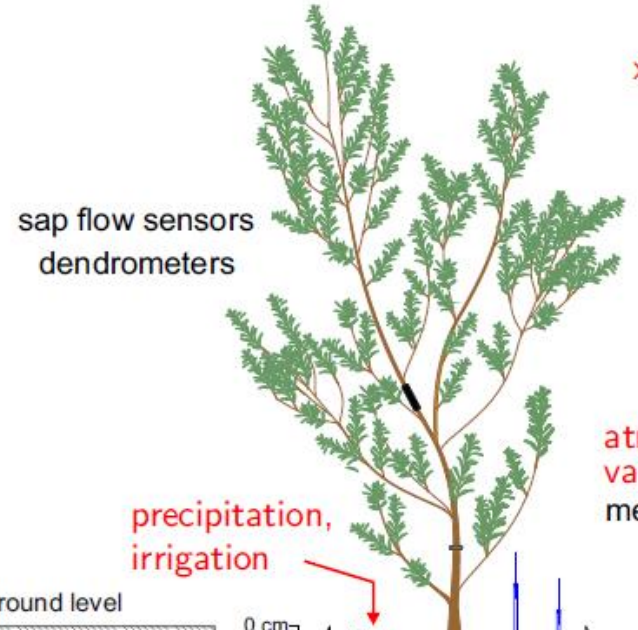
EXPERIMENTAL SETUP

METEO STATION

EVAPORATION BUCKET

#2: WILLOW TREE



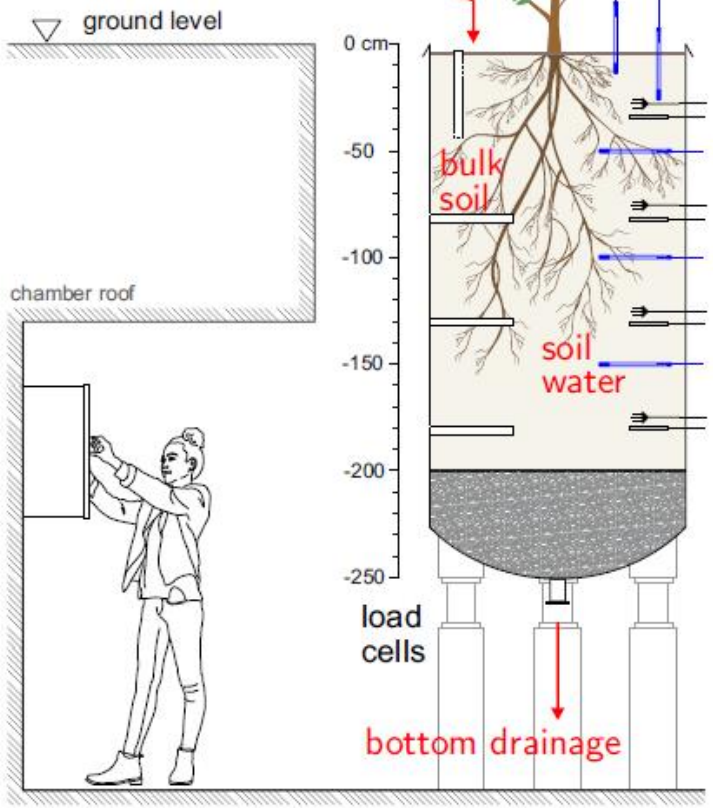


xylem
phloem
leaves
leaf cellulose

sap flow sensors
dendrometers

atmospheric vapor
meteo data

precipitation, irrigation



FDR probes
(VWC, temp.)

tensiometers
(soil tension, temp.)

Additional samples:
bulk soil, grass lysimeter #1
soil water, grass lysimeter #1
water evaporation bucket

what we measured

HYDROLOGY (15-min)
- Bottom drainage
- Precipitation
- Irrigation
- ET (x5)

METEO (15-min)
- wind speed and direction
- global radiation
- humidity
- temperature

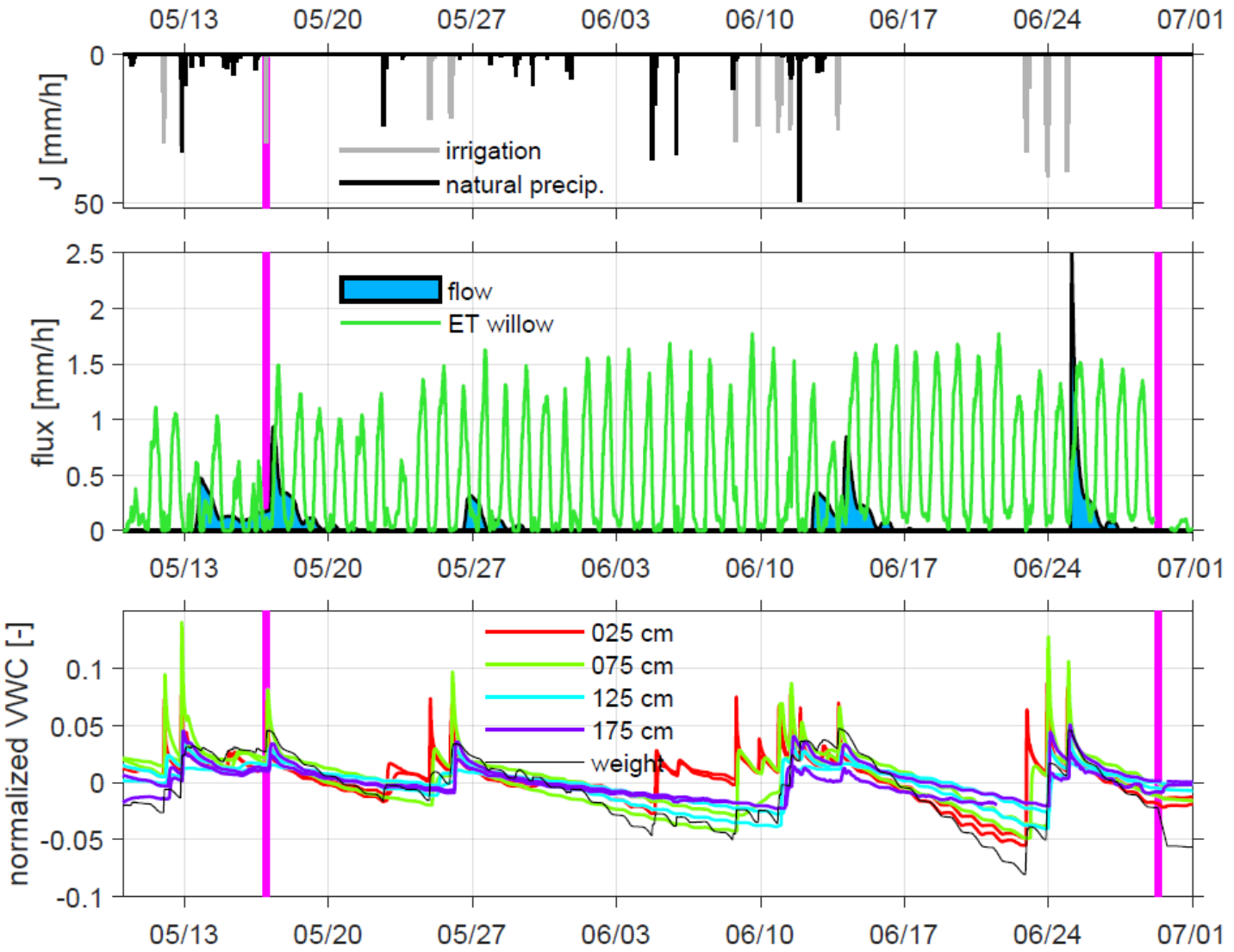
SOIL (15-min)
- VWC, 4 depths: (2x25, 2x75, 2x125, 2x175)
- Temperature, 4 depths: (3x25, 3x75, 3x125, 3x175)
- soil tension (1x25, 1x75, 1x125, 1x175)

TREE
- sap flow (15-min), 3 stems
- dendrometer (15-min), 3 stems
- leaf area, root distribution, branch distribution

ISOTOPES (~850 samples)
- bulk soil, 5 depths: (2x10, 2x25, 2x80, 2x100, 2x150), n=130
- mobile water, 5 depths: (3x10, 3x25, 3x50, 2x100, 3x150, n=318
- bottom drainage, n=37
- precipitation, n=22
- irrigation (tap water), n=10
- xylem, n=59
- phloem, n=34
- leaves, n=26
- bulk soil grass lysimeter #1, 3 depths: (2x10, 2x25, 2x50), n=24
- mobile water grass lysimeter #1, 3 depths: (2x10, 2x25, 2x50), n=53
- evaporation bucket, n=47
- atmospheric vapor, continuous
- atmospheric vapor, vacuum bottles, n=8
- bulk soil profiles (one at start and 3 at the end), n=76

1 application (30 mm of labelled water)
2 tracers ($\delta^{18}O$ and $\delta^{2}H$)
43 days of monitoring

START END



PRELIMINARY RESULTS

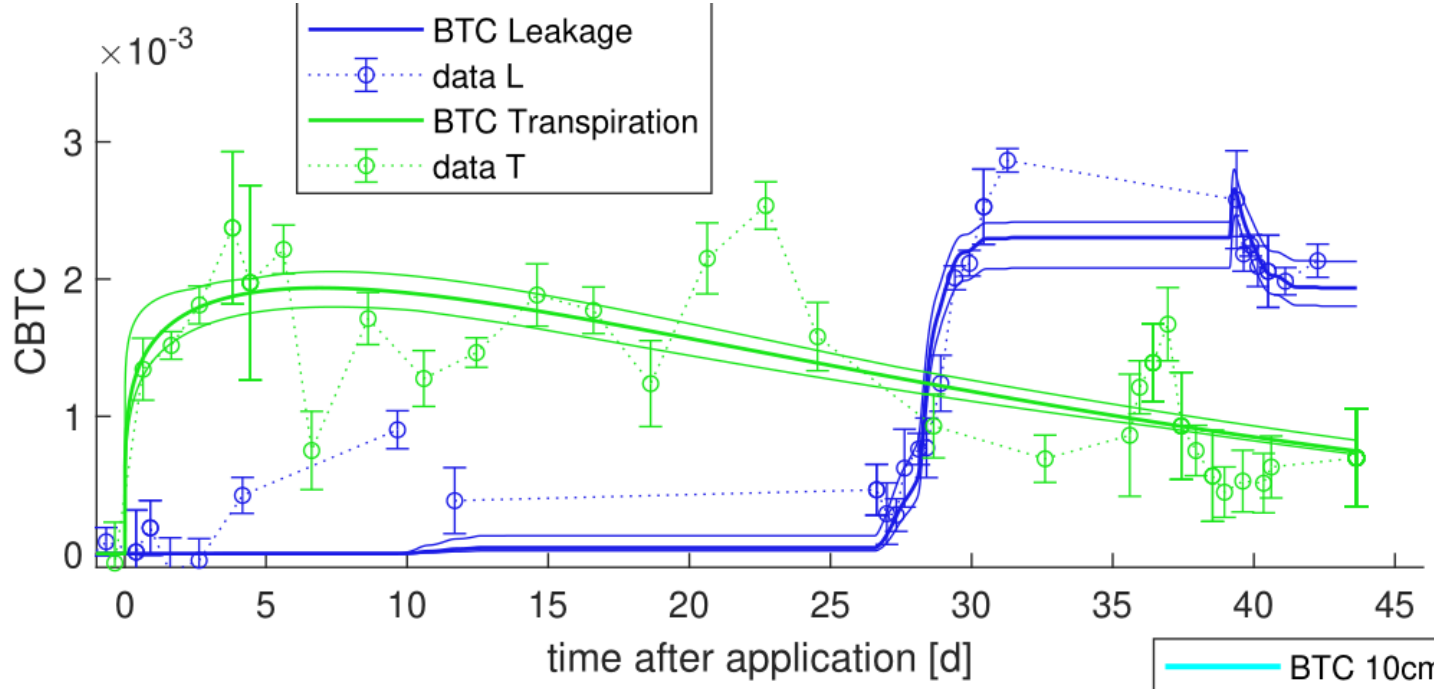
tracer breakthrough curves (BTC)

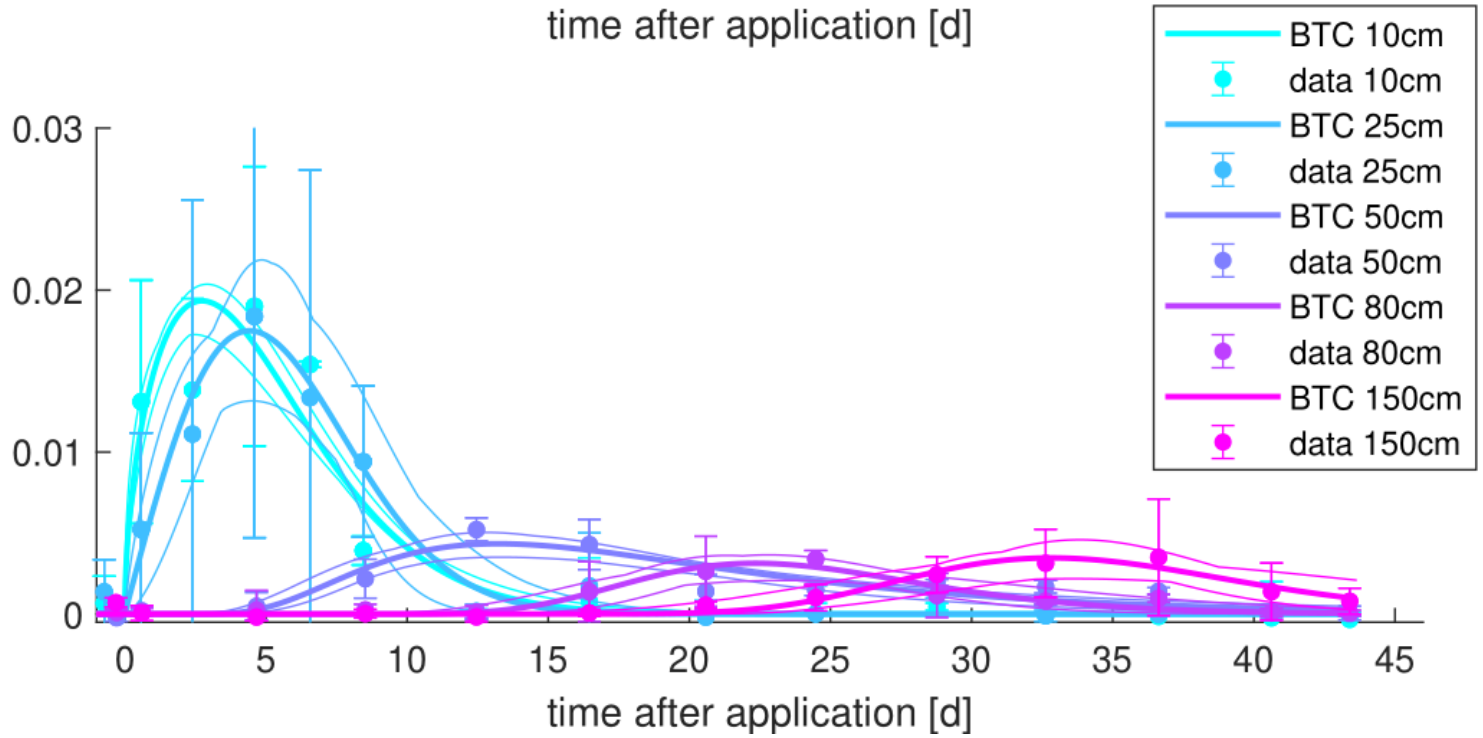
Tracer in the outflows:

-plant uptake starts right-after application
-plant uptake is persistent throughout the experiment
-plant uptake has a complex pattern
-release through deep leakage only starts after 25-30 days

Tracer within the soil column:

-high spatial variability, especially on top
-the mean behaves similarly to simple advection-dispersion



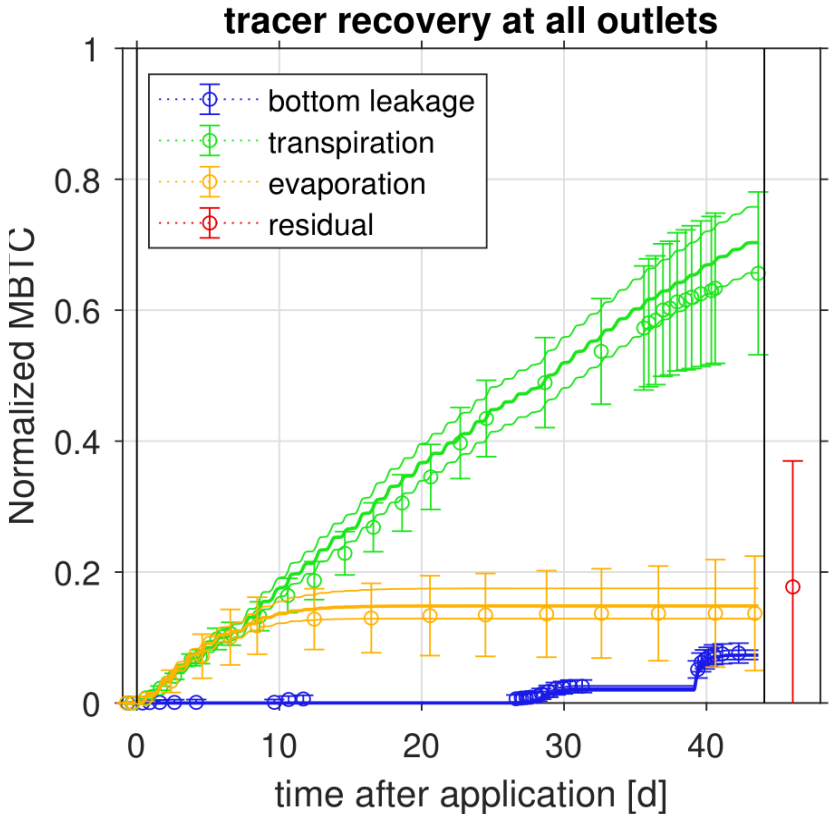


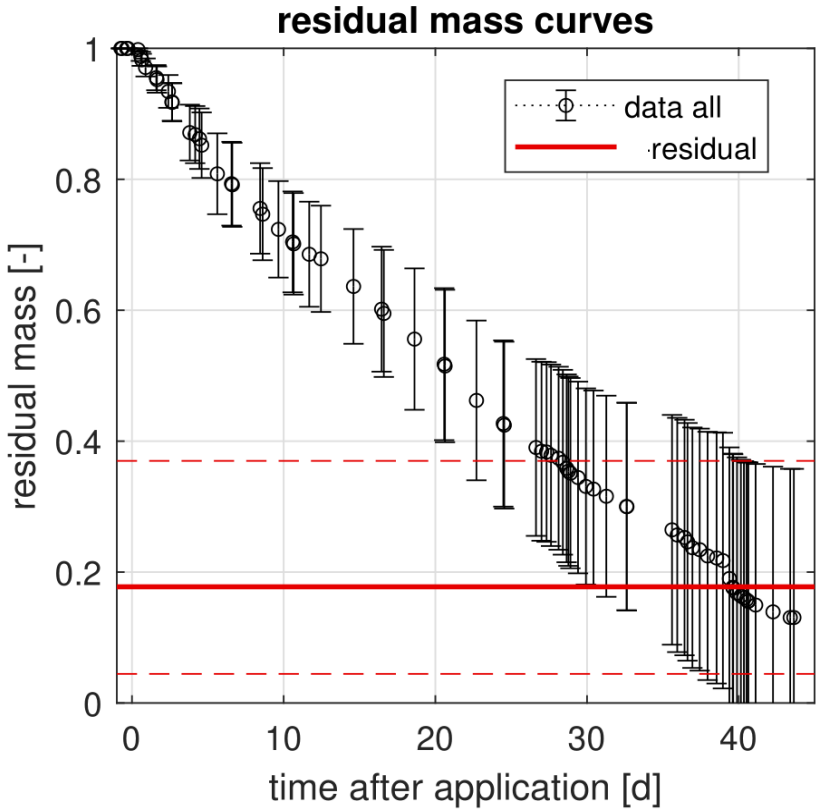
PRELIMINARY RESULTS

tracer balance closure

where did the tracer go?

LEAKAGE **8%** [CI: 8, 8]
TRANSPIRATION: **65%** [CI: 53, 76]
EVAPORATION: **14%** [CI: 5, 22]
RESIDUAL: **14%** [CI: 0, 33]





Good experimental closure: 104% [CI: 71,143]

(high spatial variability, leads to large uncertainty bounds)

We find that:

- The experimental mass balance closure is achieved and gives credibility to the estimated BTC curves
- Transpiration accounts for the large majority (76%) of the exported tracer mass in the 40 days following tracer application
- Plant uptake does not seem to occur from one characteristic depth (consistent with observed uniform root density). But mild variations in the plant uptake depth may explain the complex patterns in the transpiration BTC.
- This data is used to test:
    - age of transpiration and percolation waters
    - isotope fractionation models
    - ecohydrologic ‘separation’
    - E/ET ratio
    - (and more)

It can be easy (and very useful) to run a tracer experiment in ongoing experimental activities. Did you think about this?