Stable oxygen and hydrogen isotopes to study ecohydrology in forest ecosystems

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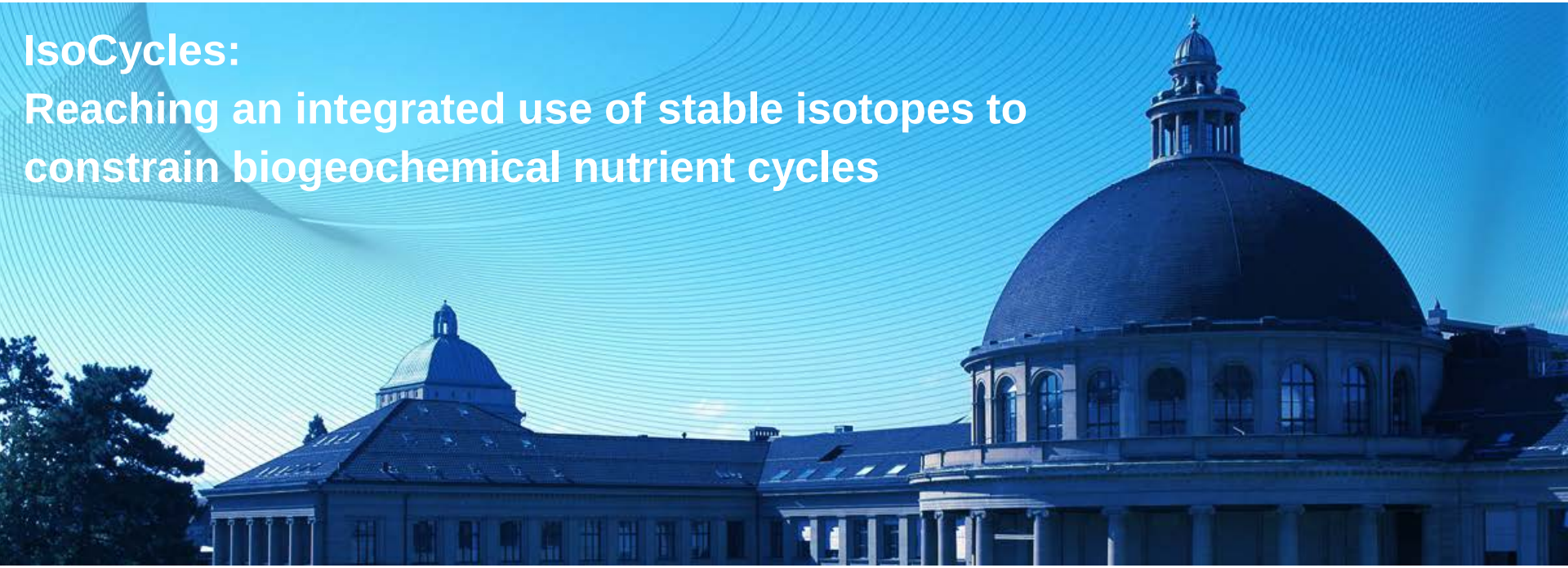

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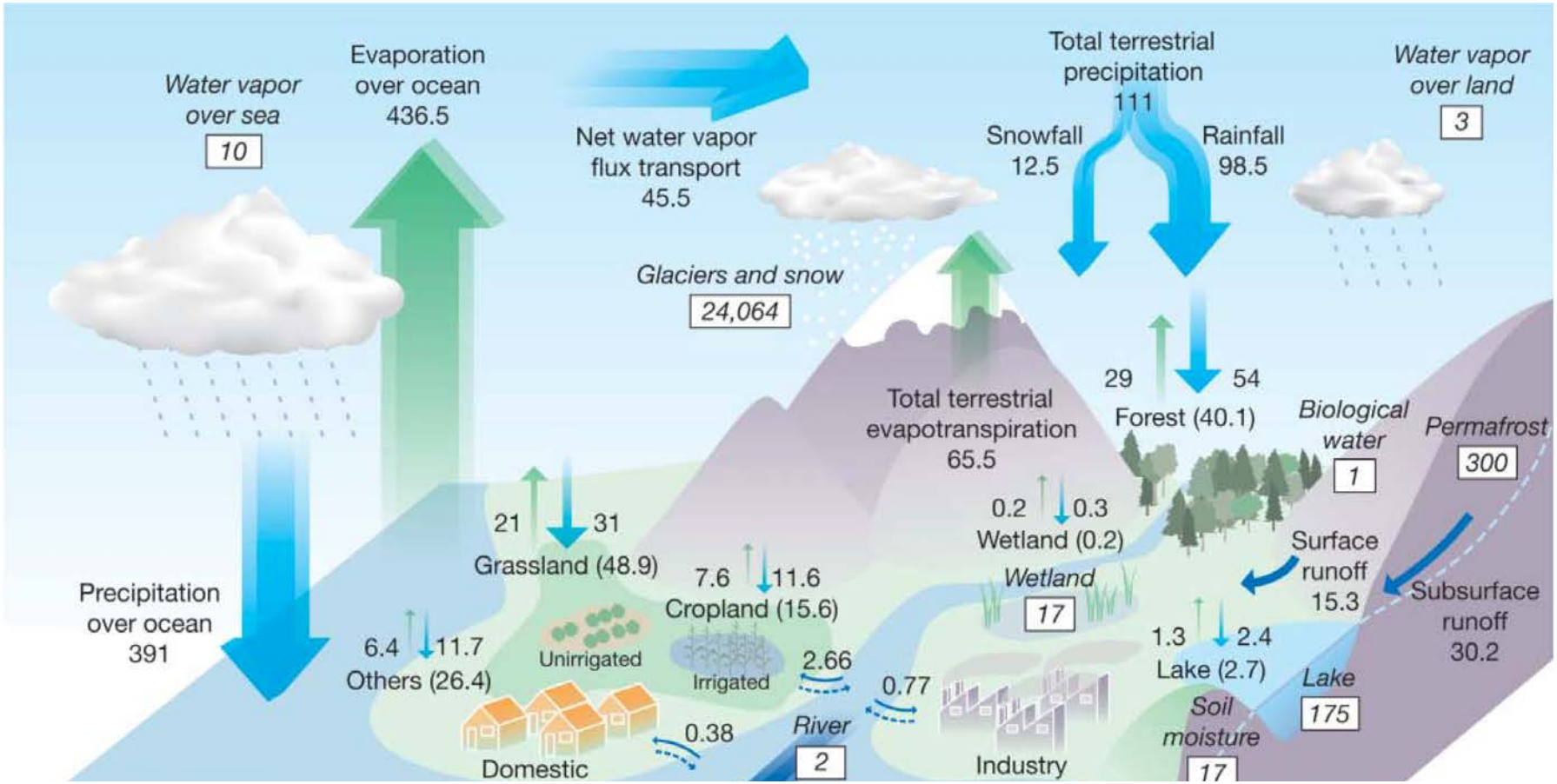
Stable isotopes to study ecohydrology

- Relevance and motivation
- Sensitivity of temperate tree species to low soil moisture availability
- Soil water sourcing: uptake depths, variations with low soil moisture
- Residence time of soil water, age of water taken up
- Tree/Ecosystem susceptibility to water limiting conditions

Why study ecohydrology?

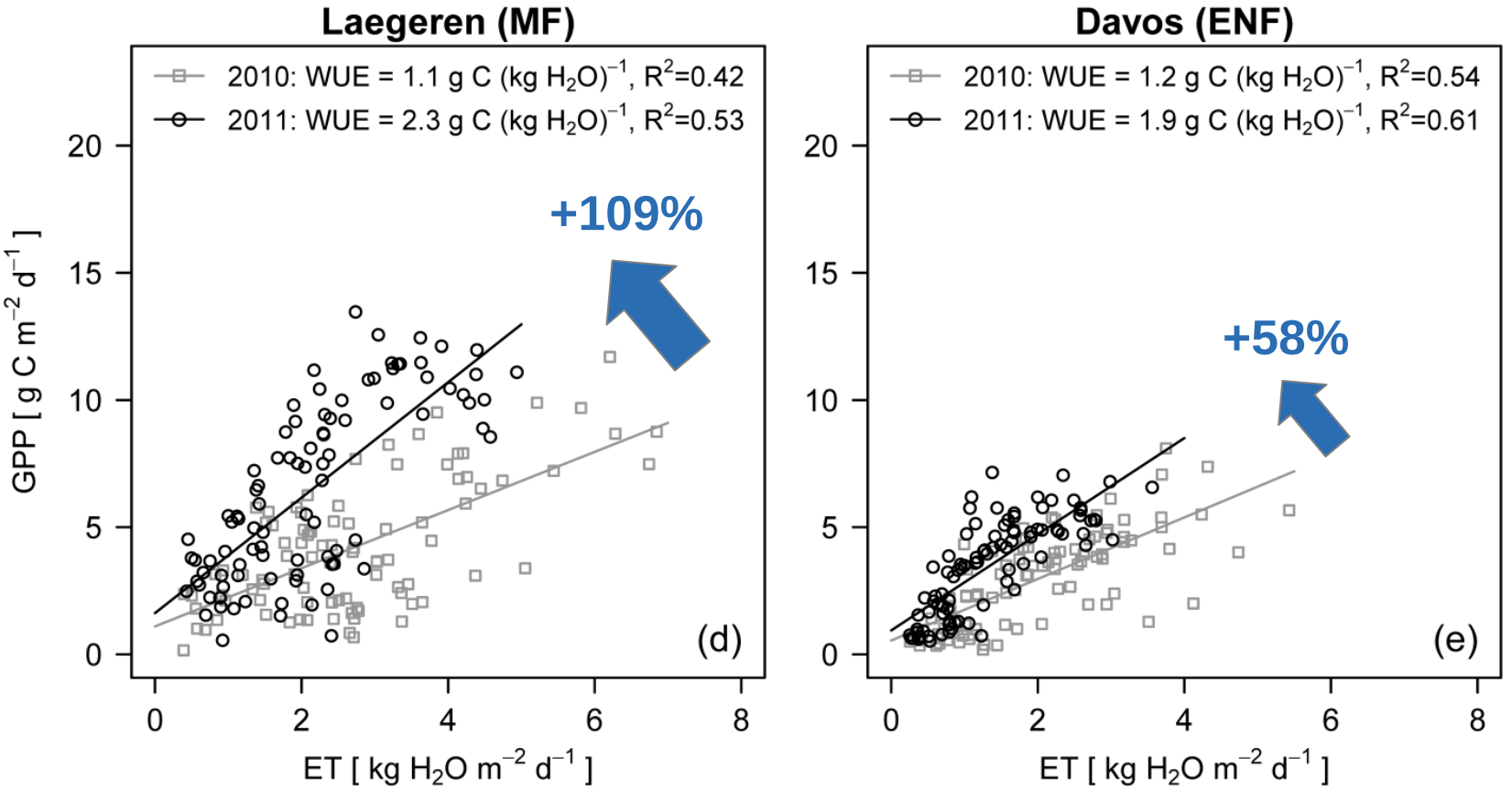


- **Forests and grasslands are important players**
- **Reactions to changes in climate? Extreme weather events?**
- **Ecosystem/Species plasticity vs. vulnerability?**

(Oki and Kanae 2006)

Responses to extreme events

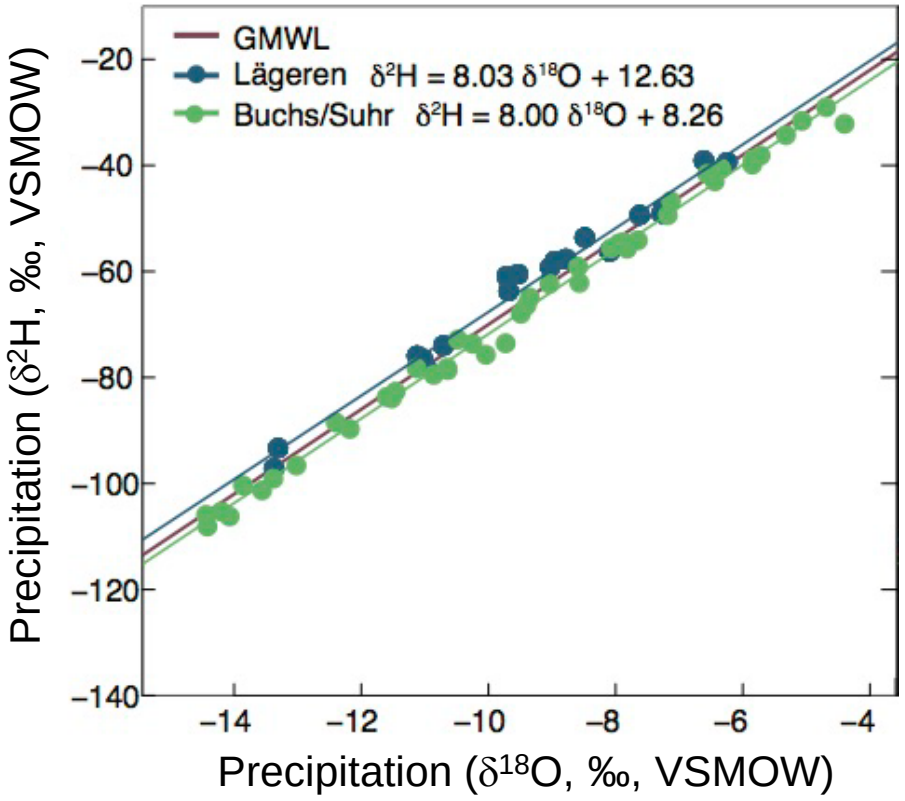
Spring drought 2011: spring precip -68% (LAE), -35% (DAV)

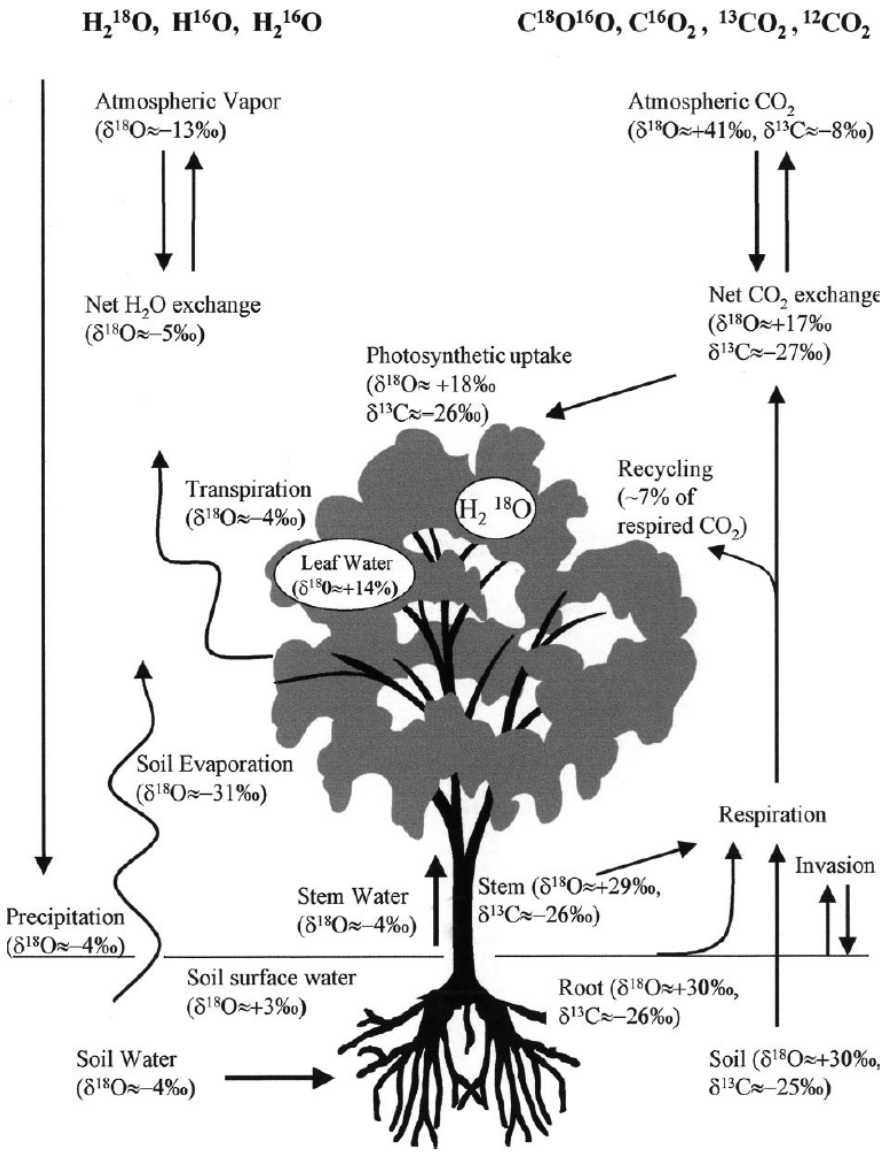


➢ **Forests acclimated very fast to spring drought, WUE ↑**

(Wolf et al. 2013, ERL)

Why use stable isotopes?



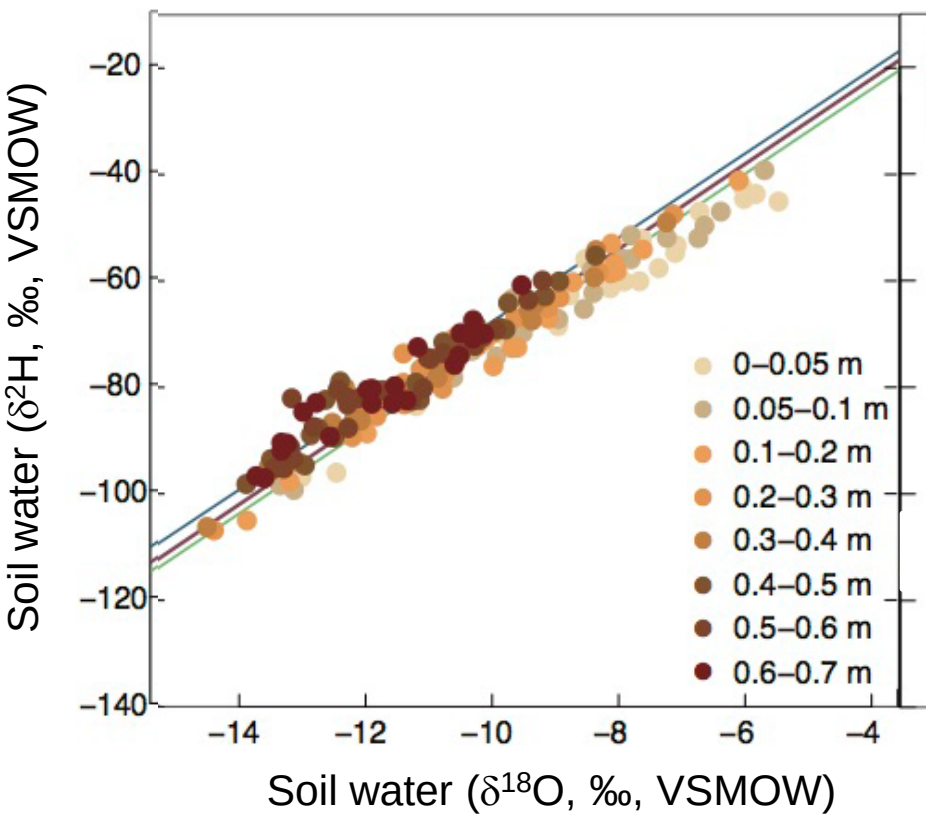


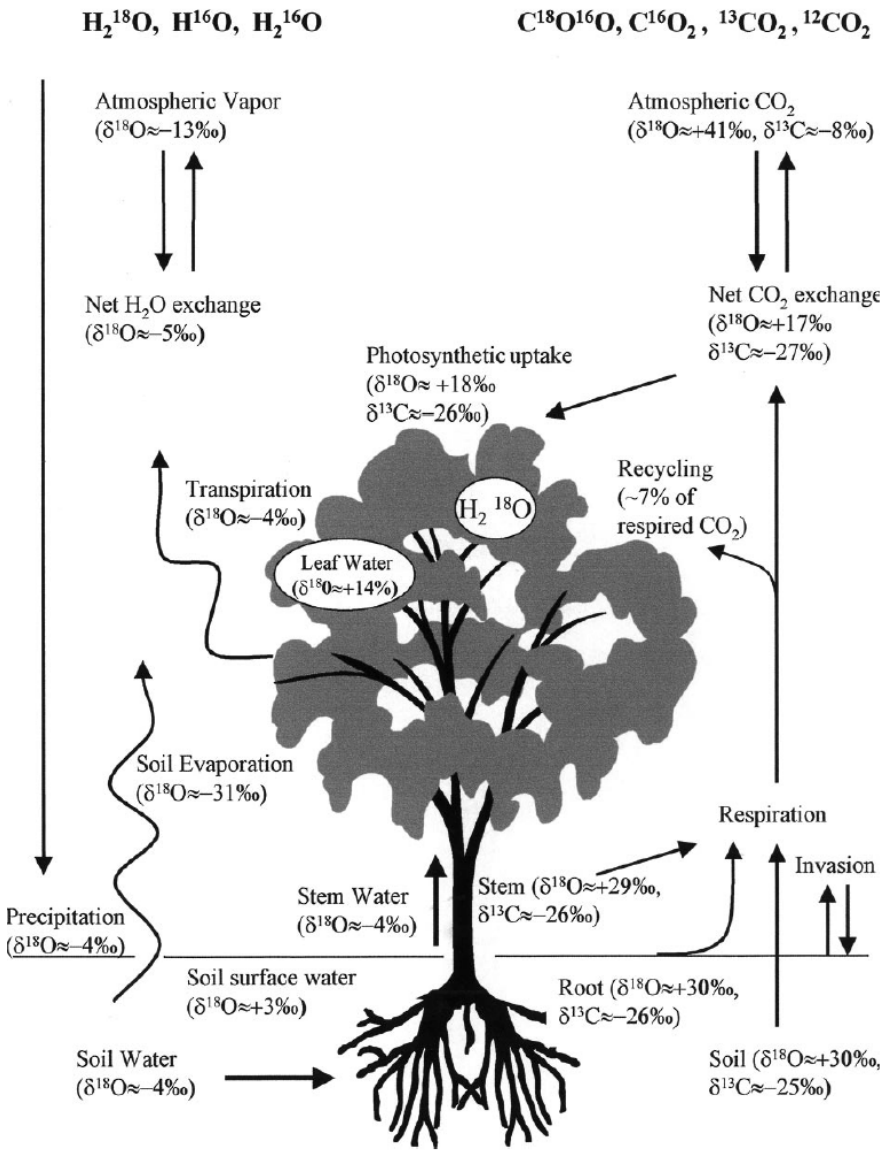
The «start» of ecohydrology: precip.

A classical dual isotope approach

(Yakir and Sternberg 2000)

Stable isotopes to study ecohydrology



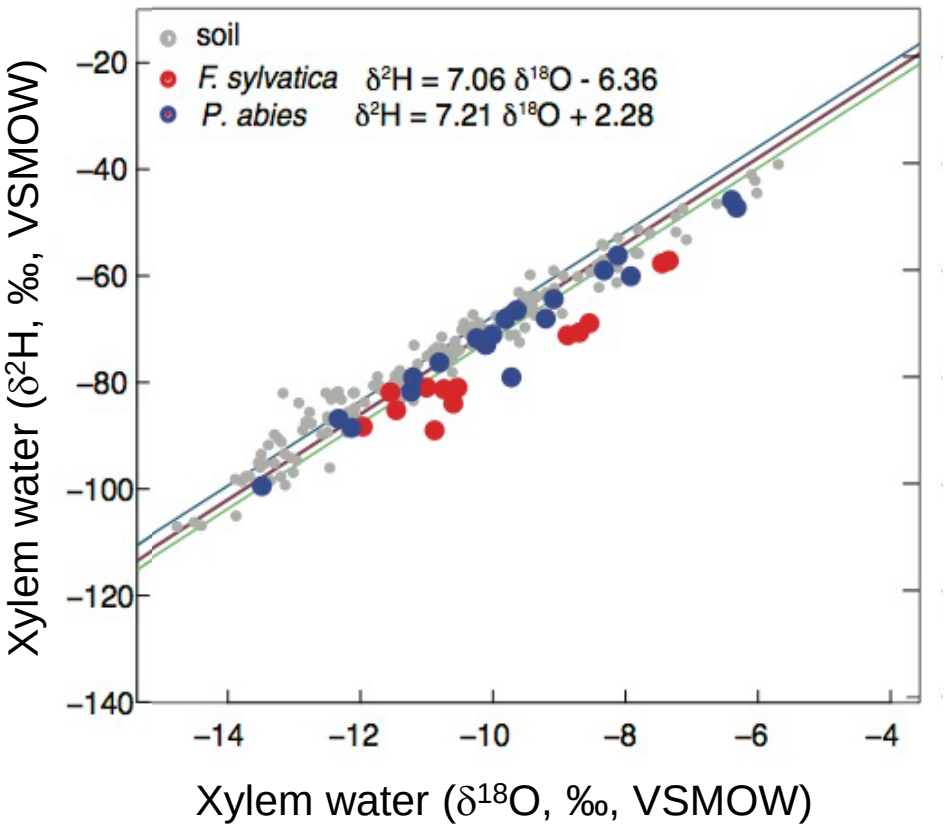


Where plants compete for water: soil.

A classical ecological question

(Yakir and Sternberg 2000)

Stable isotopes to study ecohydrology



LETTER

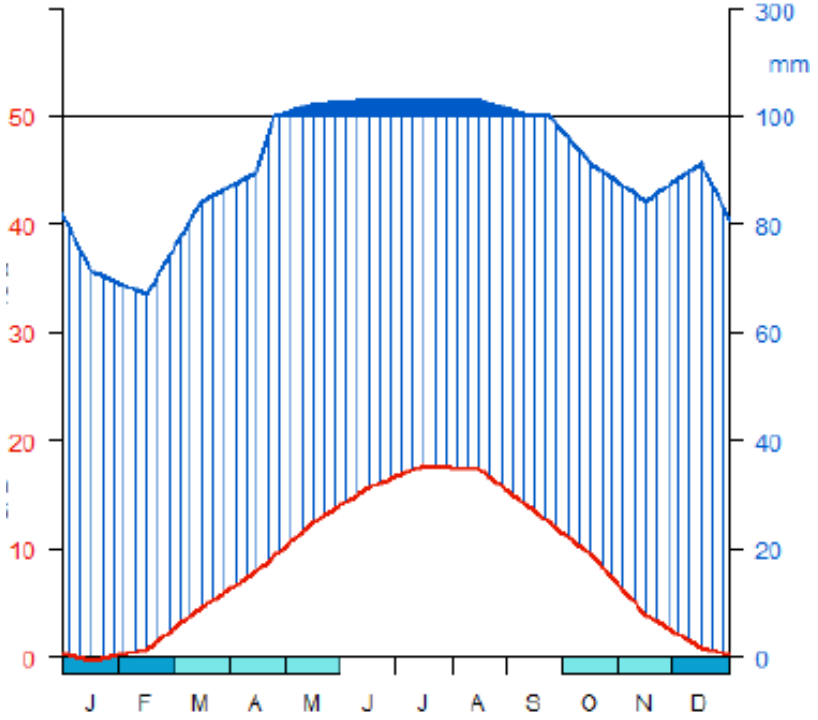
doi:10.1038/nature1

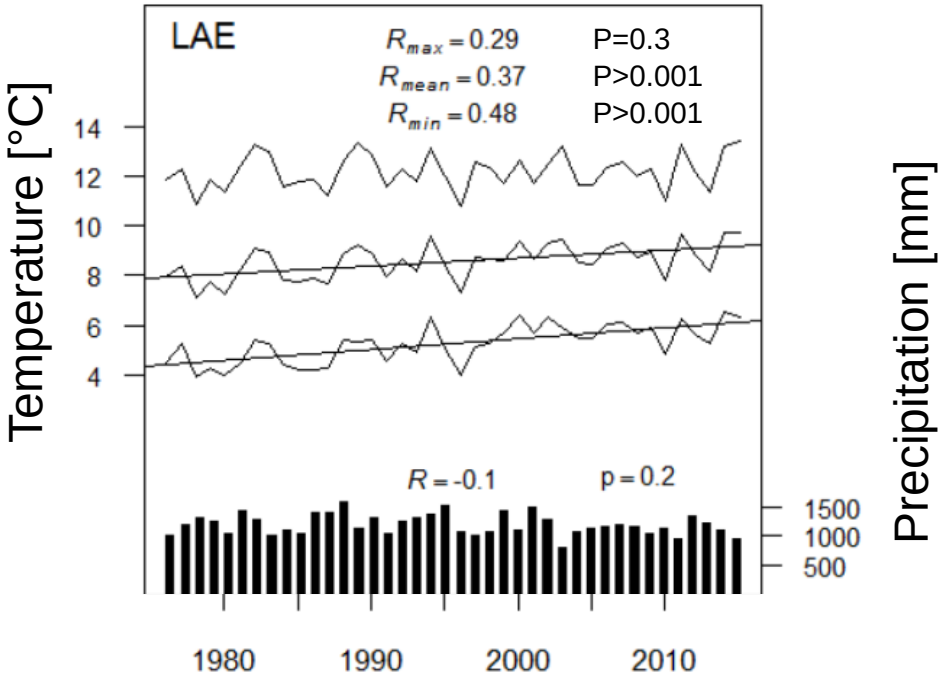
Global separation of plant transpiration from groundwater and streamflow

Jaivime Evaristo[1], Scott Jasechko[2] & Jeffrey J. McDonnell[1,3,4]

Climate in last three decades (for LAE)

Lägeren (682 m) Average T_{air} 8.7°C
1981-2010 Annual PP 1211 mm





- **T ↑, PP ±**
- **Climate sensitivity in the future? Water use?**

(Perez et al., unpubl.)

Stable isotopes to study ecohydrology

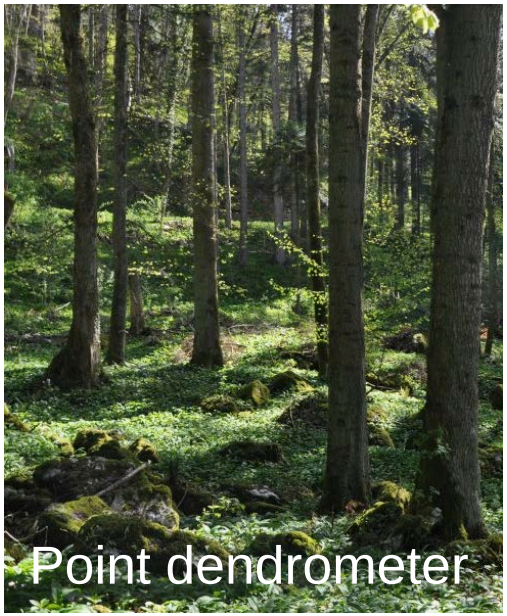
- How **sensitive** are the dominant tree species at the Lägeren **to low soil moisture availability**? Does this sensitivity differ among species?
- Where do the dominant tree species take up their water? Does the **uptake depth for water** change if environmental conditions become stressful? Do tree species differ in their plastic response to a changing environment?
- How old is the **water taken up** by the dominant trees? What is the **residence time** of soil water?

➢ What does this tell us about the **tree/ecosystem susceptibility** to water limiting conditions?

Sensitivity to low soil moisture?

How **sensitive** are the dominant tree species at the Lägeren **to low soil moisture availability**? Does this sensitivity differ among species?

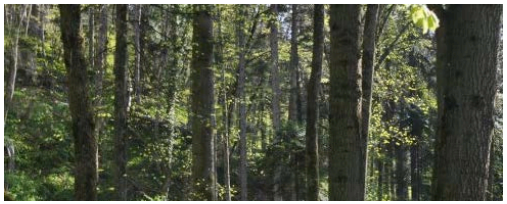
Sap flow

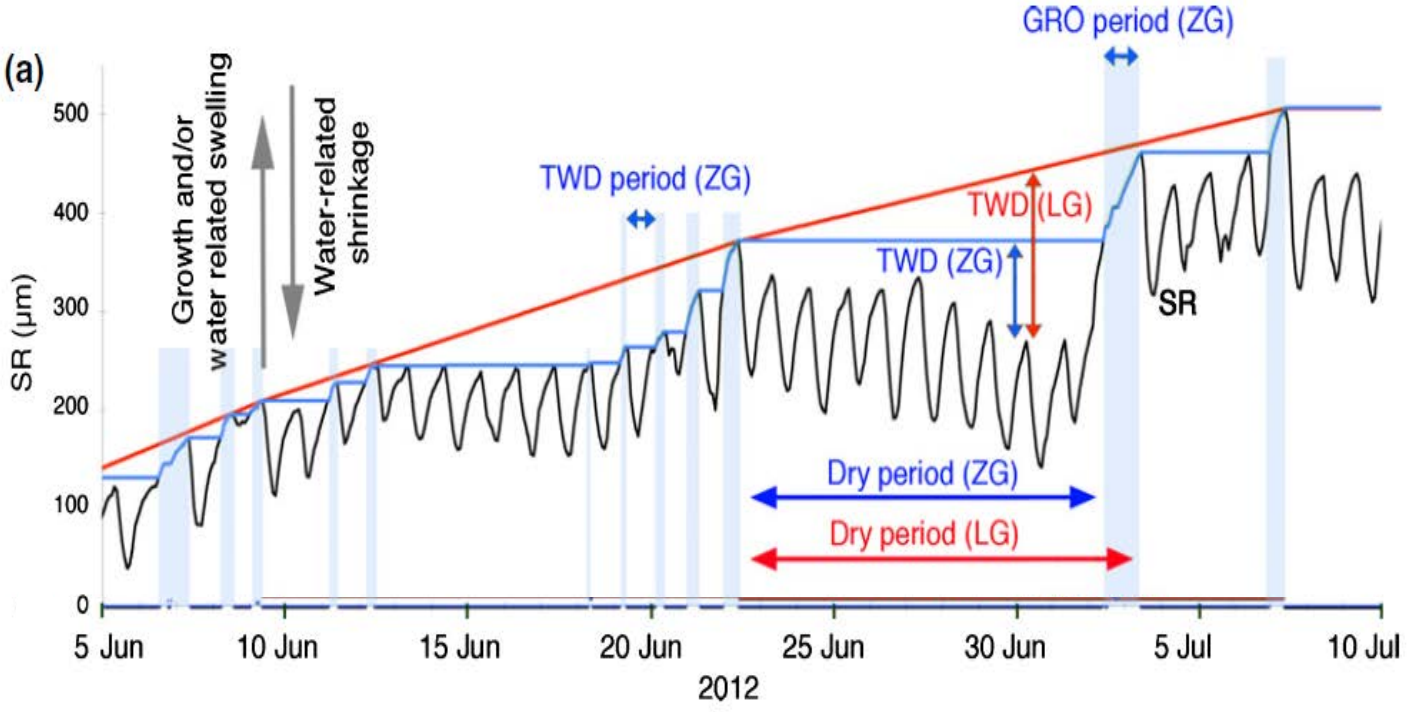


Point dendrometer

Sensitivity to low soil moisture?

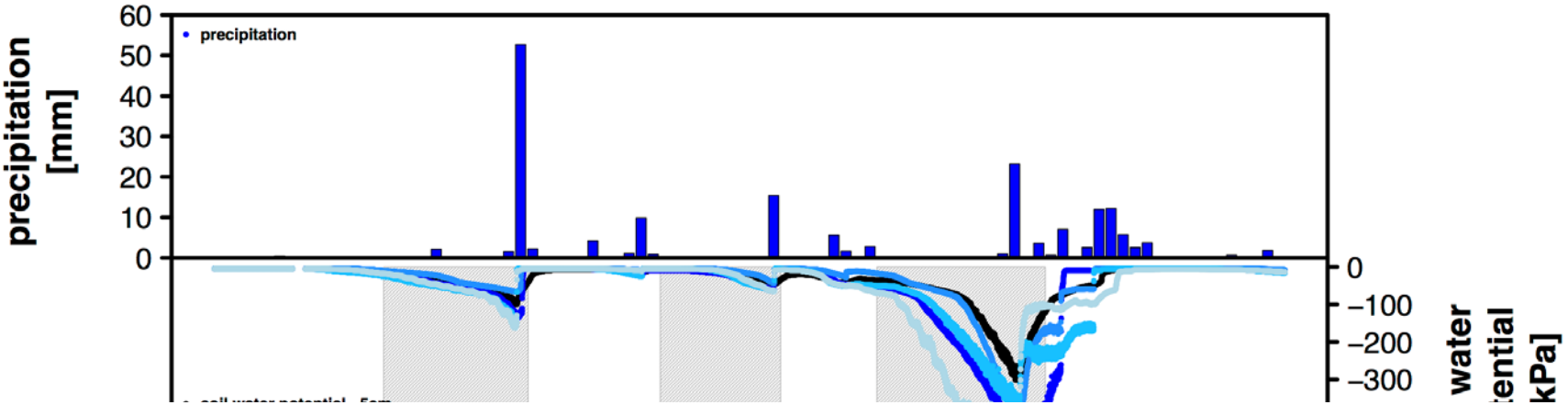
How **sensitive** are the dominant tree species at the Lägeren **to low soil moisture availability**? Does this sensitivity differ among species?



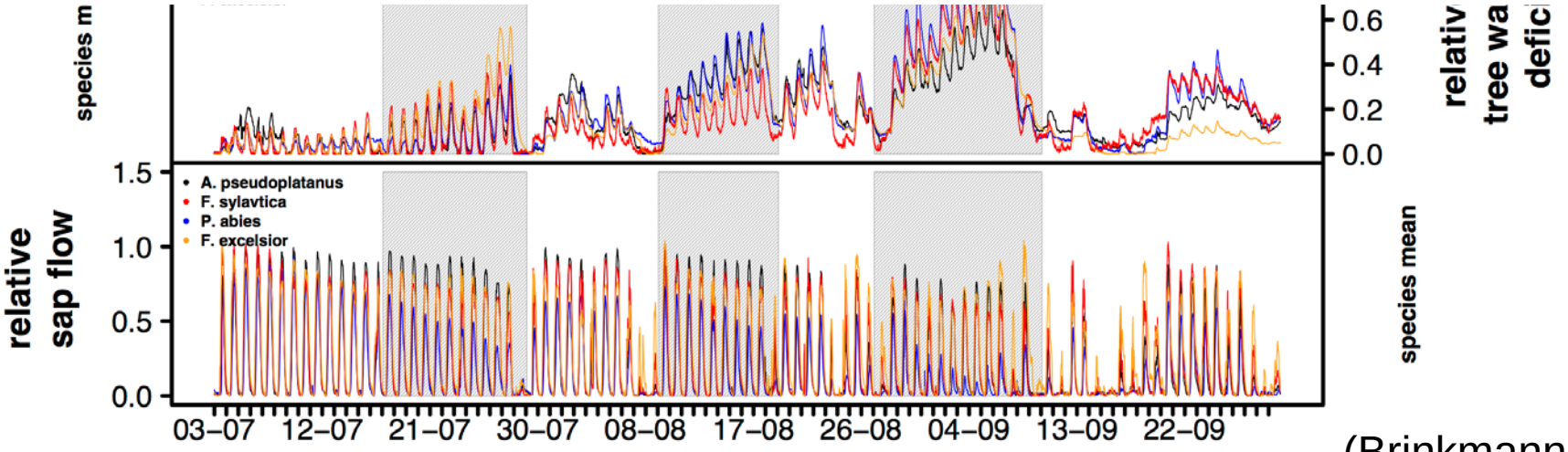


(Zweifel et al. 2016)

Responses to dry spells?

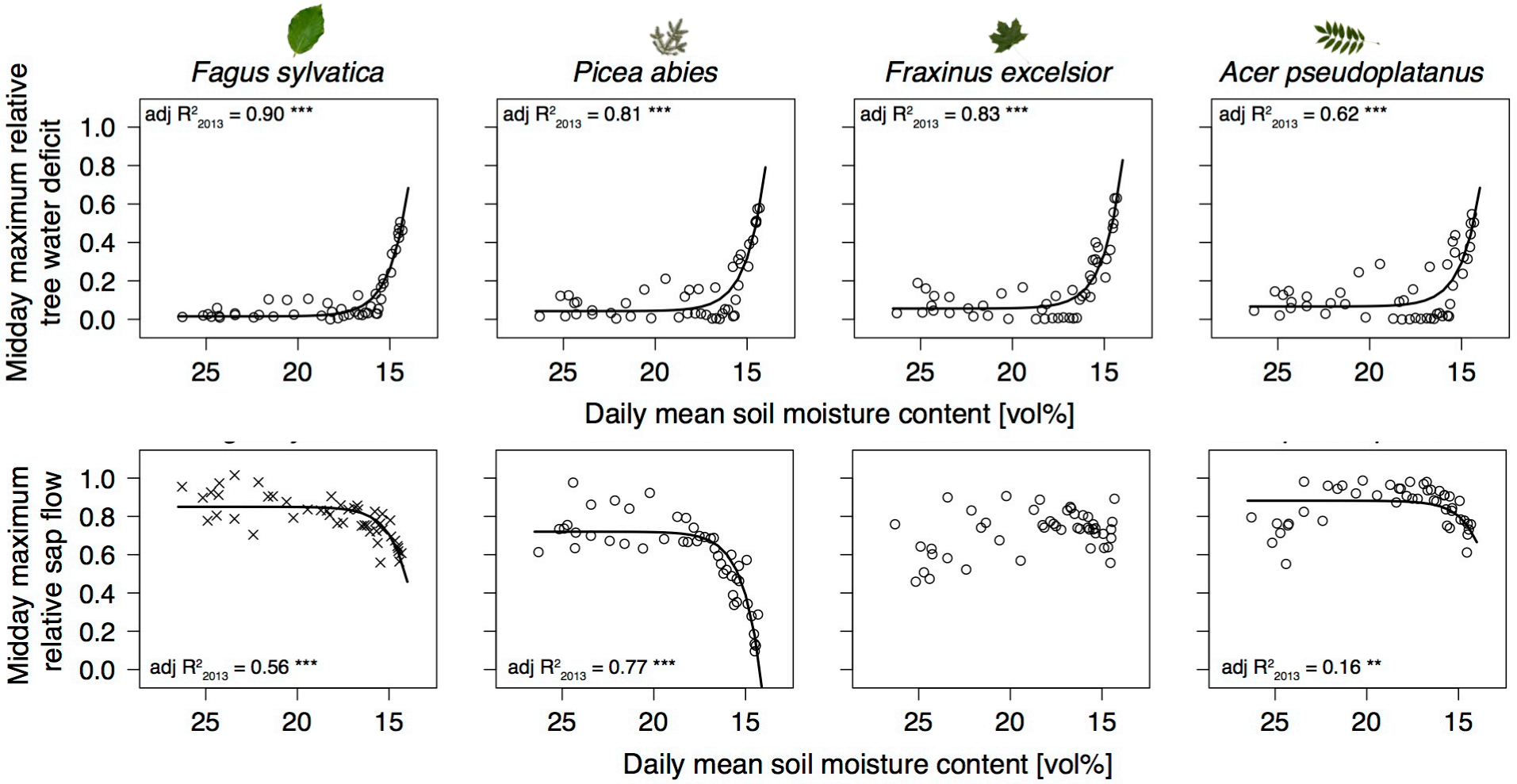


- **Fast responses to dry spells**
- **Magnitude of response: ash, maple, beech < spruce**



(Brinkmann 2016)

Sensitivity to low soil moisture?

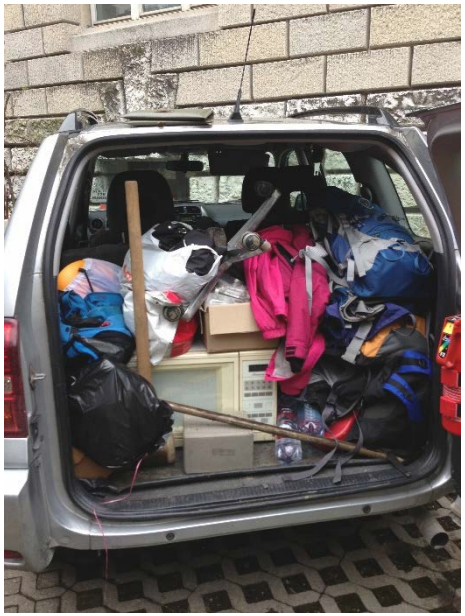


- **Sensitivity to soil moisture: ash < maple, beech < spruce**

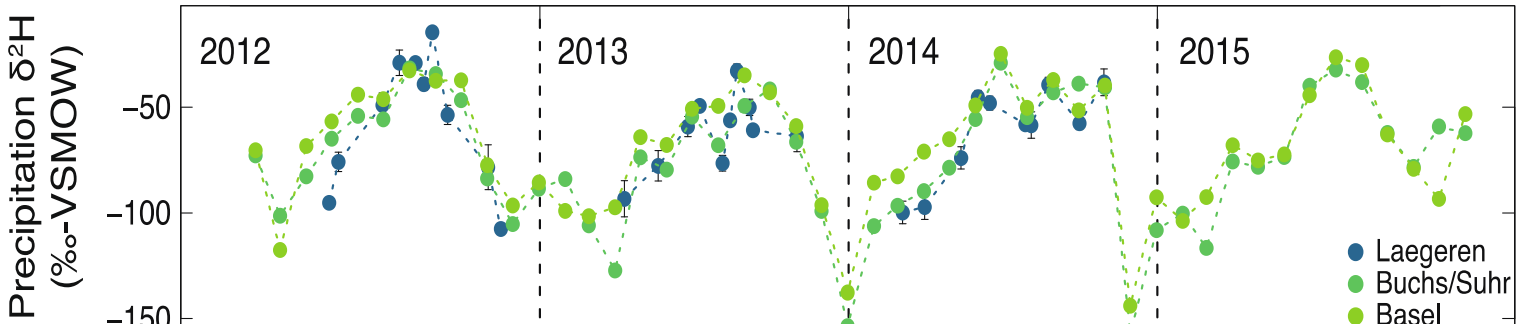
(Brinkmann et al. 2016)

Dual stable isotope approach

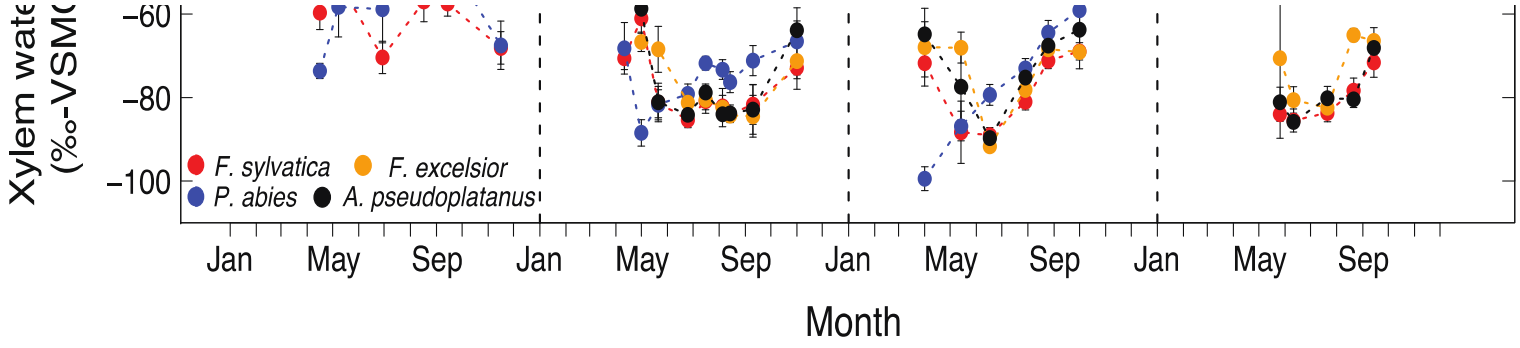
Where do the dominant tree species take up their water?



Water isotopes in a mixed forest

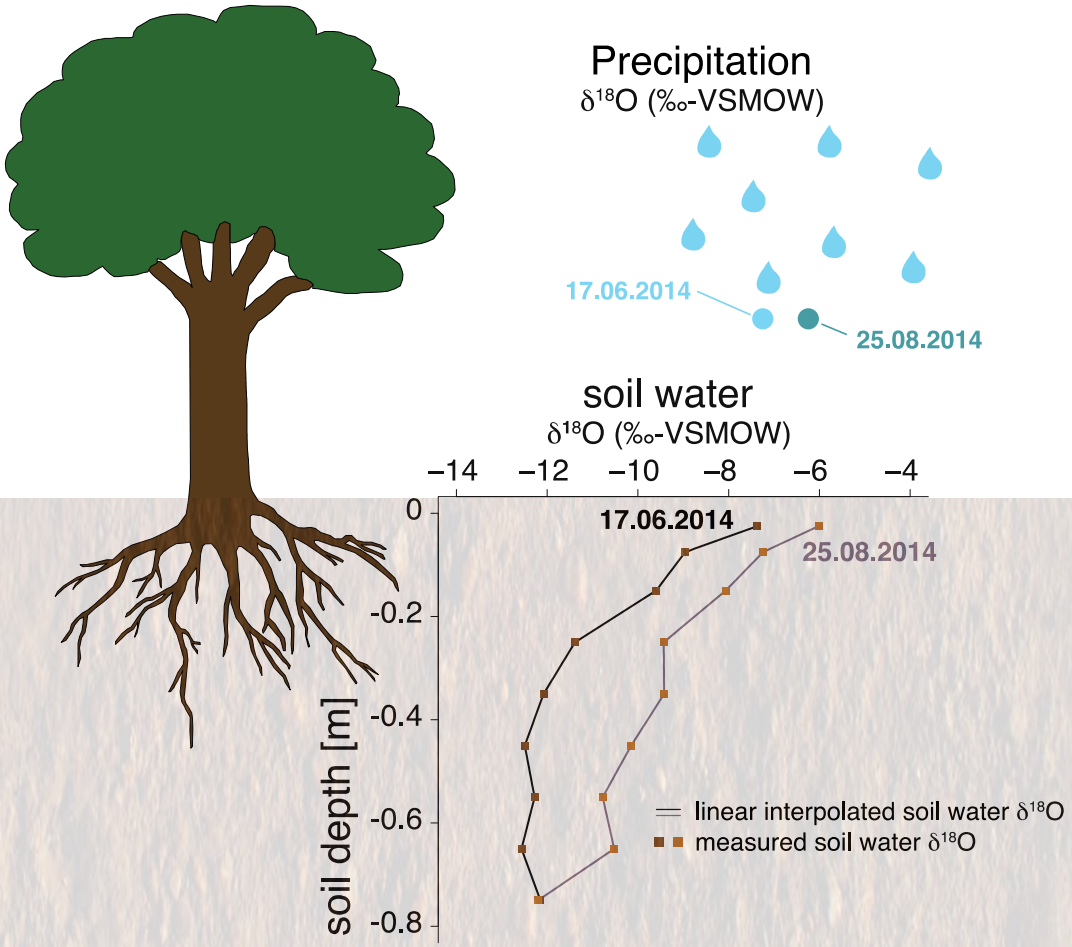


- ***Close relationships between precip, soil water, xylem LMWLs, thus translatory flow, no/low precipitation offsets***
- **Strong seasonality in xylem isotope ratios**
- **Similar patterns among species**



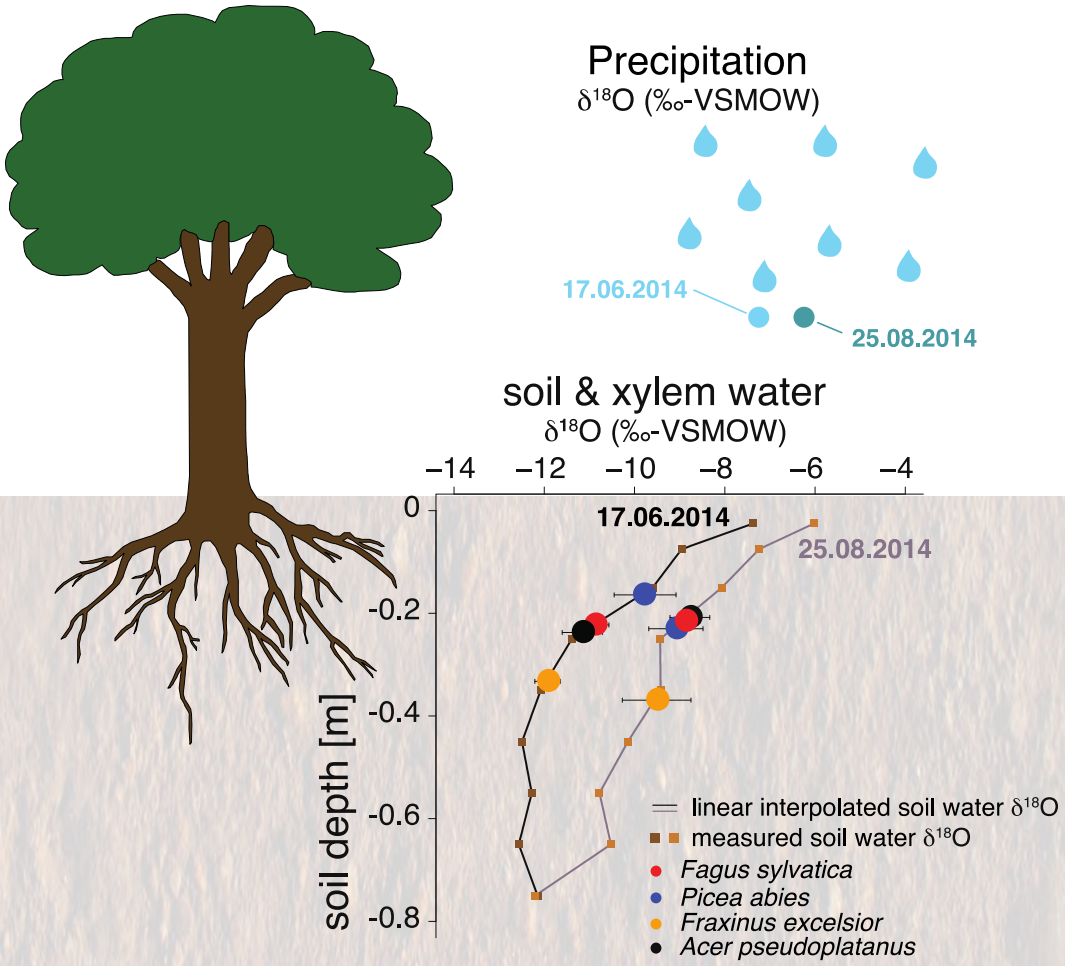
(Brinkmann et al., in rev.)

Water uptake depths? Linear approach



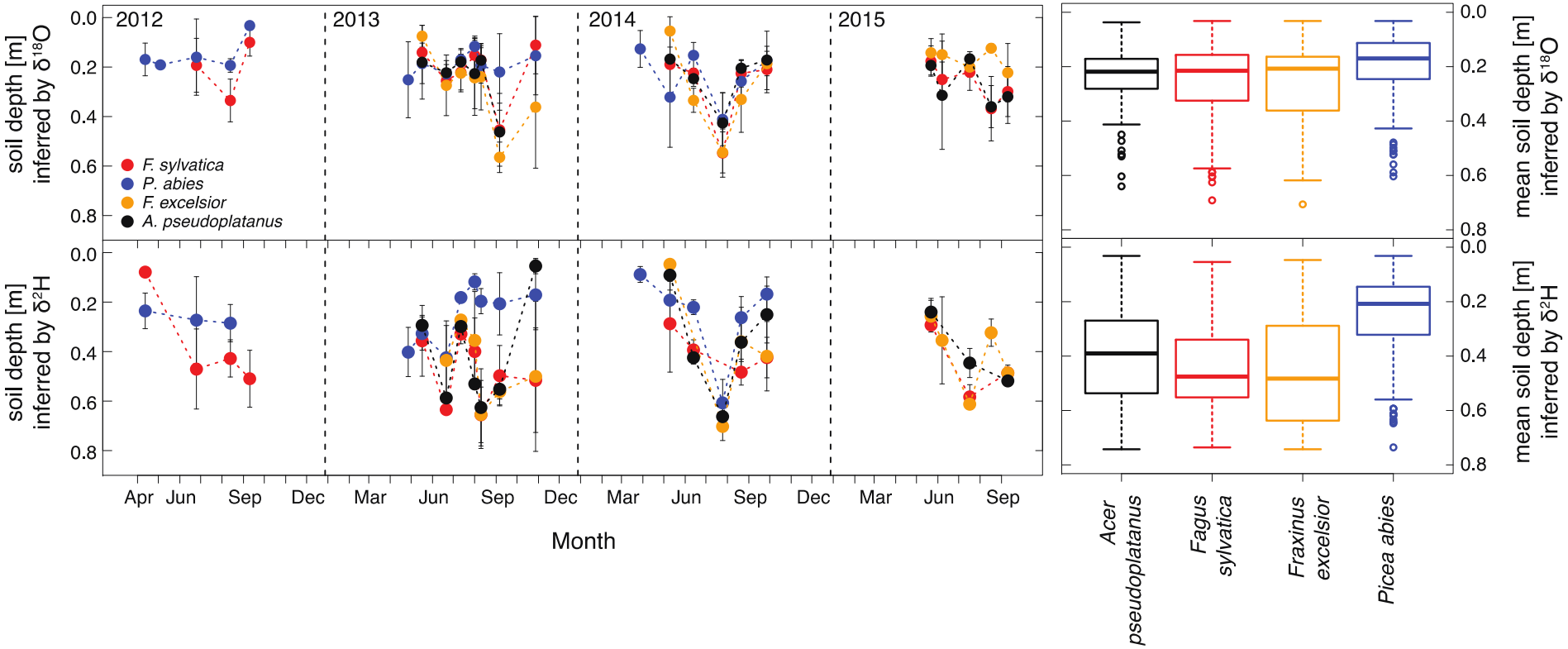
(Brinkmann 2016)

Water uptake depths? Linear approach



(Brinkmann 2016)

Water uptake depths? Linear approach



- **All species took up water from upper soil**
- **With dry spell: uptake from deeper soil**
- **Trend: Spruce stays rather shallow**

(Brinkmann 2016; Brinkmann et al., in rev.)

Water uptake depths? Bayesian approach

The **Bayesian approach** allows to estimate the probability of a specific soil depth contributing to the water uptake of trees.

Bayes' theorem:
"Update prior knowledge about a parameter with data to obtain posterior knowledge."

Observed soil water isotope values at three different depths
→ P(A)

Observed xylem water isotope values
→ P(B)

Probability of the three different soil depths contributing to tree water uptake
→ P(A|B)

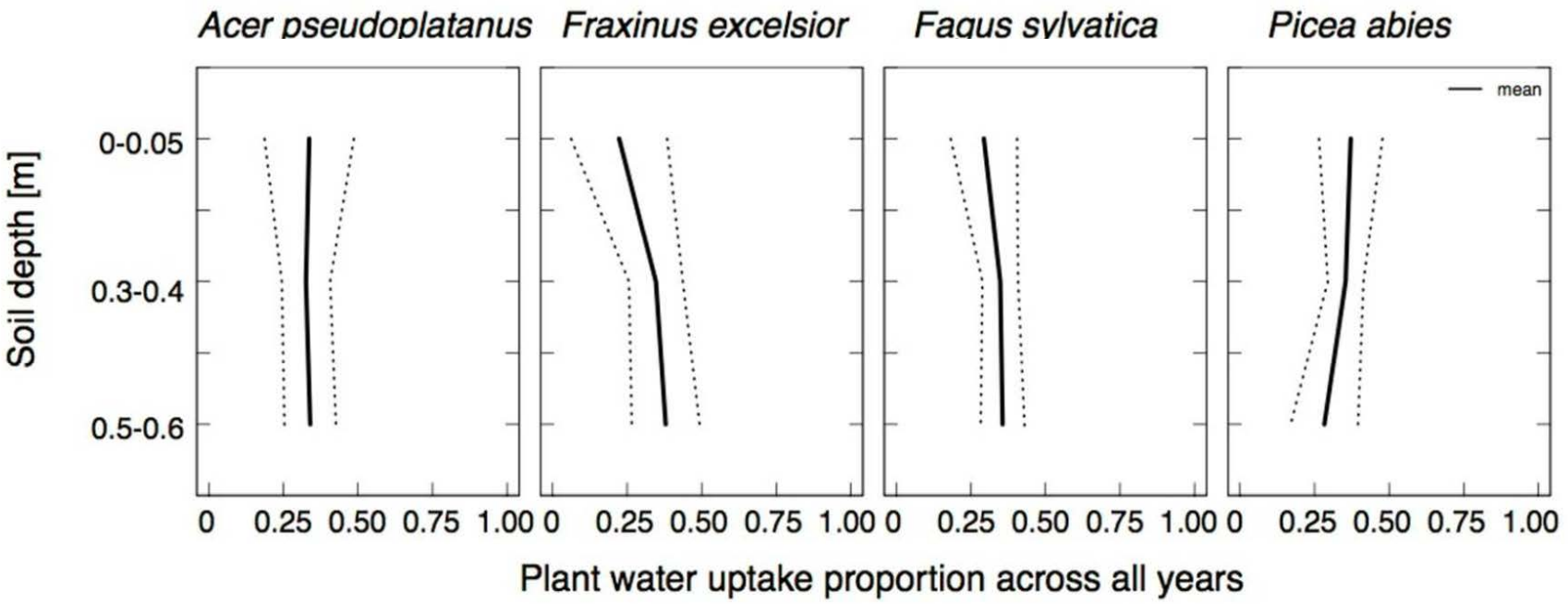
$$P(A \mid B) = \frac{P(A)P(B \mid A)}{P(B)}$$

P = Probability / Probability distributions
(e.g. Dirichlet distribution)

Calculations done for each collection day

(Brinkmann 2016)

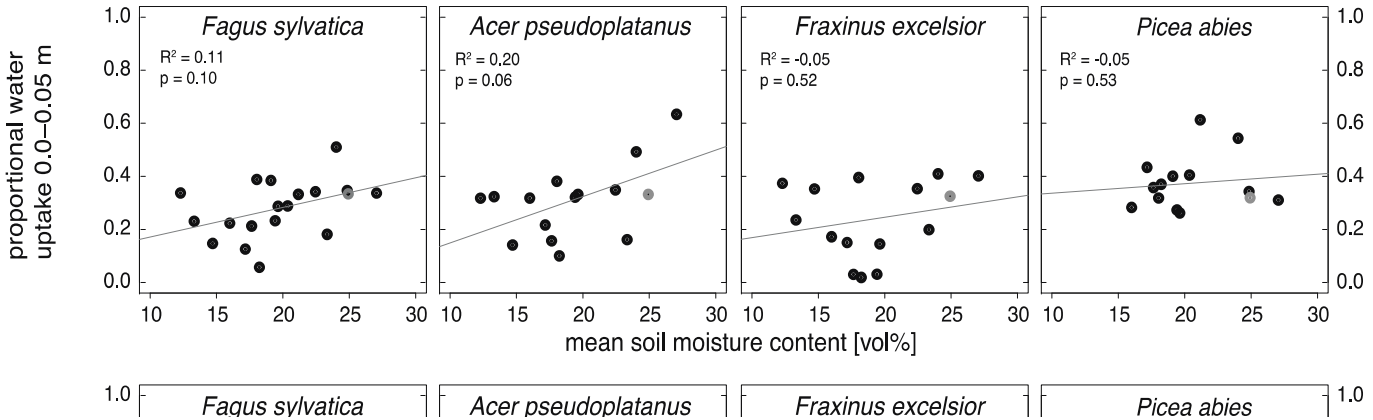
Water uptake depths? Bayesian approach



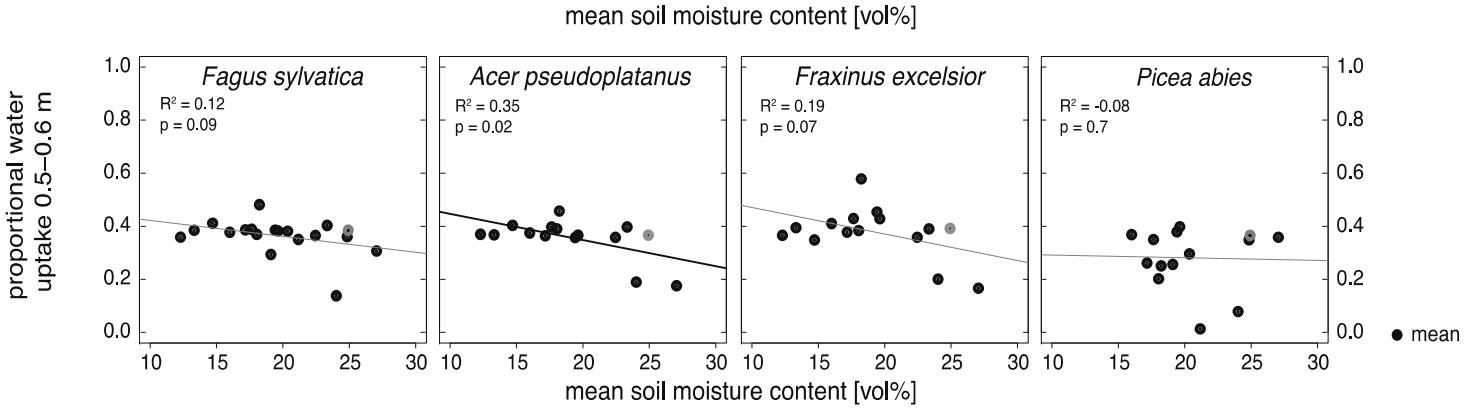
- **Similar uptake depths among dominant species**
- **Trend: Spruce stays rather shallow**

(Brinkmann 2016; Brinkmann et al., in rev.)

Uptake depth as function of soil moisture?



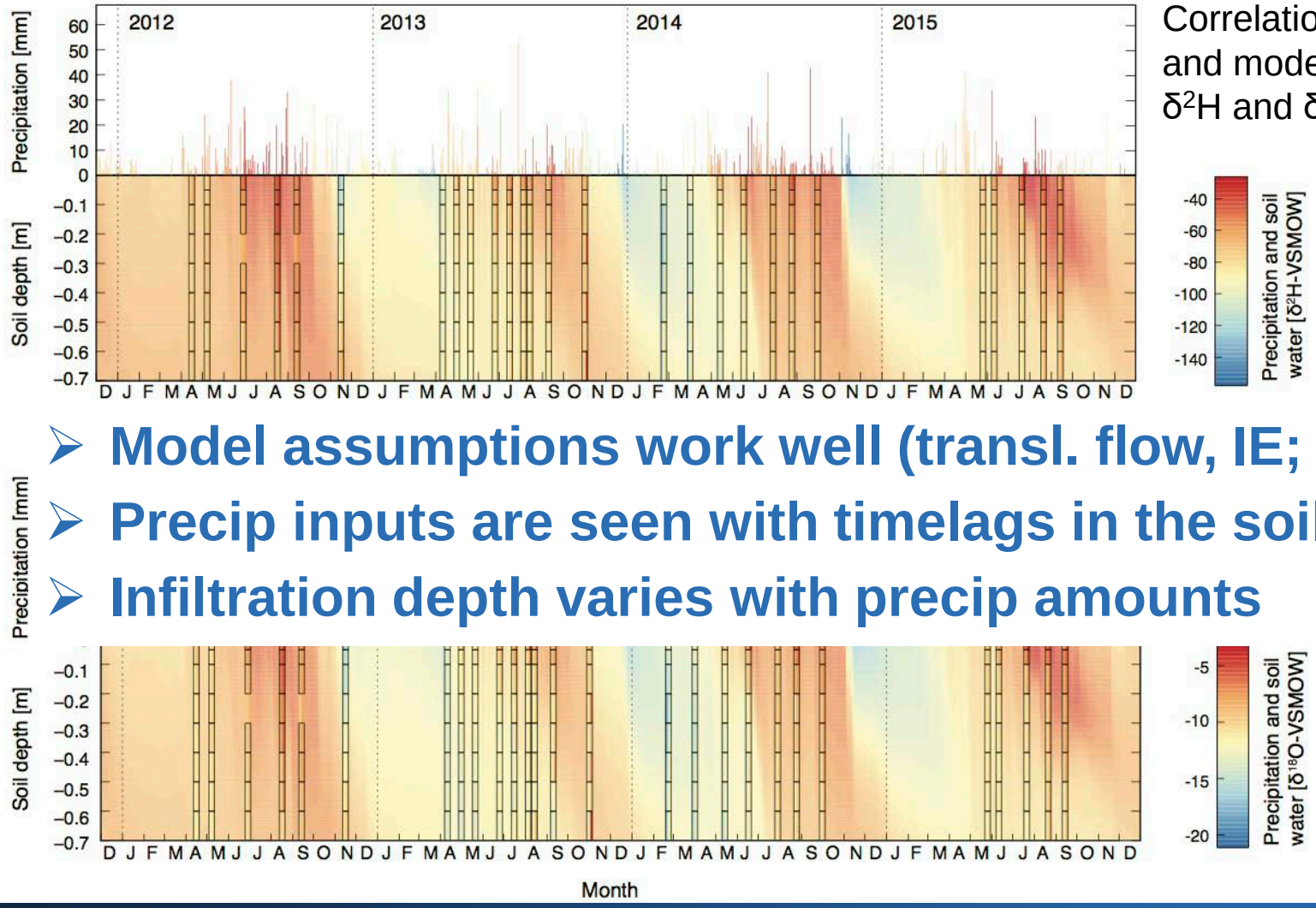
- **High SMC: reliance on top soil (0-5 cm)**
- **Low SMC: water sourcing from lower depths (50-60 cm)**
- **Valid for deciduous trees, while spruce stays shallow**



(Brinkmann et al., in rev.)

Modelling isotopes in soil water

How does the soil profile integrate precip inputs?

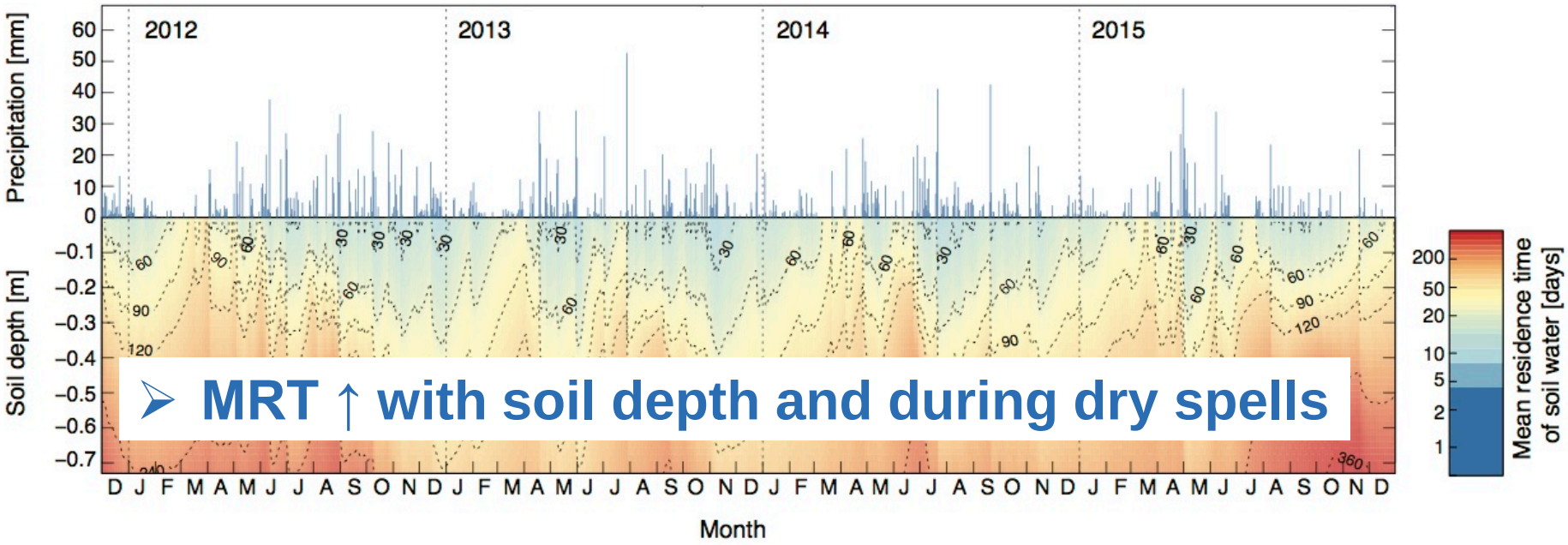


Correlation of measured and modelled soil water δ^2H and $\delta^{18}O$: r ~ 0.9

- **Model assumptions work well (transl. flow, IE; r^2 ~ 0.8)**
- **Precip inputs are seen with timelags in the soil profile**
- **Infiltration depth varies with precip amounts**

Residence times of soil water

What is the **residence time** of soil water?

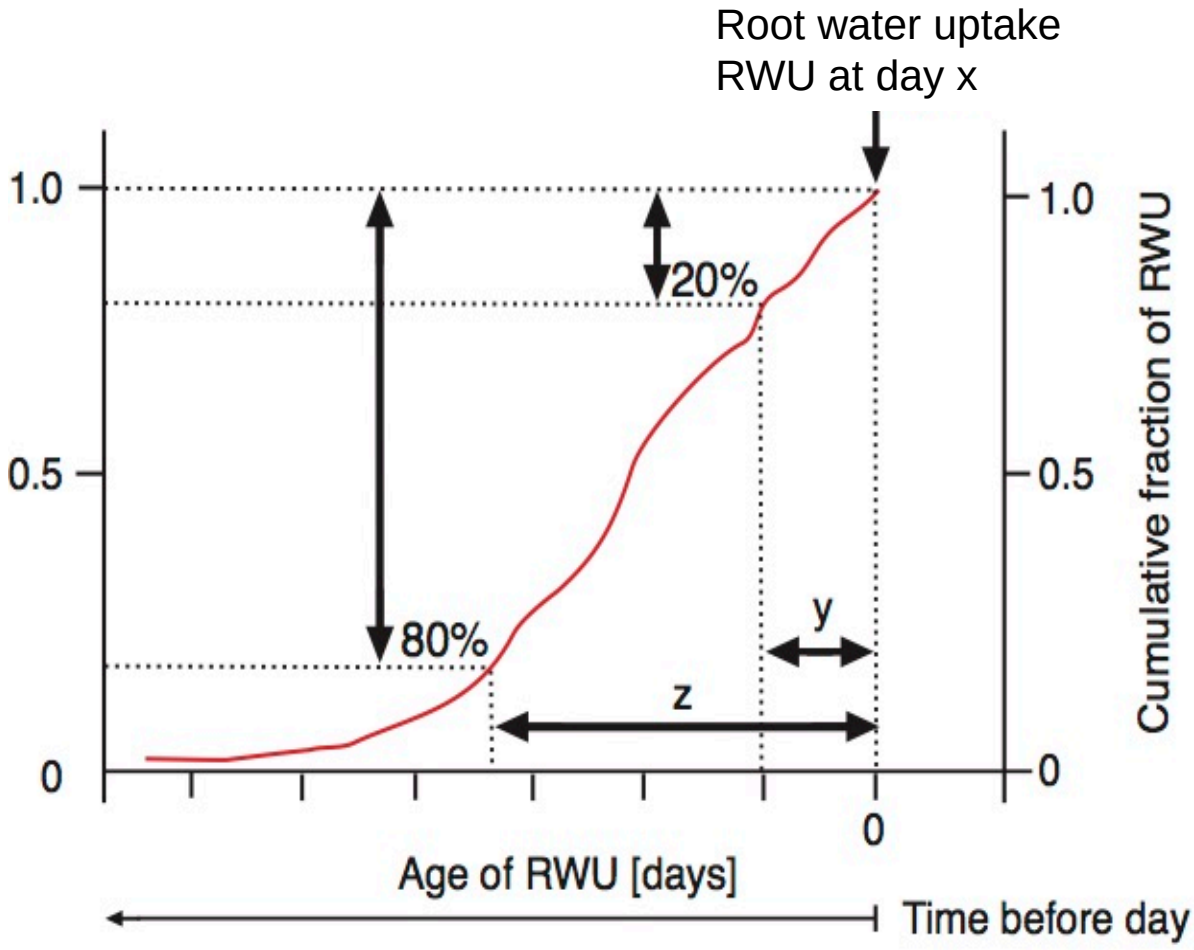


Across all years: MRT at 0.05 m = 41 ± 17 days
MRT at 0.35 m = 100 ± 28 days
MRT at 0.65 m = 176 ± 54 days

(Brinkmann et al., in prep.)

Temporal origin / Age of water taken up?

How old is the **water taken up** by the dominant trees?

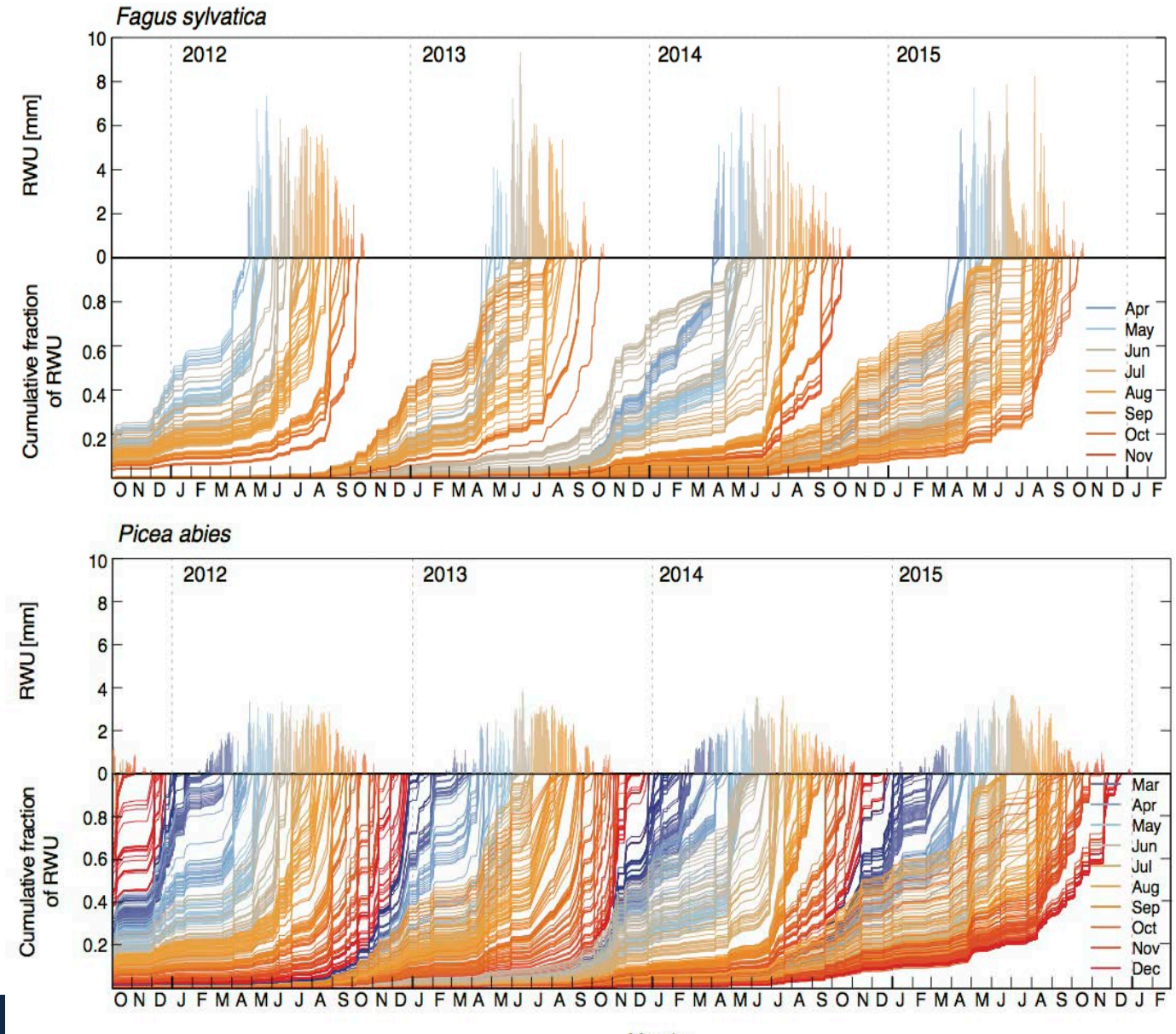


20% of RWU has been taken up over the last y days

80% of RWU has been taken up over the last z days

(Brinkmann et al., in prep.)

Temporal origin / Age of water taken up?

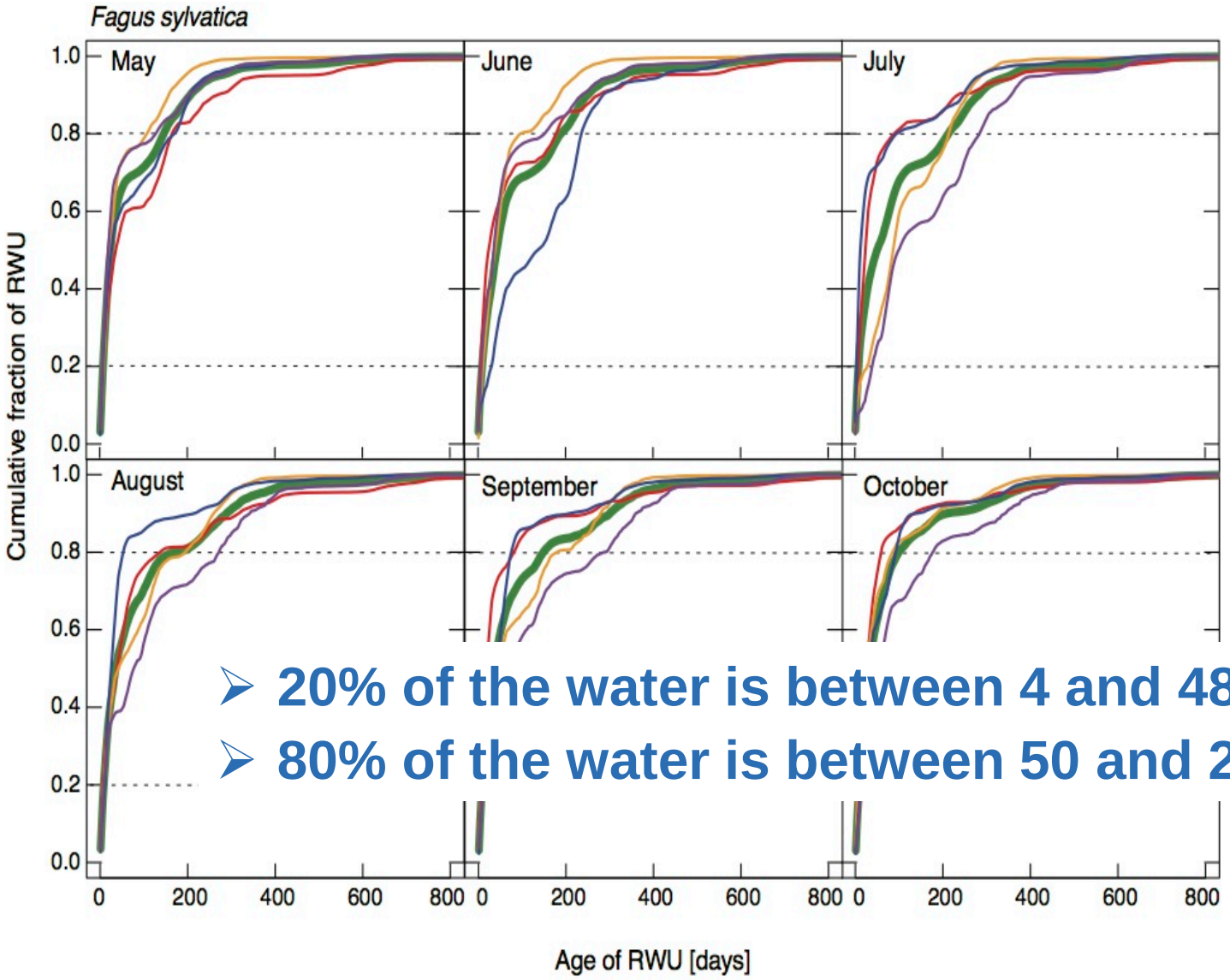


Steep curves = low age

Flat curves = high age

(Brinkmann et al., in prep.)

Temporal origin / Age of water taken up?



- **20% of the water is between 4 and 48 days old**
- **80% of the water is between 50 and 252 days old**

(Brinkmann et al., in prep.)

Temporal origin / Age of water taken p?

Beech

49% current vegetation period
41% winter months prior to vegetation period
10% previous year's vegetation period

Spruce

43% current vegetation period
45% winter months prior to vegetation period
12% previous year's vegetation period

- **≤ 50%: current vegetation period**
- **About 40%: winter months prior to vegetation period**
- **About 10%: previous year's vegetation period**
- **Tendency: higher uptake during winter months for spruce**

(Brinkmann et al., in prep.)

Stable isotopes to study ecohydrology

- **Sensitivity to low soil moisture availability?**
  Gradient of temperate tree species: ash < maple, beech < spruce.

- **Soil water sourcing?**
  (Translatory flow. No/low precipitation offset. No «two water worlds».)
  Water uptake of all species from top soil at high SMC, but from lower depths at low SMC. Valid for deciduous species (highly plastic), but spruce stays always rather shallow.

- **Residence times of soil water, age of water taken up?**
  Precip inputs seen with timelags in soil profile. Infiltration depth varies with precip amounts. MRT ↑ with soil depth (41 … 176 days) and during dry spells.

  ≤ 50% tree water uptake originated from current vegetation period, about 40% from winter months prior to vegetation period (spruce !), about 10% was even older (implications for tree ring studies….)

Tree/Ecosystem susceptibility

What does this tell us about the **tree/ecosystem susceptibility** to water limiting conditions?

(Isotopes are great to address such questions)

Species-specific responses to water limiting conditions: deciduous species highly plastic, but spruce not

- very different sensitivities of temperate trees to future droughts, particularly spruce
- Implications for silviculture and provision of ecosystem services

Reliance of all species on summer AND winter precipitation

- winter precip (projected to stay as today, but as rain, not as snow) can act as a buffer against water deficits during spring/summer
- Works best for species which can acclimate fast

Thank you!