



Soil drought: Comparing tree species strategies for soil water uptake (using water stable isotopes). Impact on the carbon and water dynamic

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Soil drought:

**Comparing tree species strategies for
soil water uptake
(using water stable isotopes)**

**Impact on the carbon and water
dynamic**

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Carbo-Europe partenaires

Drought:

Impact on the carbon and water dynamic in forest ecosystems

Context

- Network of European Eddy Covariance (EC) sites :
Measurements of CO₂ and H₂O fluxes exchanged by forest ecosystems
- Analysis of the temporal and spatial variability (due to climate, specie, soil, management,...)
- Focus on drought 2003: Extreme event should be more frequent in future

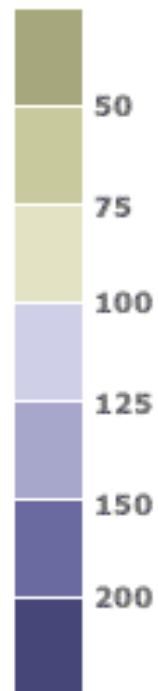
Objectives

- Quantify drought intensity in European EC sites
- Analyse effects of drought on CO₂ and H₂O fluxes (compare with 2002: reference year)

RAINFALL IN EUROPE: 1 April - 30 June

Percentage of normal rainfall

Drier



Wetter

Drought 2003

EC sites	Country	Tree specie
San Rossore	Italy	Maritime Pine
Loobos	Netherlands	Scots Pine
Norunda	Swedeen	Pine + Spruce
Renon	Italy	Mixed coniferous
Tharandt	Germany	Spruce

EC sites	Country	Tree specie
Hesse	France	Beech
Hyytiälä	Finland	Scots Pine
Hainich	Germany	Beech
Le Bray	France	Maritime Pine
Puéchabon	France	Mediterranean oak
Soroe	Denmark	Beech

Ecosystem Fluxes



Eddy Covariance system

Sonic anemometer

3 wind speed components at high ν (20 Hz)

Data record and storage system



**Net Fluxes : CO₂ (NEE), Evapo-transp
every 30 min**

Tower



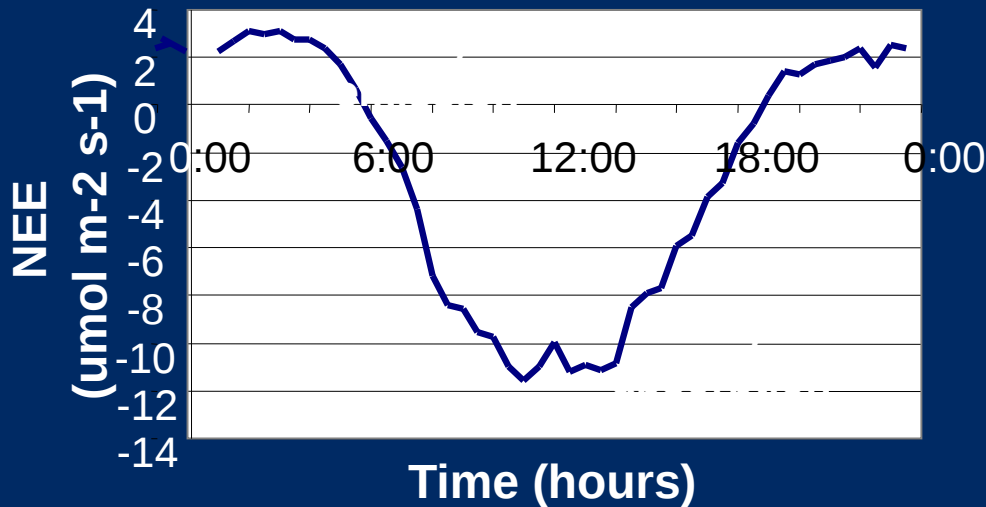
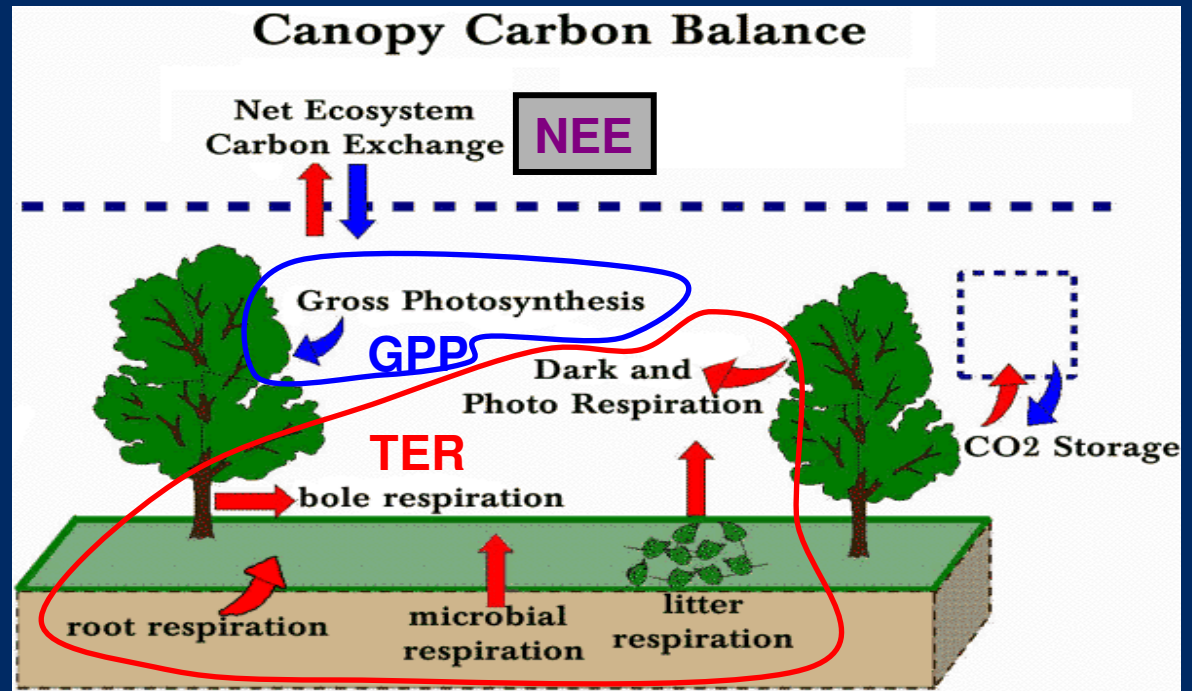
IRGA

[CO₂] and [H₂O] at high ν (20 Hz)

Ecosystem Fluxes

Partitioning

$$NEE = GPP + TER$$



Night : $TER > 0$

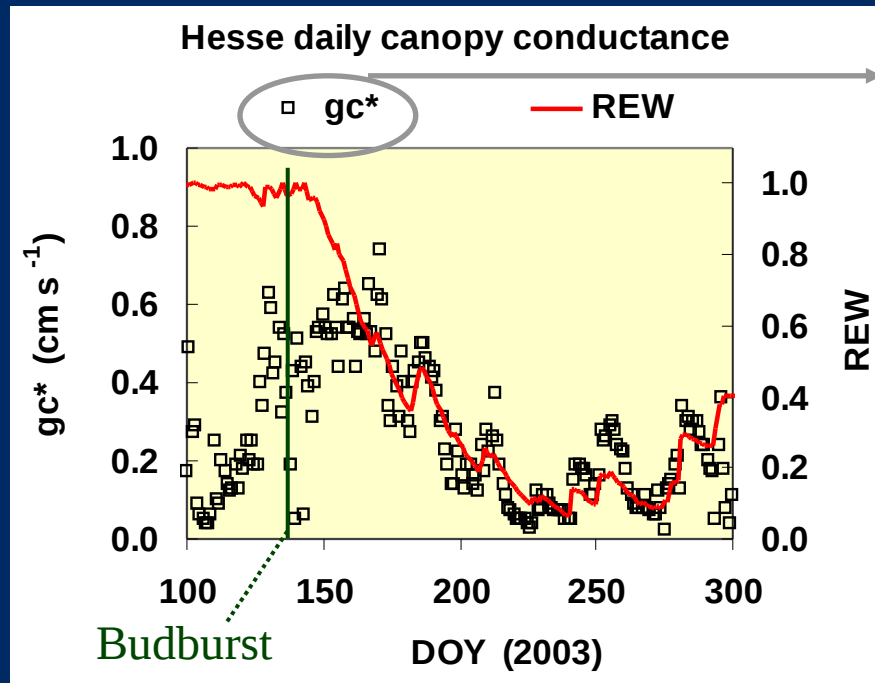
Day : $GPP = (NEE - TER_{mod}) < 0$

Which variable to describe soil water stress?

Find one controlling stomatal opening and soil CO₂ production...

Relative Extractable Water (REW) =

$$\frac{\int_{\text{surf}}^{\text{root_layer}} SWC}{\int_{\text{surf}}^{\text{root_layer}} SWC_{fc}} \rightarrow \text{EW (mm)}$$



gc : canopy conductance

≈

Stomatal opening
integrated over canopy

Stomatal opening
strongly regulated by
REW

Quantification of drought intensity: Use of REW

REW determination on EC sites

SWC not always measured along all the root profile

⇒ REW estimation from BILJOU (*Granier et al.*, 1999)

Model of forest water balance

Processes:

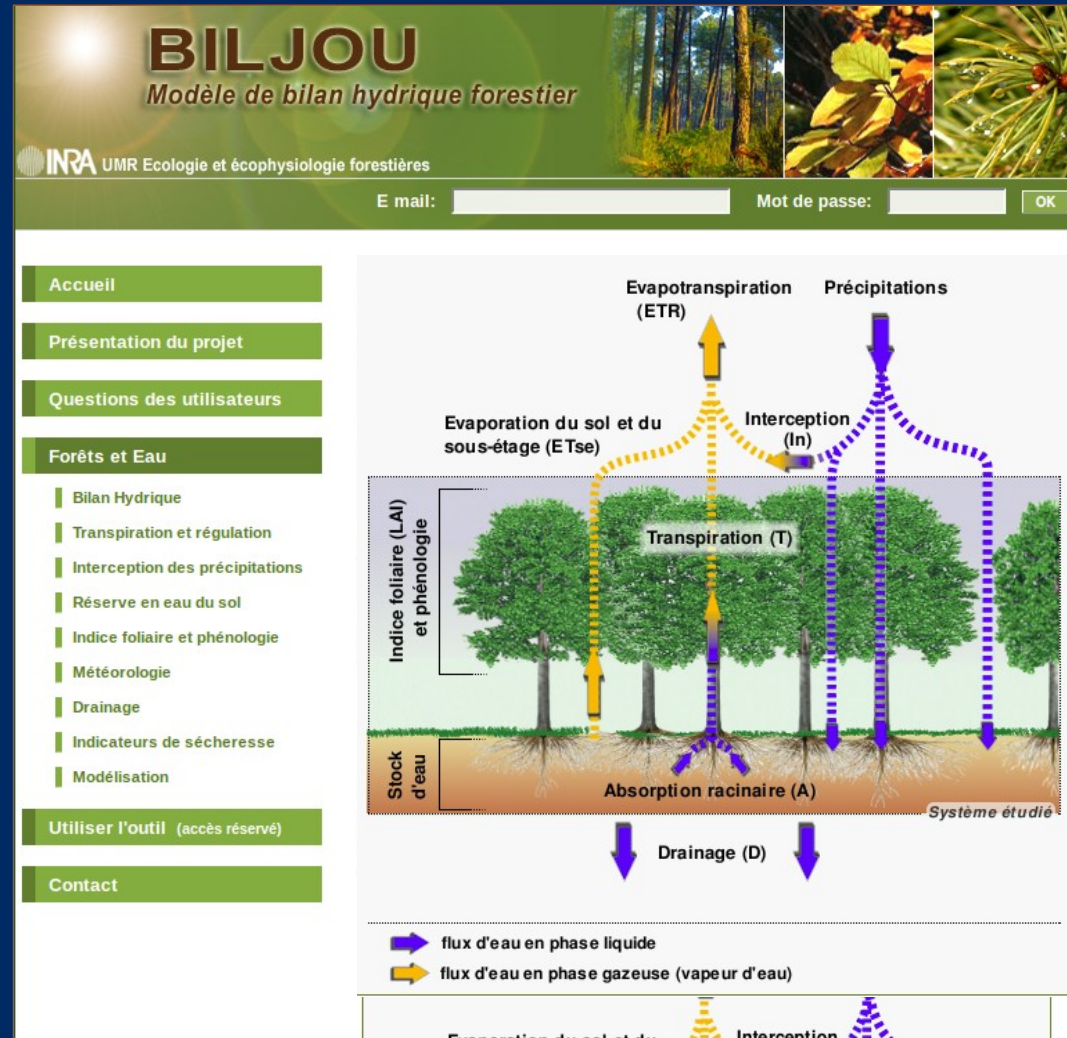
- Root water uptake (transpiration)
- Soil evaporation
- Rainfall interception
- Drainage

Now, possibility to run
BILJOU via Website interface

<https://appgeodb.nancy.inra.fr/biljou>



(soon)



REW determination on EC sites

Inputs:

- Climatic data (precipitations, radiation, air temperature & humidity, wind speed)
- Soil characteristics (root, SWCfc-wp, bulk density profile)
- Canopy characteristics (LAI, phenology)

Formulaire des caractéristiques du sol et du peuplement :

Titre de la simulation :

Type : ☐ Résineux ☒ Feuillus

Jour de débourrement :

Jour de chute des feuilles :

LAI max :

Nombre de couches : ☐ 2 ☒ 3

	Profondeur de la couche (cm)	Réserve en eau (mm)	Proportion de racines	Humidité pondérale pF4.2	Densité apparente
Couche 1	<input type="text" value="30"/>	<input type="text" value="30"/>	<input type="text" value="0.40"/>	<input type="text" value="0.0665"/>	<input type="text" value="0.882"/>
Couche 2	<input type="text" value="55"/>	<input type="text" value="17"/>	<input type="text" value="0.30"/>	<input type="text" value="0.0273"/>	<input type="text" value="1.332"/>
Couche 3	<input type="text" value="125"/>	<input type="text" value="50"/>	<input type="text" value="0.30"/>	<input type="text" value="0.0249"/>	<input type="text" value="1.461"/>

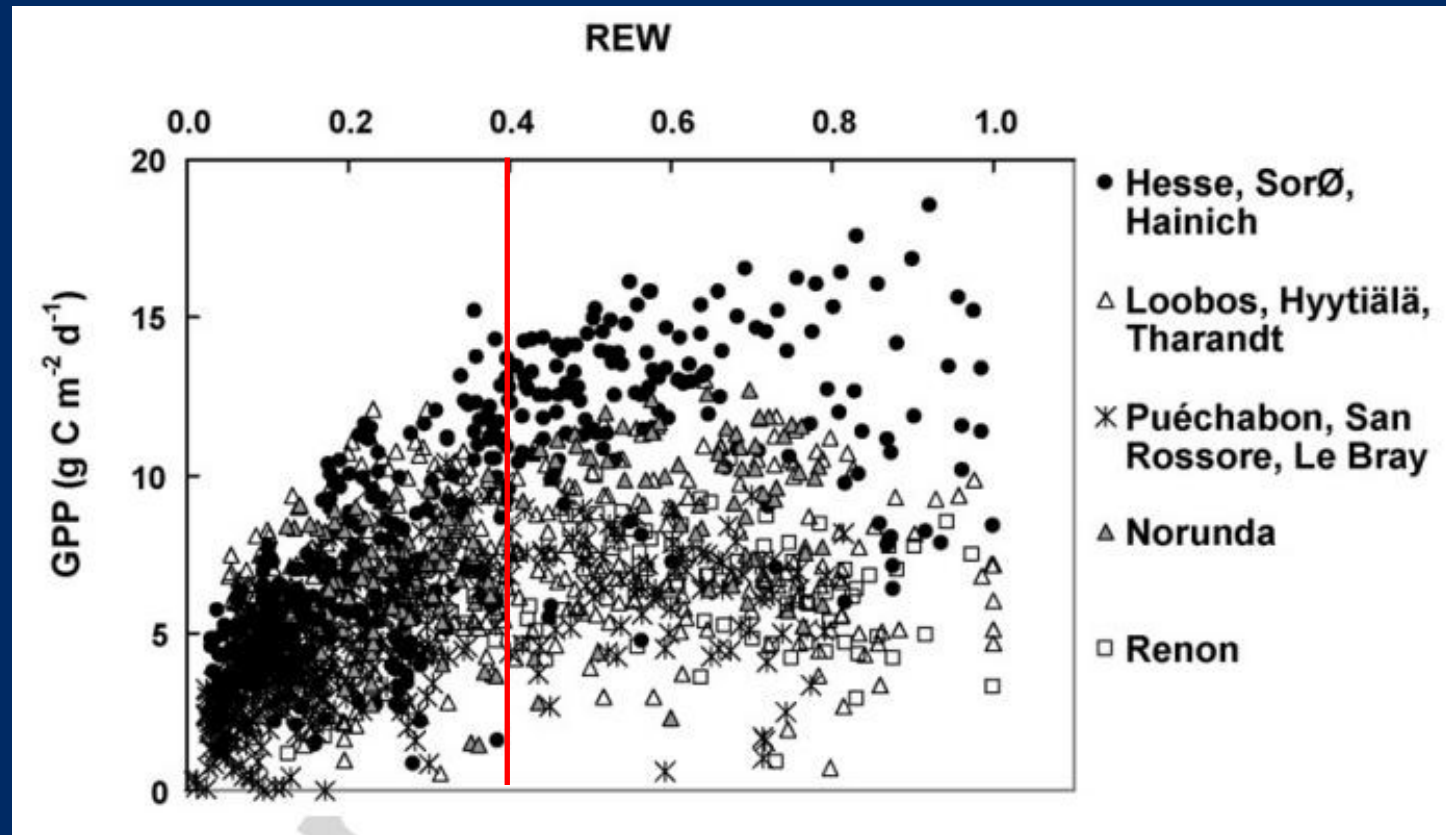
Outputs:

- Soil water content at different depths

⇒ REW

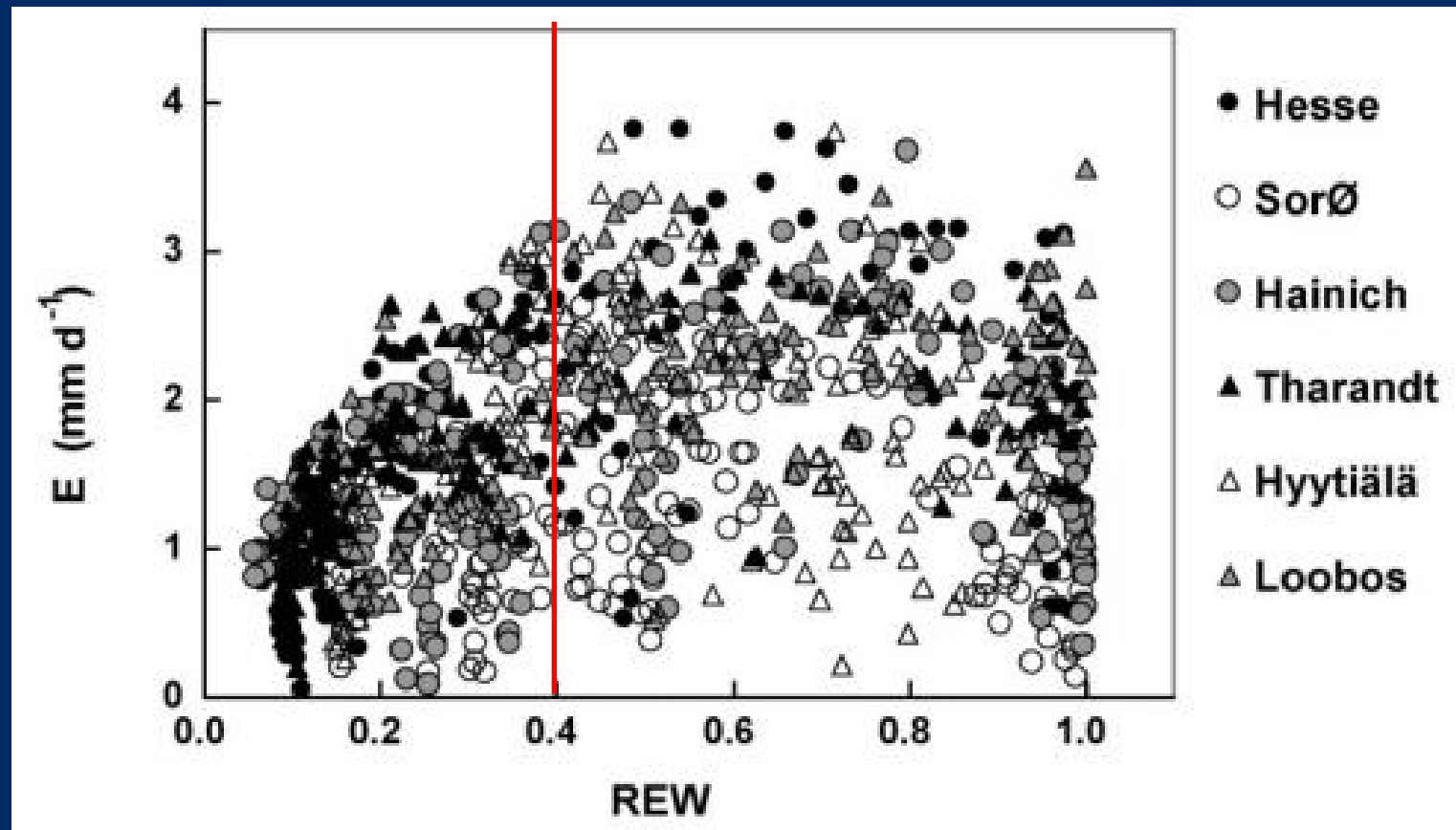
Drought impact on GPP

Clear impact (↘)
for all the sites
when $REW < 0.4$



Stomatal closure or impact of t° on photosynthesis biochemical reactions?

Drought impact on GPP

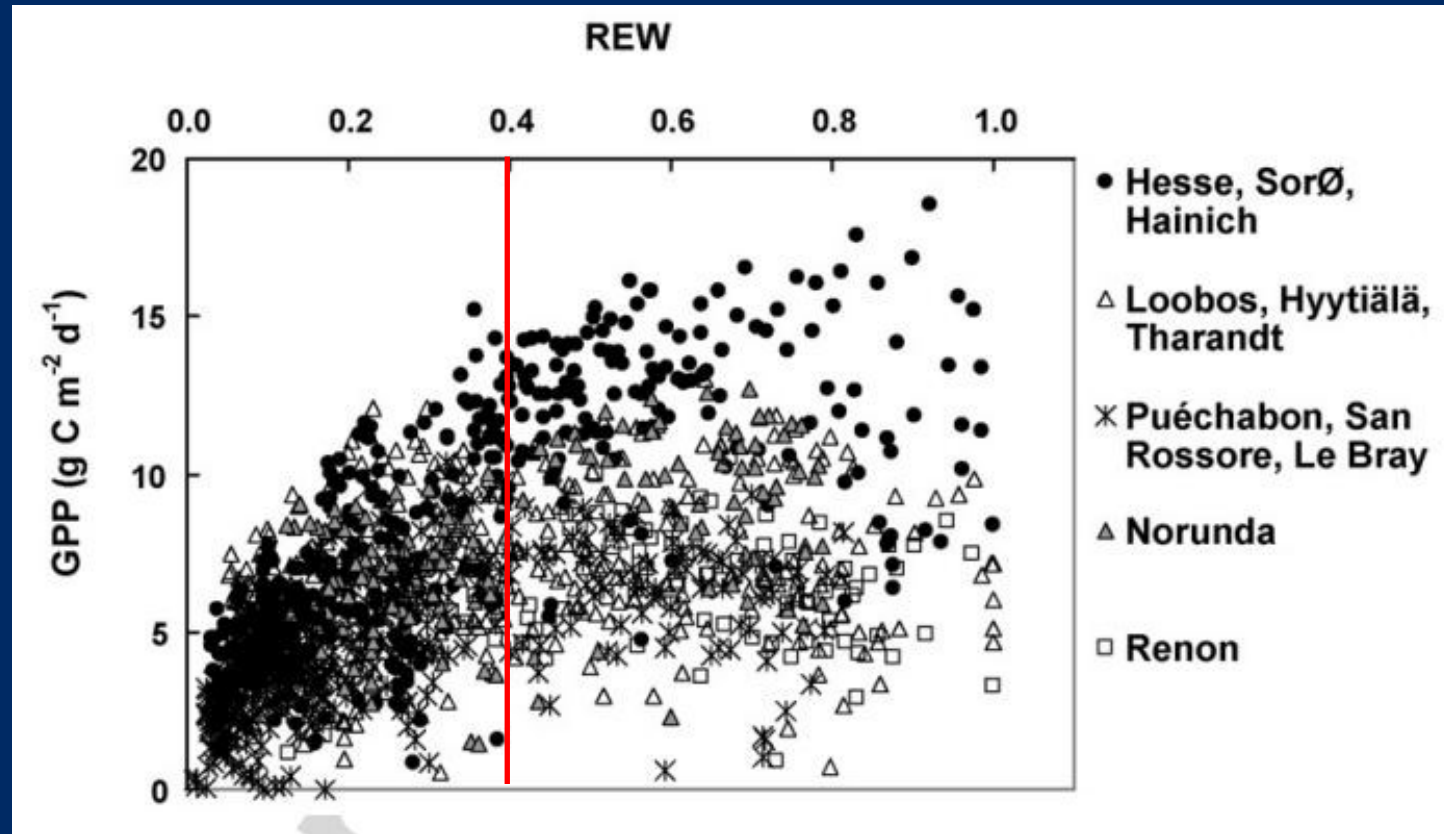


Evapotranspiration \searrow
also when $\text{REW} < 0.4$

Lack of soil water
 \Rightarrow Low leaf water potential
 \Rightarrow Stomatal closure

Drought impact on GPP

Clear impact (↘)
for all the sites
when $REW < 0.4$



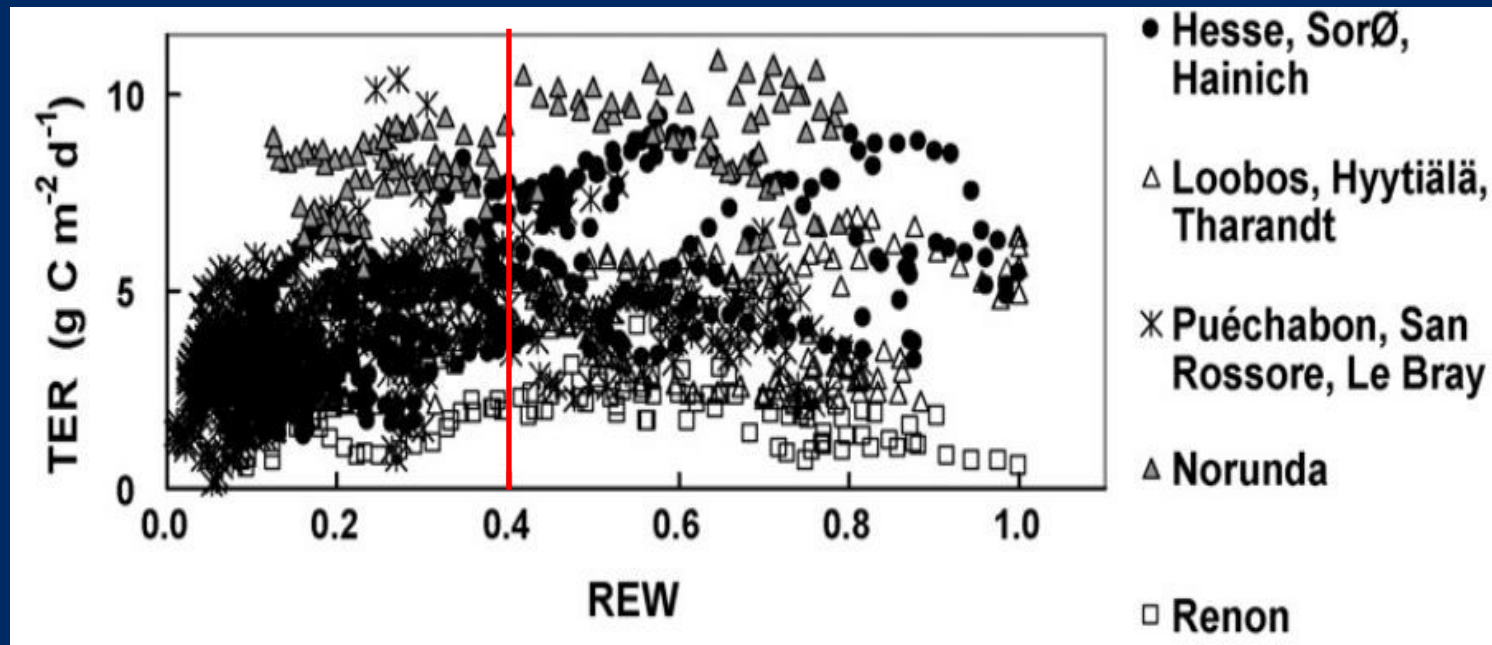
Stomatal closure or impact of t^o on photosynthesis biochemical reactions?

Parameterization: GPP (REW, Global Radiation) $R^2 = 0.59 - 0.87$ (0.77)

Set of parameters adjusted for each sites

Similar behaviour : C absorption decrease when $REW < 0.4$ for all sites

Drought impact on TER



Not all the sites impacted, those impacted less clearly

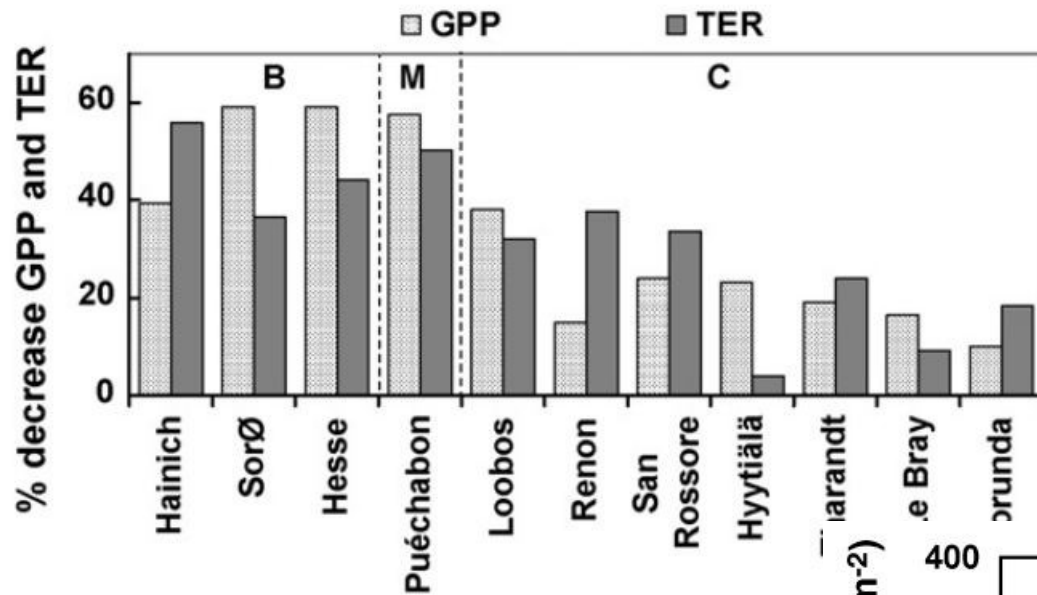
Still threshold around REW = 0.4

Parameterization: TER (REW, T_{air}) R² = 0.4 – 0.73 (0.62)

Set of parameters adjusted for each sites

Inter-specific similarity (REW_{th} ≈ 0.4) and differences (set of parameters)

Impact of drought : annual scale



Comparing 2003 to 2002:

- **||GPP|| and ||TER|| decrease for all the site (up to 60% !!)**
- **Trees sequester less C & Soil loss less C**
- **Relative decrease more important for GPP or TER following the site**

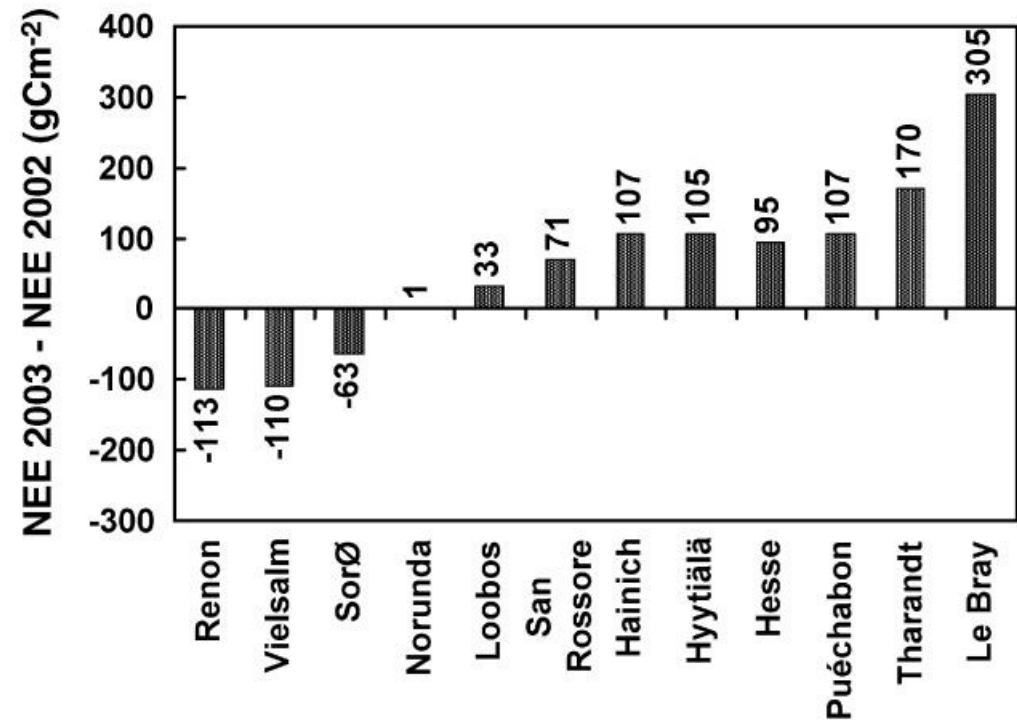
Broadleaf forest more impacted than coniferous (influence of species !)

||GPP|| decrease > ||TER|| decrease

⇒ less C sequestration by ecosystem



NEE 2003 – NEE 2002 > 0



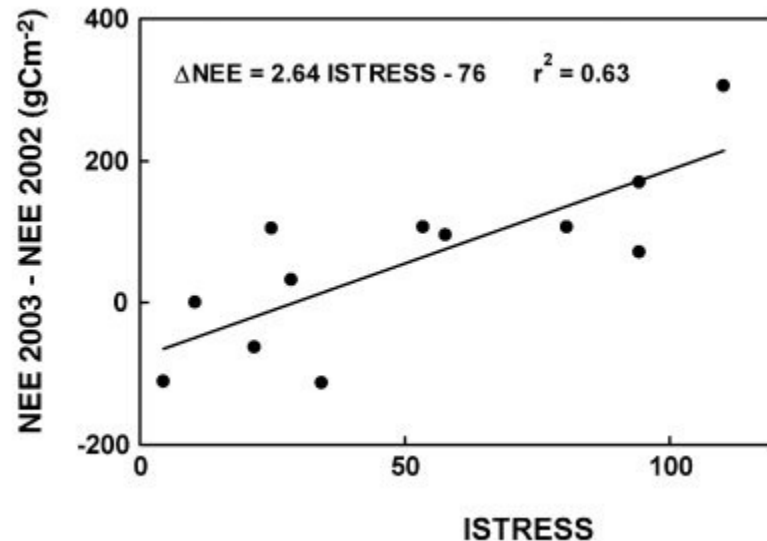
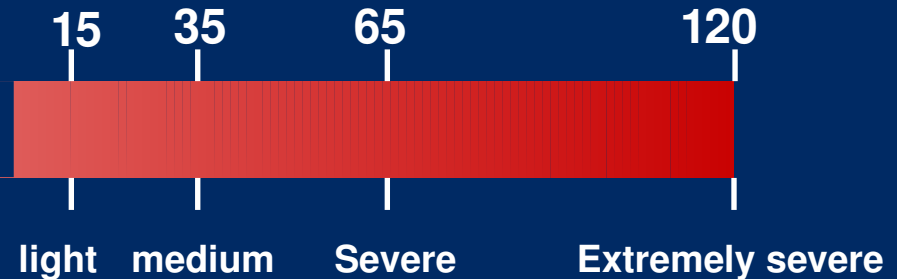
Impact of drought : annual scale

Which part of these ΔNEE are really due to soil water stress ?

Annual drought quantification with stress intensity index :

$$I_{stress} = \sum_{d=1}^{365} \max \left(0, \frac{0.4 - REW_d}{0.4} \right)$$

from 0 to 365

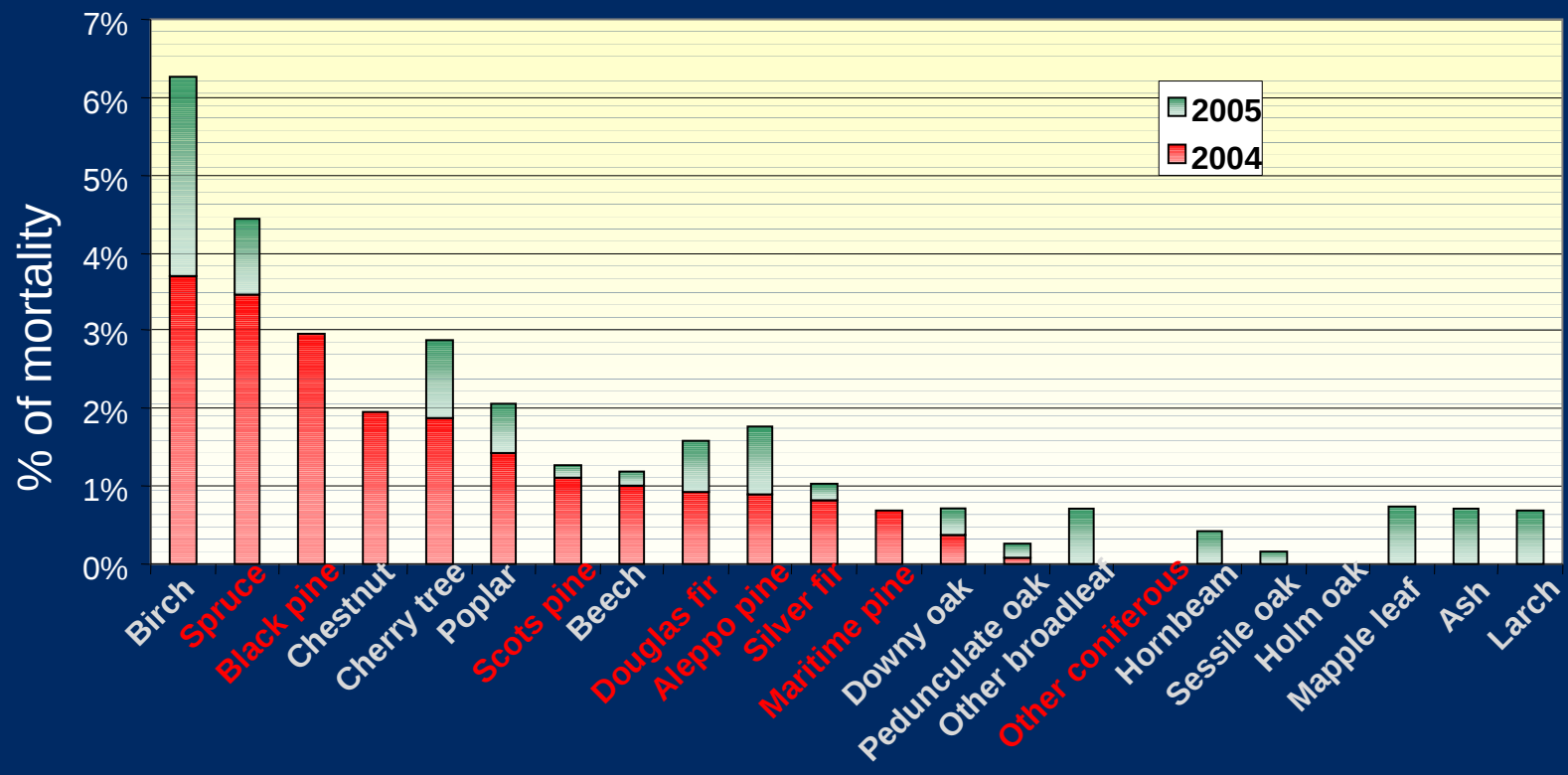


Istress explain 63% of drought impact on NEE

Comparing tree species strategies for soil water uptake (using water stable isotopes)

Context

- Study of the 2003 drought impact shows inter-sites and inter-species variability
- Mortality rates following drought can be significantly different between two species



Objectives & Method

Objectives

- What are the species specific strategies to have soil water (SW) available during drought ?
 - Deep SW uptake, leaf unfolding delayed, embolism (by cavitations) in some xylem vessels
- Are mixed forests more drought-resistant ?

Method

- Comparing behaviour of different tree species :
 - who grew up on same soil
 - submitted to artificial drought
- For these trees :
 - Localize SW uptake depth
 - Follow the phenology
 - Measure vulnerability to cavitations

Experimental set up

Hesse state forest, Moselle
Naturally regenerated forest

Age: 20-30 yrs

Soil: neoluvisol redoxisol
mesosaturated

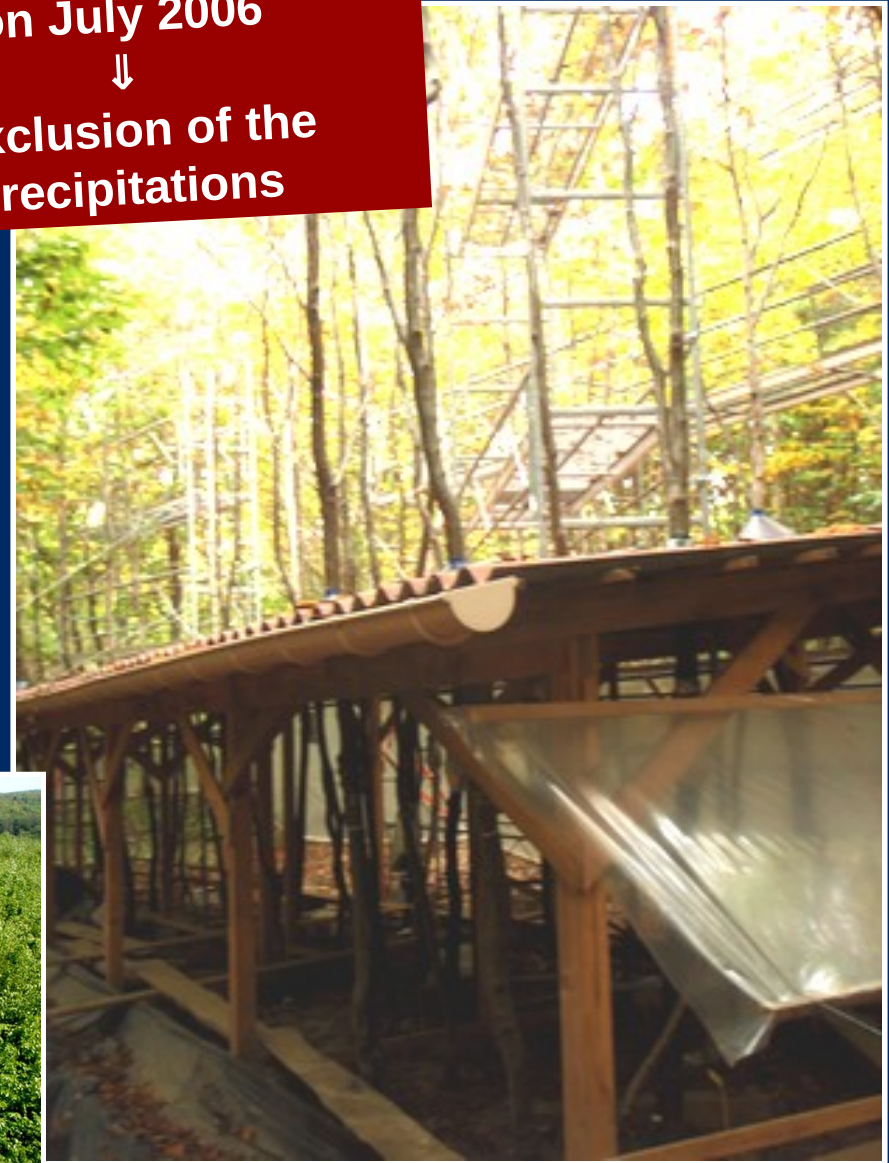
Basal area: 12.6 m²/ha (2002)

LAI: 7.6 (2006 & 2007)

**Roof (80m²) installed
on July 2006**



**Exclusion of the
precipitations**



Experimental set up



✓ 80 m² plot submitted to water shortage (36 trees)

✓ 4 tree species:

Birch (*Betula pendula*)

Sessile oak (*Quercus petraea*)

Beech (*Fagus sylvatica*)

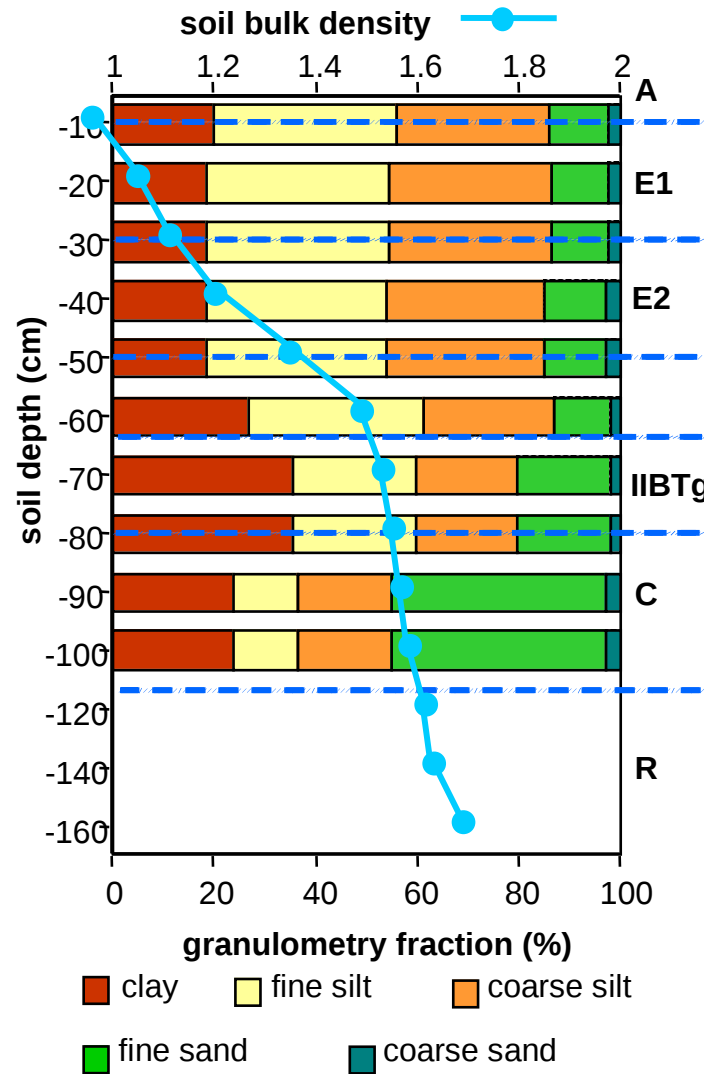
Hornbeam (*Carpinus betulus*)

✓ surrounding trenches (1m depth), roof

Stand equipments and measurements

- Climat / microclimate
- SWC profile (TDR sensors)
- Micropsychrometers
- Sapflow
- Growth (dendrometers)
- Phenology
- Root profile

Soil description



Upper soil compartment
(EW 125mm)

BT: clay soil layer

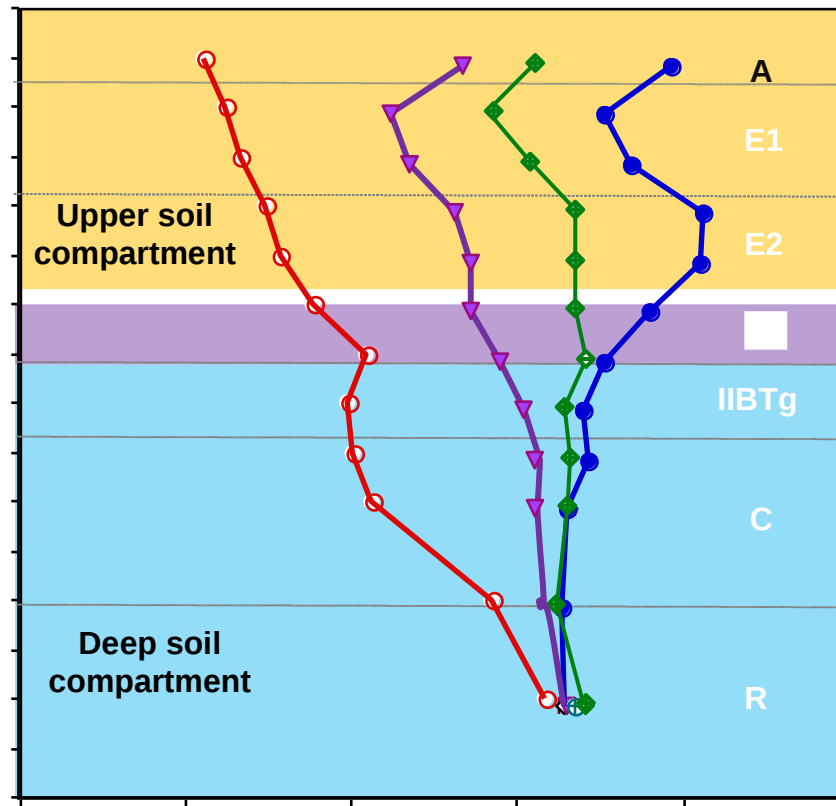
Deep soil compartment
(EW 115mm)

2 soil compartments with
contrasted hydrodynamic
properties

(d'après Zapater et al., 2008)

Artificial drought

Water shortage

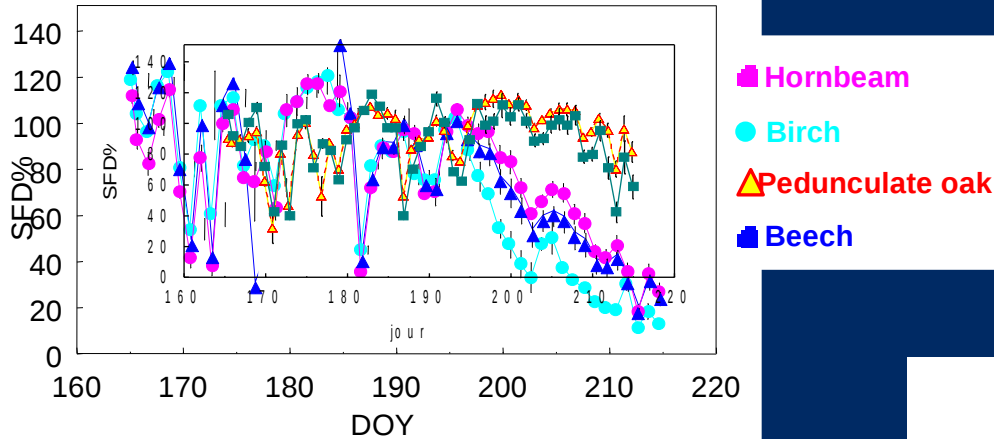


Progressive
deeper soil water
uptake as water
shortage occurred
?

- 12 January
 - 5 June
 - 26 June
 - 13 Aout
- 2007

Water uptake

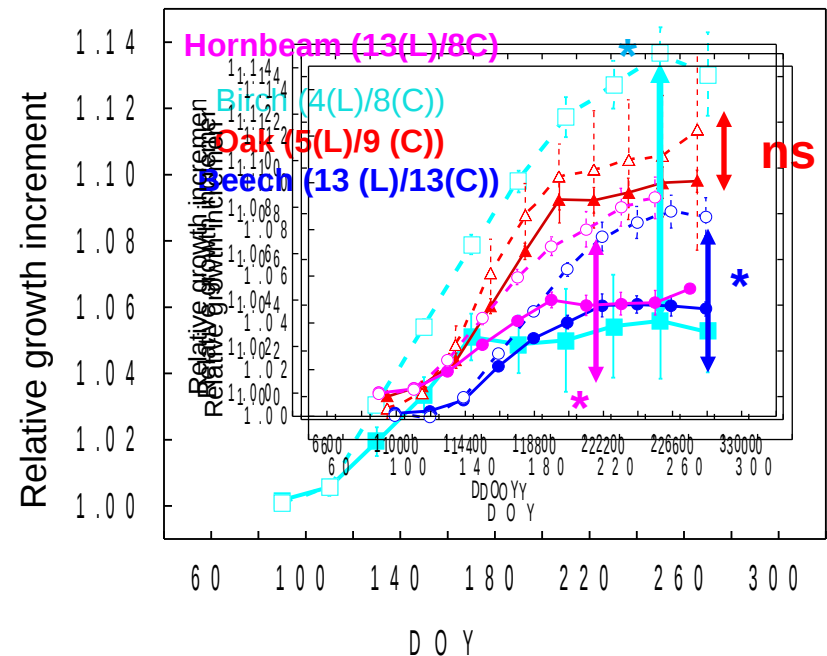
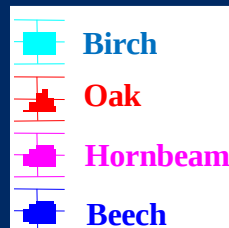
Sap Flow Density (relative to max)



- Strong decrease in SFD(%) : birch, hornbeam, beech
- Late / no decrease : oak

- Significant decrease in tree growth % : birch, hornbeam, beech
- Not significant decrease : oak

□ Have Oaks a better access to deep SW?



Fine roots vertical distribution

Count performed in relatively homogenous subplots



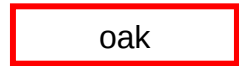
$\approx 4\text{m}^2$
mapped



Fine roots vertical distribution

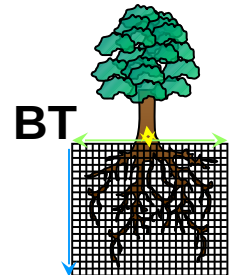


Beech



oak

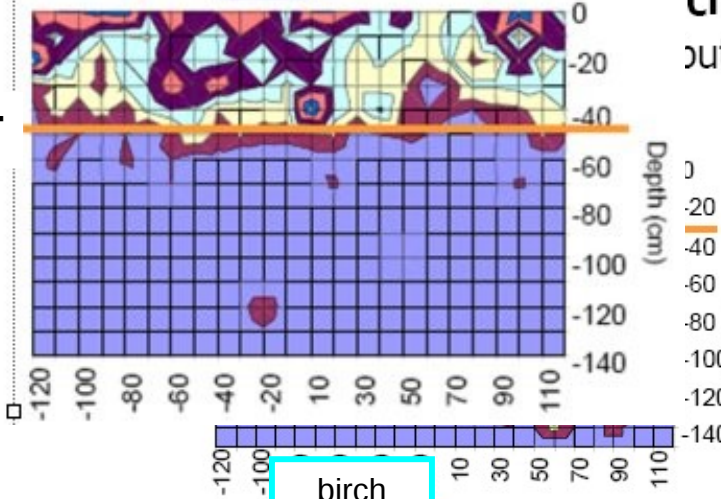
tion de l'eau
oution racinaire



BT

BT

15%

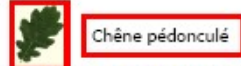
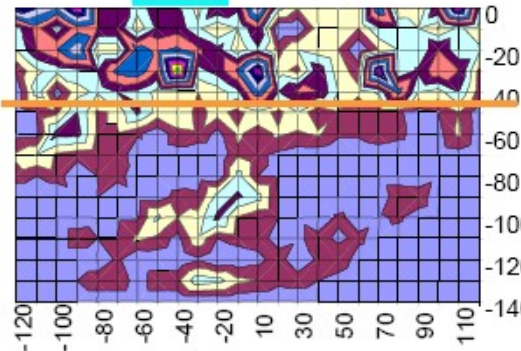


birch

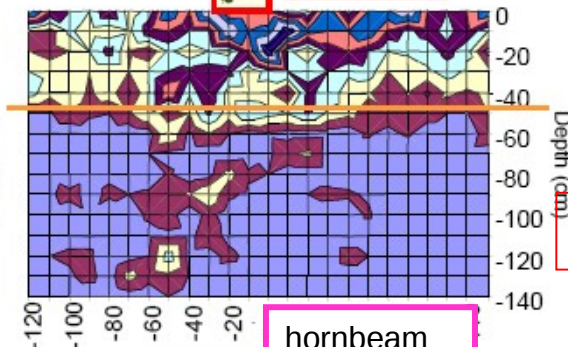
Bouleau

BT

40%



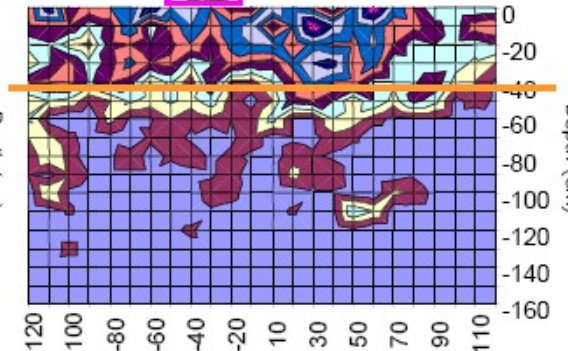
Chêne pédonculé



hornbeam



Charme



33%



BT

23%

□ Root distribution doesn't explain the oak special behaviour

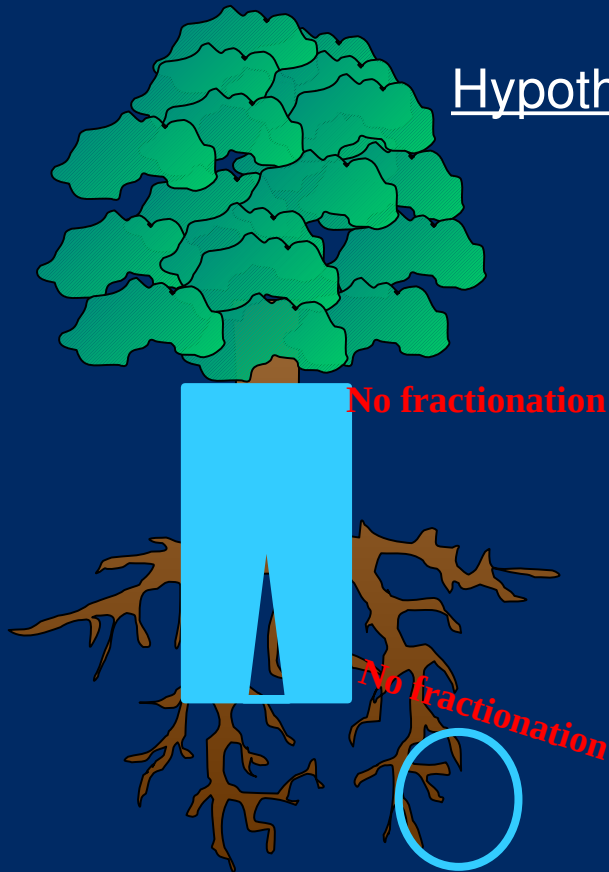
□ Is there difference between root distribution and water uptake profile ?

Water uptake profile

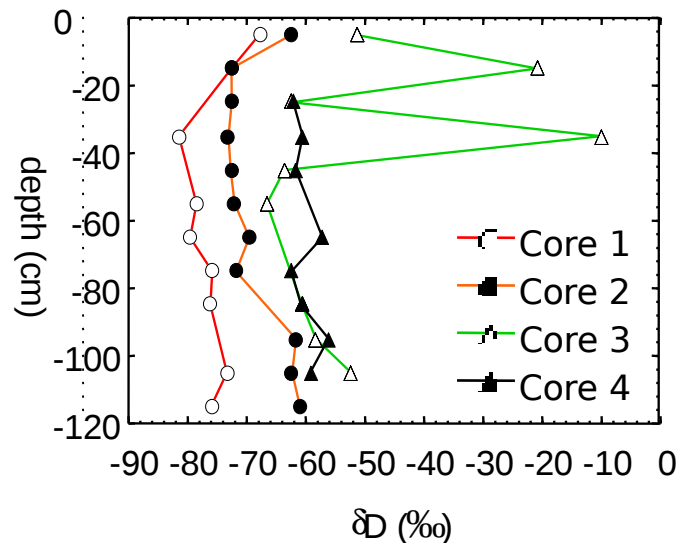
Use of H₂O stable isotopes ²H₂O (Deuterium) and ¹H₂O: δD (‰)

If soil δD vertical profile \Rightarrow Comparison of xylem sap δD enable to assess difference between soil water uptake depth

Hypothesis: No Fractionation against D during root water uptake or transport to leaves



Profile of natural δD abundance:



No adequate vertical SW gradient
 \Rightarrow
D labelling

Water uptake profile

Deuterium labeling of upper soil layer

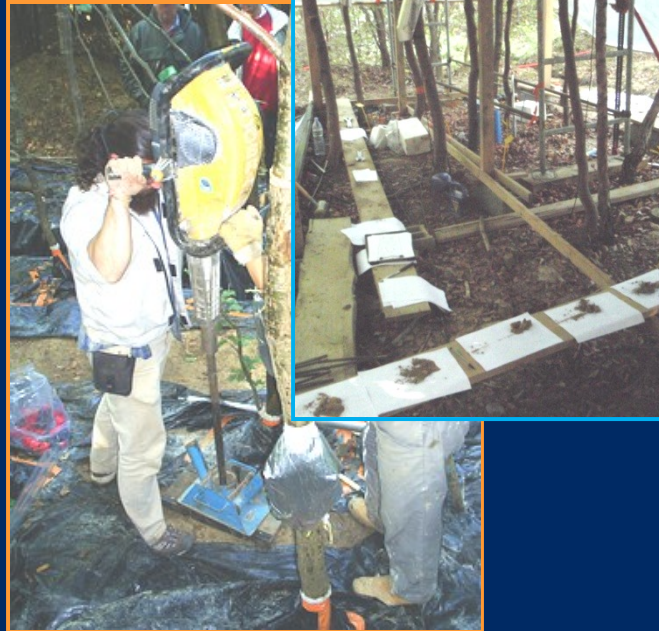


1. Preparation of the labelling solution +2500‰



2. Watering (10 mm rain simulated)

3. Soil sampling



4. Xylem sampling



6. Isotopic analysis (Isotopic Ratio Mass Spectrometer)

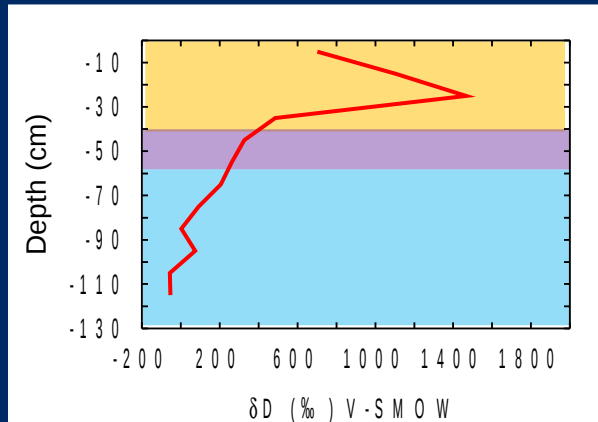


5. Cryogenic extraction line

Water uptake profile

Deuterium labeling of upper soil layer: results

Soil water isotopic composition
30 days after watering



Isotopic mass balance

$$SF = Vu + Vd$$

$$\delta_{xyl.}(Vu + Vd) = \delta u.Vu + \delta d.Vd$$

Species	Shallow roots (%)	Transpiration decrease (%)	Upper compartment absorption (%)
beech	85	64	77
birch	60	71	76
hornbeam	77	53	34
oak	67	21	9

Strategy

Shallower water uptake

Deeper water uptake

□ Oak deep roots are able to uptake water, not the birch ones (passives)

Mixed forest

Are mixed forests more drought-resistant ?

Could shallow water uptake species (beech) benefit from the proximity of deep water uptake species (oak) ?

Yes, if a hydraulic lift (water transfert between the 2 soil compartments)

Water :

- **absorbed** by deep roots in deeper compartment
- **goes up** to the upper comp. depth
- during night, **released** in the upper comp.
- **diffuse** in the upper comp.



Hydraulic lift

Detection by experimentation:

^{18}O labeling of deep soil comp. water (H_2^{18}O)

Active lift if H_2^{18}O traces in the upper comp.

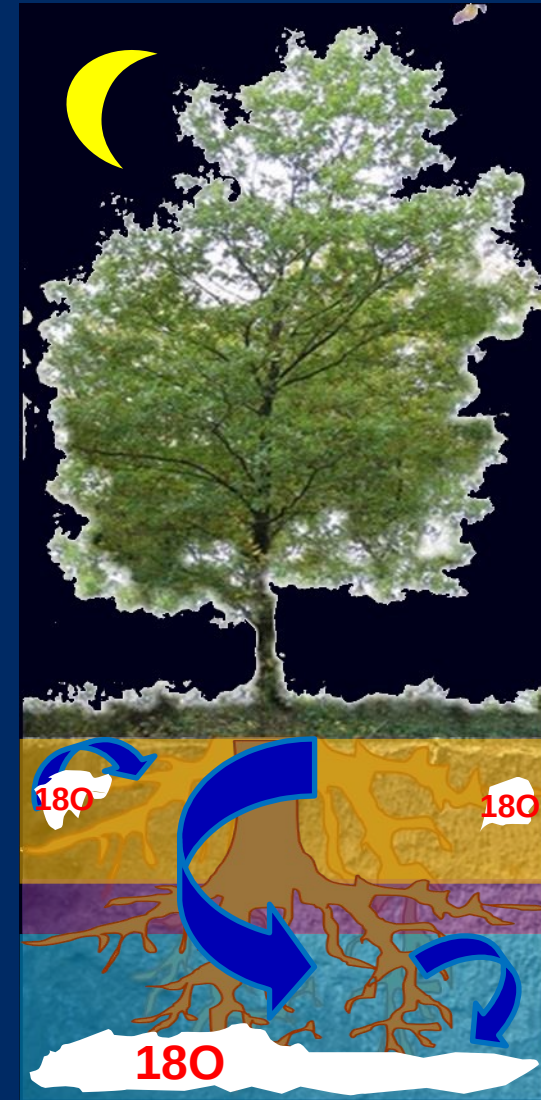
&

No traces in the BT layer
(H_2^{18}O not going up by capilarity)

Upper soil compartment:
low Ψ_{soil} : -1.6 MPa

BT: clay soil layer

Deep soil compartment:
 Ψ_{soil} : -0.8 MPa



Hydraulic lift

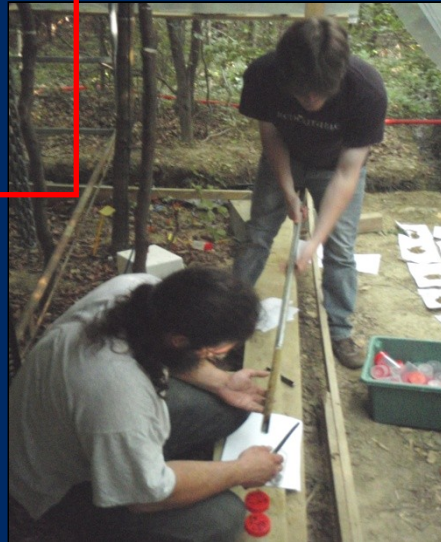
^{18}O labeling of deep soil compartment



1. Tube
insertion
in soil at
- 0.9 m
depth

6 days

2. labelling soil:
1 litre of H_2^{18}O solution



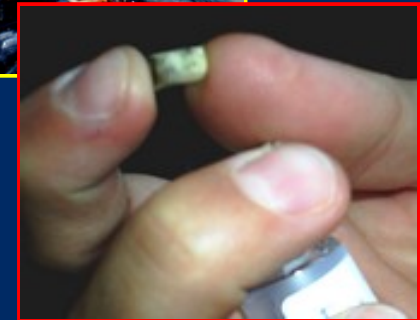
3. Coring soil



4. soil separation
from roots

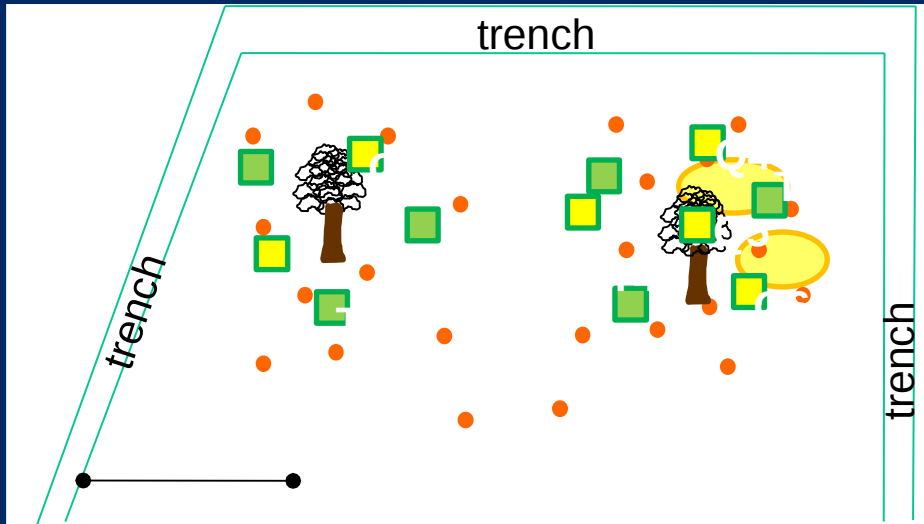


5. Xylem
sampling



Hydraulic lift

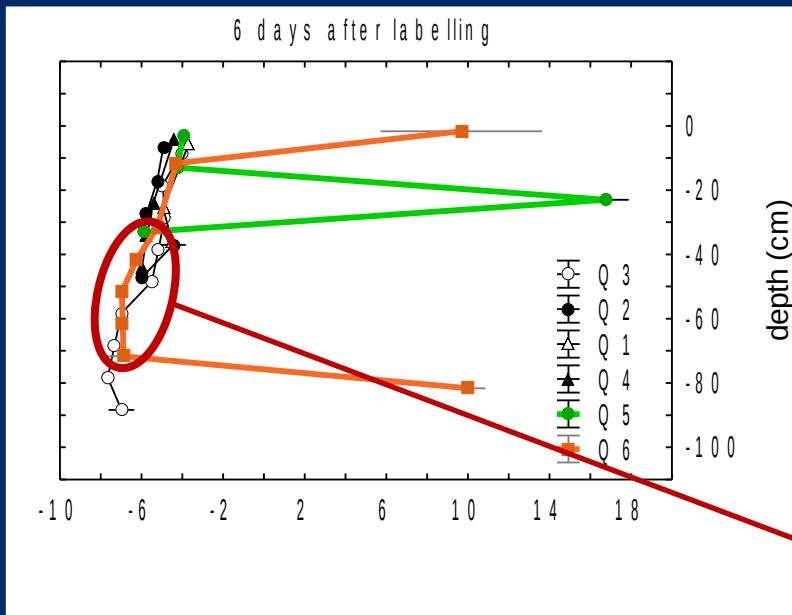
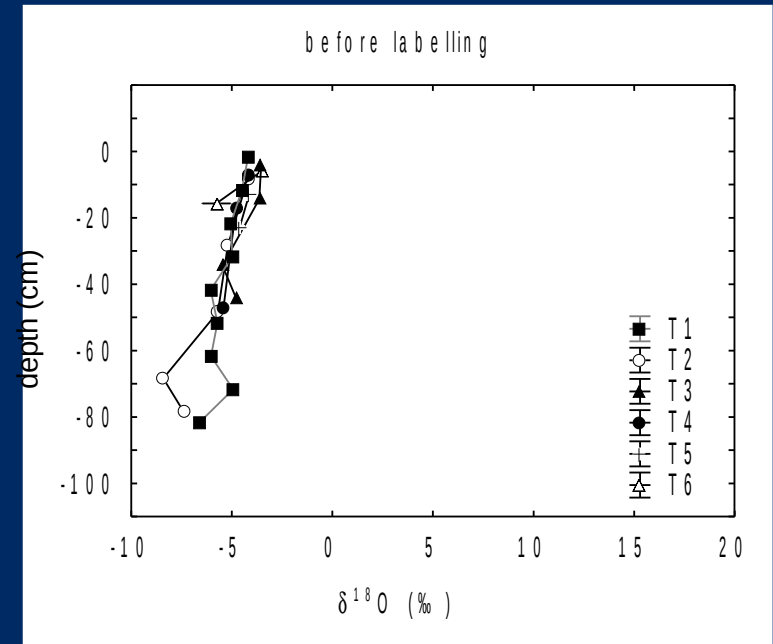
18O labeling of deep soil compartment: results



18O Labelling injection point

Q Soil core sampling

Upper soil compartment
18O enrichment



6 days after labeling:

- Deep and upper soil comp. enrichment
- No traces of capillary rise

CONCLUSIONS

- Large impact of drought on GPP and Reco ($REW < 0.4$), less on NEE
- Variability in annual NEE mainly explained by I_{stress}
- Species with “active” deep fine roots more resistant to drought (oak)
- Mixed forest can be more adapted to future climate (species solidarity like hydraulic lift)



Thank you