Water isotope monitoring to study transpiration and tree drought responses on Mediterranean karst


26 sept. 2019
- **Evapotranspiration (ET)**
  \[\approx 70\% \text{ of precipitation at continental scale } (\text{Oki et Canae 2006; Fisher et al. 2017})\]
  \[\approx 80\% \text{ of continental precipitation around Mediterranean sea } (\text{Brutsaert 2005})\]

- **Transpiration**
  \[\approx 70-80\% \text{ of ET } (\text{Rambal 2014})\]

**Fate of continental precipitation**

- Vegetation impact strongly groundwater resources
  Generally poorly considered in hydrogeological studies!
Karst

- *a priori* not very favorable to vegetation
Karst

- *a priori* not very favorable to vegetation

Example of Fontaine-de-Vaucluse

- 84% of the catchment area is covered by forest *(Ollivier et al. 2019)*
Is it possible that trees uptake deep water in karst unsaturated zone?
Material and methods

- Experimental sites
  - Southern France
  - Cretaceous urgonian limestone
  - Thin and stony soils
  - Mediterranean forest
  - Altitude 1350m
  - Altitude 530m
### Water isotopic tracing

- $^{18}\text{O}$ – inform about water origin uptake plants
  
  *(e.g. Ellsworth et Williams 2007; Bertrand et al. 2014; Barbeta et al. 2015)*

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**Material and methods**

- **Shallow water**
  - Precipitation *(IAEA protocol)*
  - Soil *(mini-lysimeters)*

- **Tree** *(5 to 7 individuals)*
  - Xylem
  - Phloem

- **Groundwater** *(Rustrel → 2 seepages within underground laboratory; Ventoux → 2 springs)*
  - Limestone with high water content
  - Limestone with low water content

- **Deep water**
  - Mass spectrometer analysis

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*Carrière et al. 2016 – Hydrogeol. J*
**Ecophysiology**

- **Leaf water potential**
  
  ➔ inform about tree water status (*Schlander et al. 1965*)

![Diagram of water potential gradient]

- Atmosphere: $\approx -100\text{MPa}$
- Leaf of tree: $\approx -1.5\text{MPa}$
- Root: $\approx -0.6\text{MPa}$
- Soil: $\approx -0.3\text{MPa}$

![Leaf potential measurement image]
Material and methods

- **Hydrogeophysics**

  - **Electrical Resistivity Tomography (ERT)**
    - inform about:
      - underground structure
      - water dynamic
      (eg. Dahlin 2001; Günther 2004)

    - signal influenced by: **water content**, clay content, type of rock, temperature,...

    ![Diagram of Electrical Resistivity Tomography (ERT)](image)

    **Loke, 2010**
**Temporal dynamic of isotopic tracing**

Results and interpretations

Rustrel

Wet summer

Dry summer

Precipitation (mm)

Results and interpretations

*Temporal dynamic of isotopic tracing*

[Graph showing temporal dynamics of isotopic tracing with wet and dry summer periods.]

- Precipitation (mm)
- $\delta^{18}O$ values for different plant species and water sources.

Legend:
- Deep water Rs
- Holm oak
- Silver fir
- Deep water Vx
- Beech
- Shallow water
Temporal dynamic of isotopic tracing

Results and interpretations
Trees uptake deep water from unsaturated zone

Deep water extraction is more intense during dry years

Silver firs uptake less deep water than Beech and Holm oak
Results and interpretations

Proportion of the origin of xylem water

Trees uptake deep water from unsaturated zone
Deep water extraction is more intense during dry years
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Carrière et al. 2019- STOTEN
Results and interpretations

**Proportion of the origin of xylem water**

- Trees uptake deep water from unsaturated zone
- Deep water extraction is more intense during dry years
- Silver firs uptake less deep water than Beech and Holm oak

*Carrière et al. 2019- STOTEN*
**Hydrogeophysics (ERT)**

- Estimation of Total Available Water (TAW) by layer

![Resistivity change due to water](image)

\[
PVR (%) = \frac{\rho_{\text{dry}} - \rho_{\text{wet}}}{\rho_{\text{dry}}} \times 100
\]

- After 2 month drought
- After 230mm of cumulate rainfall (in 2 weeks)

*Carrière et al. 2015 - ISKA*
**Results and interpretations**

**Hydrogeophysics (ERT)**

- Estimation of Total Available Water (TAW) by layer

\[
PVR (%) = \frac{\rho_{dry} - \rho_{wet}}{\rho_{dry}} \times 100
\]

After 2 month drought

After 230mm of cumulate rainfall (in 2 weeks)

Resistivity change due to water

Proxy of TAW

Carrière et al. 2015 - ISKA

ERT: Electrical Resistivity Tomography

No Change = outcropping bedrock

Rustrel
Hydrogeophysics and isotopic tracing

Results and interpretations
**Hydrogeophysics and isotopic tracing**

- **Severe drought period**
  - Shallow water
  - Deep water
  - Only 6 trees!

- **Results and interpretations**
  - Percent Variation in Resistivity - PVR (%)
  - $\delta^{18}O$
  - $R^2 = 0.6$
  - $p < 0.05$
Is it possible that trees uptake deep water in karst unsaturated zone?

Yes

- When trees are stressed

- But we identify different behavior between:
  - species
  - individuals

- We need to quantify volume of deep water uptake with additional measurements or ecophysiologica modeling

- We need to integrate this knowledge in hydrogeological models
Thank you for your attention!

**Related papers:**

Carrière et al. 2020

Carrière et al. 2019

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**Science of The Total Environment**

Volume 698, 1 January 2020, 134247

Impact of local soil and subsoil conditions on inter-individual variations in tree responses to drought: insights from Electrical Resistivity Tomography

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The role of deep vadose zone water in tree transpiration during drought periods in karst settings – Insights from isotopic tracing and leaf water potential
Global change and vegetation

- What is the impact of combined effect (vegetation + global change) on groundwater?
- Is there possible retroaction between vegetation and groundwater?
- We need to better understand interactions between vegetation and groundwater
Water isotopic tracing

- $^{18}$O – inform about water origin uptake plants
  (e.g. Ellsworth et Williams 2007; Bertrand et al. 2014; Barbeta et al. 2015)

- Ellsworth et Williams (2007) or Barbeta et al. (submitted) show that there is possible fractionation of deuterium when water enter in roots
Ecophysiological and hydrogeological modeling

- KARAMEL $\rightarrow$ TAW : 189mm
- CASTANEA $\rightarrow$ TAW : 120mm

On the same site (Rustrel) the two type of model use very contrasted TAW.

However, TAW is a critical parameter in water balance modeling \((Garrigues et al. 2014; Ollivier et al. 2019)\)

- These differences have repercussions on recharge calculation!
- Which is better?
**Mixing proportion calculation**

*(Dawson 1993; Phillips and Ehleringer 1995)*

\[
d_{xyl} = f_{sw} \cdot d_{sw} + f_{dw} \cdot d_{dw}
\]

\[
f_{dw} = \frac{d_{xyl} - d_{sw}}{d_{dw} - d_{sw}}
\]

Where \(d_{xyl}\) is the plant xylem water \(\delta^{18}O\), and the proportions shallow water \((f_{sw})\) and deep water \((f_{dw})\) of the two sources with isotopic signatures \(d_{sw}\) and \(d_{dw}\), respectively

**Incertitude calculation** *(\(Wf_{sw}\))*

*(Genereux 1998)*

\[
W f_{sw} = \left\{ \left[ \frac{d_{dw} - d_{xyl}}{(d_{dw} - d_{sw})^2} \cdot W \delta_{sw} \right]^2 + \left[ \frac{d_{xyl} - d_{sw}}{(d_{dw} - d_{sw})^2} \cdot W \delta_{gw} \right]^2 + \left[ -\frac{1}{d_{dw} - d_{sw}} \cdot W \delta_{xyl} \right]^2 \right\}
\]

Where \(W\delta_{sw}\), \(W\delta_{dw}\), \(W\delta_{xyl}\) are the standard deviation