Modélisation des transferts d'énergie et d'eau à l'interface Surface-Atmosphère dans les forêts méditerranéenne en zone karstique

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MODELLING SURFACE WATER AND ENERGY TRANSFER IN KARSTIC MEDITERRANEAN FORESTS

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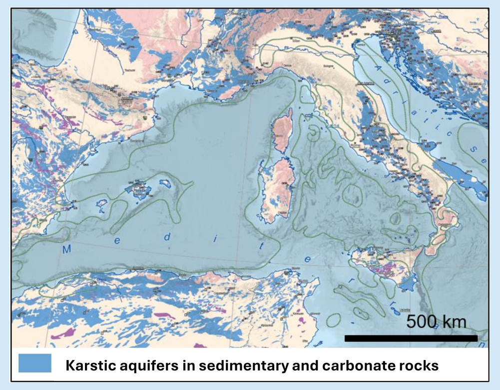
INTRODUCTION

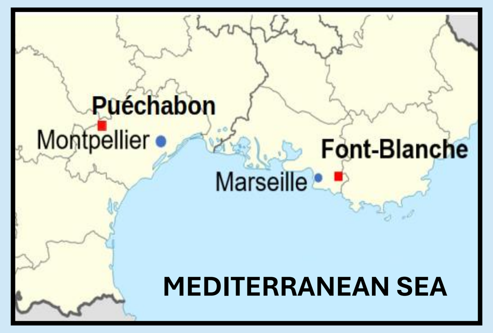
Droughts are a major factor in the vulnerability of **Mediterranean ecosystems**, particularly forest ecosystems, which are mainly located in **karstic environments**. Under the effects of **global change**, these environments are exposed to increasingly frequent and intense droughts.

Recent eco-physiological and isotopic studies have shown that **tree roots** are able to feed deep enough in the epikarst to **support transpiration during periods of water stress**. However, the quantification of stocks and temporal dynamics are not yet fully established.

This calls for the development of models adapted to the complexity of the environment, with the aim of improving our knowledge of both **aquifer recharge** and the **hydric functioning of forests.**



Map of karst aquifers in the Mediterranean basin (MEDKAM, 2023)



Map of the french Mediterranean region, with observation stations in red

MedECC, 2020 Carrière et al., 2020 Tramblay et al. , 2020

SITE OF STUDY

This study is based on data from two observation stations (ICOS network) **Font-Blanche and Puechabon located around the mediterranean basin** (see map 1).
They are two non-managed/**'natural' forests** with typical **mediterranean caracteristics** :

- pines and holm oaks
- dense understorey of bushes
- shallow and dry soil
- large fraction of rocks

Flux tower in the Font-Blanche forest (Etchanchu), and typical karstic soil profile

	Font-Blanche	Puéchabon
Affiliation	URFM, Avignon	CEFE, Montpellier
Species	Aleppo pines, holm oaks	Holm oaks
Height of canopy	13 m	6 m
Soil	Clayey, 60-90% pebbles	Clayey, 80% pebbles
Period of study	2014-2022	2014-2020

Main characteristics of the studied sites

Equipements of the sites:

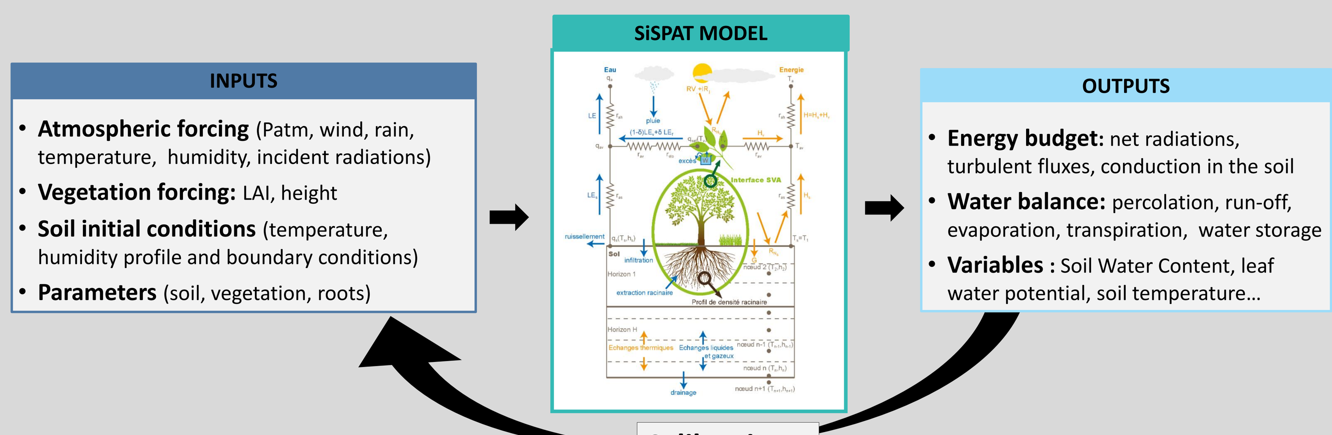
- **atmospheric measurements on a flux tower** (radiation, turbulent fluxes, hydro-meteorology)
- **measurements in the soil** (humidity, temp., respiration)
- **ecophysiological measurements** on individuals and canopies (sap flow, carbon flux,..).

Limousin et al., 2022 Moreno et al., 2021

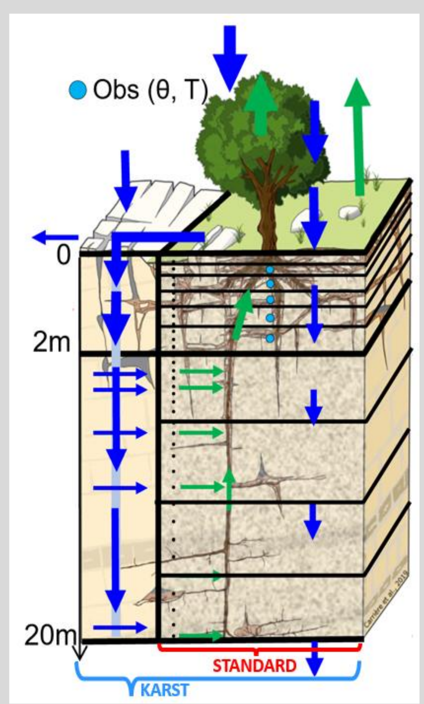
METHODOLOGY

SiSPAT model (Simple Soil Plant Atmosphere Transfer) , Braud et al. (1995)

Vertical 1D physical model dedicated to the coupling of water and energy cycles



Simplified diagram of SiSPAT operation system



NEWEST KARST VERSION

Conceptualize a network of karst fractures.

By adding **preferential infiltration** processes (karst version) in parallel to the diffuse (standard version), see diagram.

With 2 parameters:
→ Partial **recovery of runoff water** and rainwater into the soil *(0-100 %).*
→ **Water linearly redistributed throughout the soil profile** *(define depth interval),* by adding excess water to each node.

Conceptual diagram of water infiltration in the epikarst by the standard SiSPAT model (red) with karst module (blue). (Modified from Carrière et al., 2019)

SPECIAL FEATURES OF THE SISPAT MODEL

- Electrical Analogy (Resistors)
- **Coupled equations of energy and mass transfer** in soil (Richards, 1931)
- **Fine vertical discretization of soil**: suitable for heterogeneous soils (litter, coarse materials)
- Evapotranspiration (ET) separates transpiration and soil evaporation
- Separate thermal operation between bare soil and vegetation
- Plant hydraulics via **foliar water potential**
- **Big leaf** (Jarvis, 1976): No separation between vegetation stories and tree species
- Evolutionary Root Density Profile

WORKFLOW

1) Calibration and evaluation with standard version (Dynamics of infiltration, evapotranspiration , energy balance,)
→ **Reference simulation**

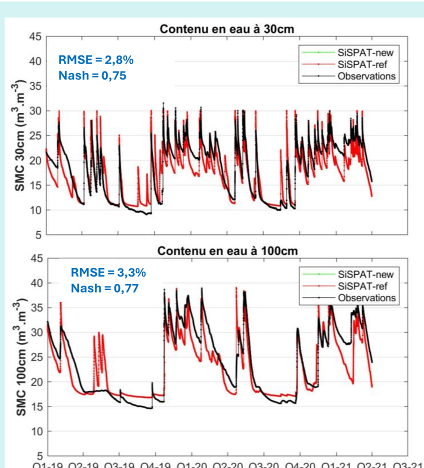
2) Same parameters but karst parameters activated
→ **Karst simulation**

Compare both

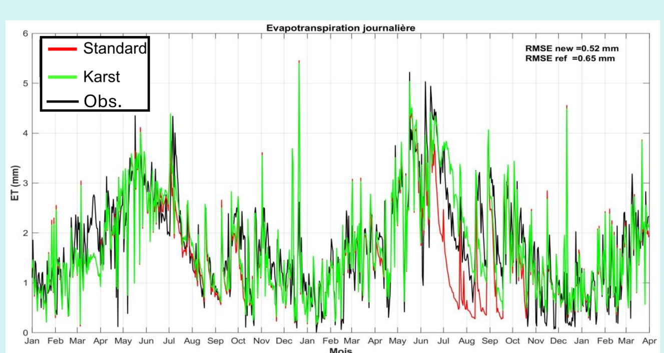
3) Finer calibration afterwards (**still in progress**)

FIRST RESULTS IN PUECHABON

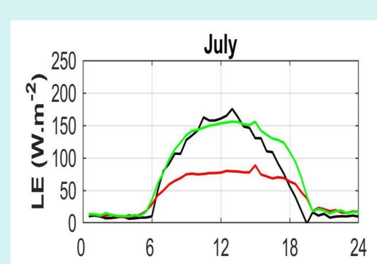
Demarty and Etchanchu, 2021



Soil moisture (m3/m3) observed and simulated at 30cm and 1m



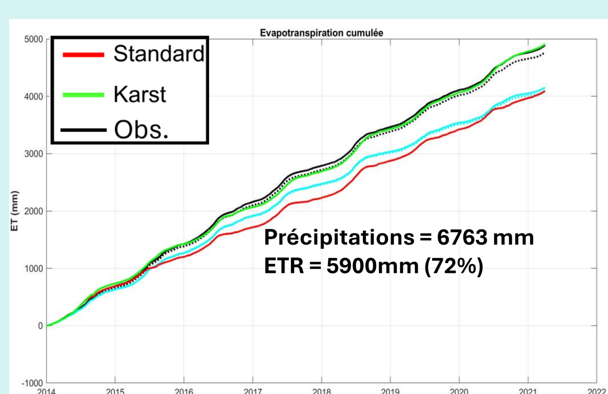
Observed and simulated daily evapotranspiration (Jan. 2019 - Apr. 2020)



Average daily variations in the observed and simulated latent heat flux LE in July

- Lack of 1000 mm of evapotranspiration over 7 years of simulation.
- ET major process: 72% of water balance.

Cumulative observed and simulated ET (2014 – 2021)



- **Satisfactory performance** on all simulated components of the **energy cycle**
- **Good reproduction of infiltration dynamics**

But without considering the preferential infiltration(standard version) :
Systematic underestimation of ET especially in summer.

KARST version: Systematic improvement for ET

- Reproduction of daily/ seasonal dynamics
- Filling the transpiration deficit with a supply of water from deeper soil

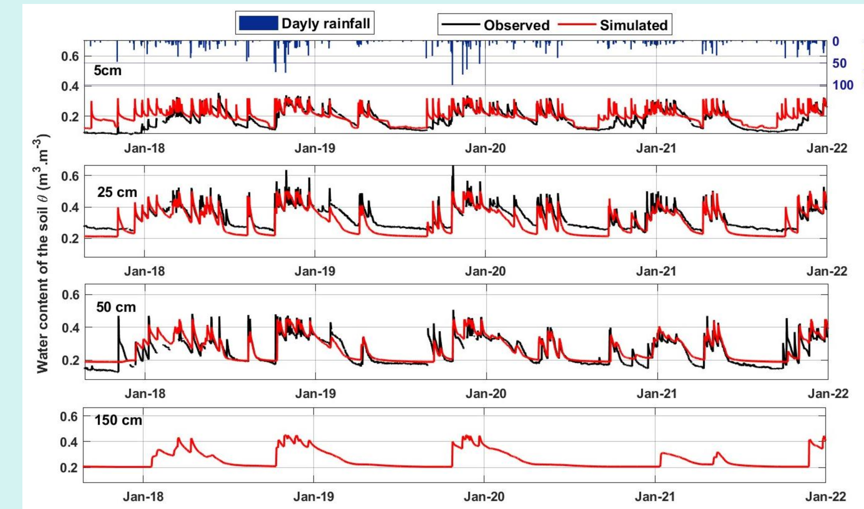
This configuration was then used as the basis for calibration at the Font-Blanche site

MAIN RESULTS IN FONT-BLANCHE

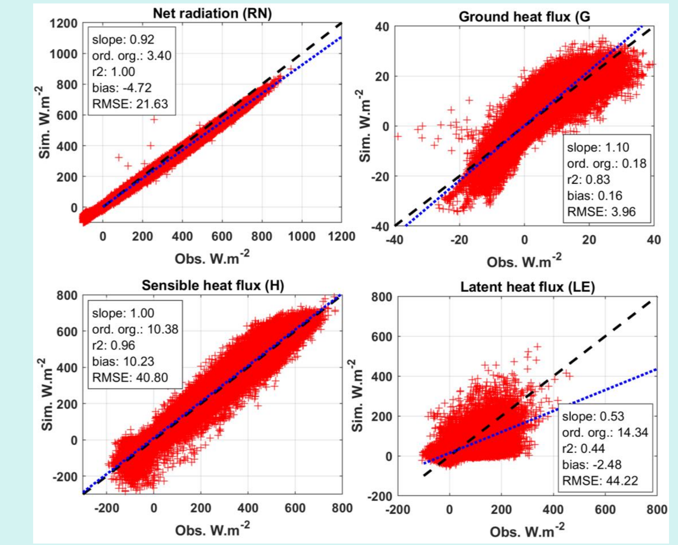
Calibration method

- Calibration for the years 2017-2022.
  - Spin up for deep profile
  - Exploitable period 2015-2022

- **Good coherence of infiltration dynamics, temperatures and radiation balance,**
- but poor reproduction of **turbulent flows**



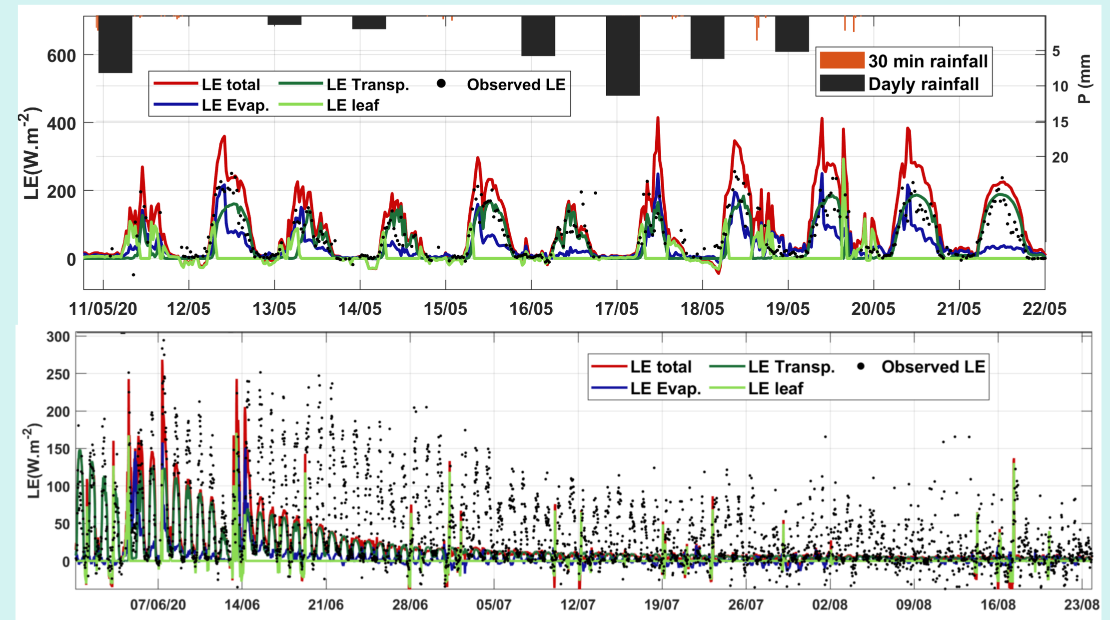
Observed and simulated soil moisture profile (m3/m3)



Scattergrams of energy balance components (2015-2021) simulated and observed

Rainy episodes

Dry season



Seasonal dynamics of the latent heat flux observed and simulated at Font-Blanche, with evaporation and transpiration partitions

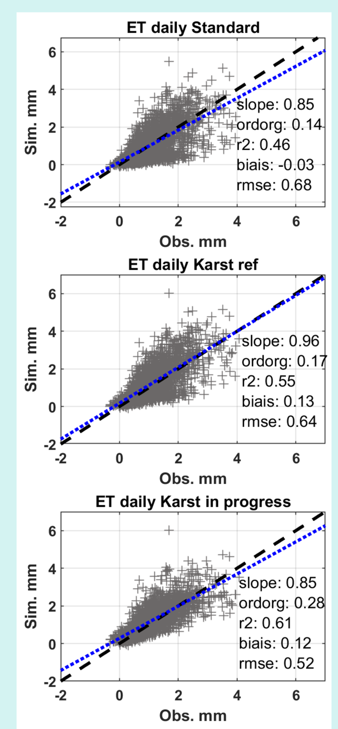
FOCUS ON EVAPOTRANSPIRATION (67% of water balance)

- Transpiration daily amplitude are mostly correct, but
- The model often **overestimates soil evaporation during wet periods**
- **Systematic underestimation of transpiration especially in summer.**

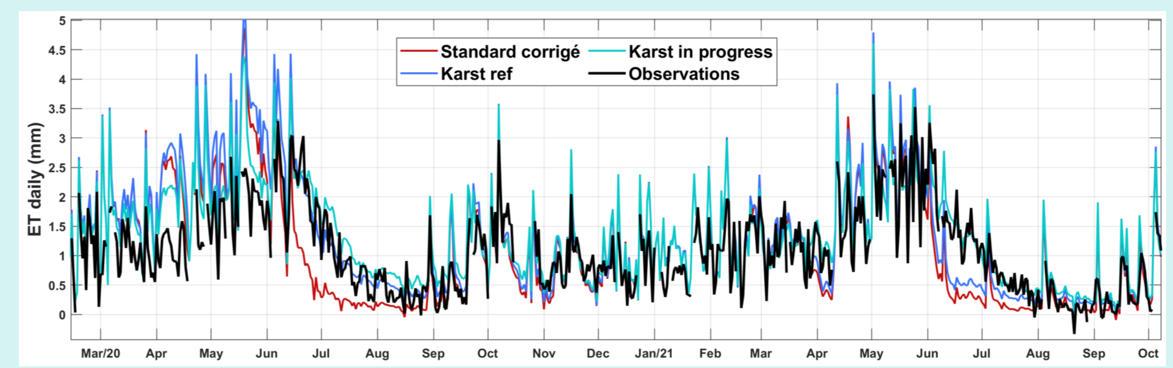
So available water in the soil is needed to sustain evapotranspiration

Through modelling of karst fractures — With different root network

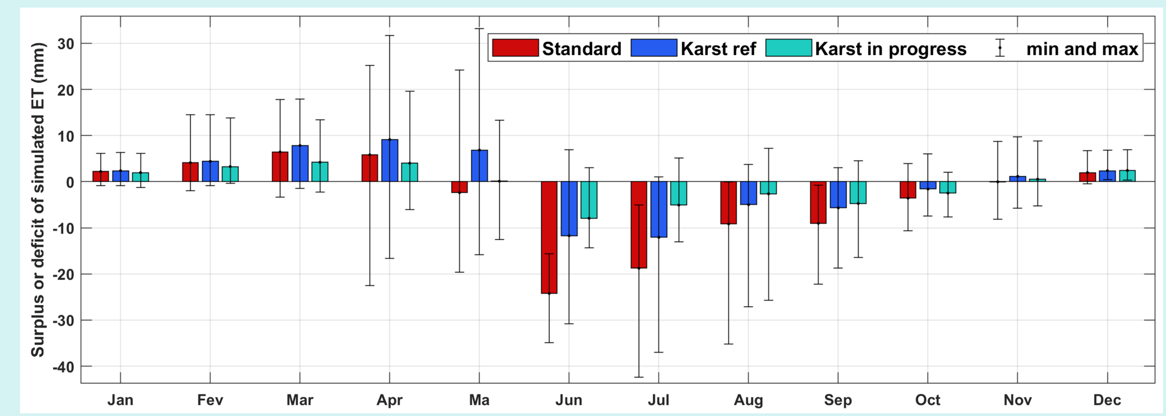
Contribution of the Karst version of the model



Daily ET scatter plot



Daily evapotranspiration (ET) chronicle between April 2020 and August 2021



Excess and deficit of simulated monthly ET (mean, min and max for 2015-2021)

Simulations

Ref parameters, no fractures	70% of runoff recovered Fractures from 1 to 15 m Root network, very dense	Same parameters but a decrease in root density

With karst fractures

- **Evapotranspiration increases** (75% of the water balance instead of 67%)
- **Large reduction of underestimation bias in summer**
- **Root water extraction at deeper level** during summer stress

With karst fractures + change in root network

- Every summer **modelled transpiration is sustained** (2021)
- **Reduction of the overestimation of ET after rainy episodes**

Preferential infiltration process provides the water needed for deep water uptake by the roots to support transpiration during periods of water stress.

CONCLUSIONS

Contributions of SVAT modelling and the karst module for the study of Mediterranean forests:

- Attribution and quantification of the dynamics of the evaporation/transpiration
- Without deep water supply with preferential infiltration, trees would not be able to sustain the transpiration level observed during the summer → Creation of a water reserve underlying the soil

LIMITATIONS AND OPENINGS

- Calibration work to be finalized : uncertainties with ET and root network
- Drainage to unsaturated zone of karst -> not quantified yet
- Studying finer processes of the plant
- Big leaf approach to be surpassed
- Compare transpiration simulation with sap flows (seasonal dynamics and quantities)
- Spatialised work on mediterranean ecosystems ("guarrigues" and forrest)

This project belongs to the ANR project One Water