XIII Séminaire STICS

Towards a coupling of CFD and STICS crop model

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Picture : AgriPV demonstrator in 2020 at EDF Lab Les Renardières (near Fontainebleau, France)

Outline

1. Context
2. Study question
3. State of the art
4. CFD
5. Results
6. Conclusions and perspectives

STICS

INRAE science for people, life & earth

code_saturne

EDF

Context

We need to

- Increase **renewable energies**
- Reduce the **human footprint** on lands
- **Adapt farming** practises

Context

GLOBAL WARMING

We need to

Increase **renewable energies**

Reduce the **human footprint** on lands

Adapt farming practises

Agrivoltaism is the combination of
PV production

Context

We need to

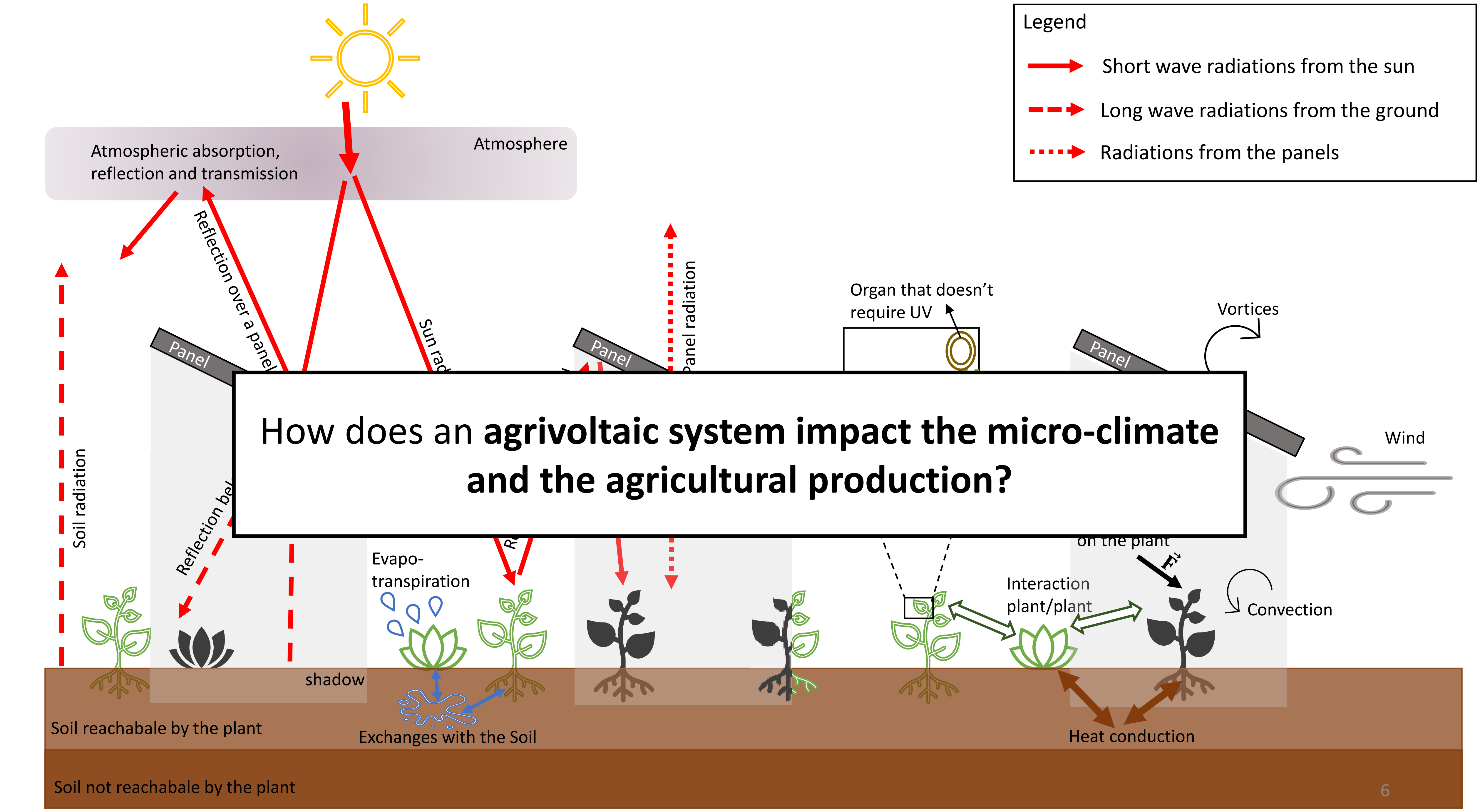
Increase **renewable energies**

Reduce the **human footprint** on lands

Adapt farming practises

Agrivoltaism is the combination of **PV production** and **agricultural production** on **the same land.**

Agrivoltaism over 1% of the agricultural lands would produce 150 clean GW


Legend
Short wave radiations from the sun
Long wave radiations from the ground
Radiations from the panels
Atmospheric absorption, reflection and transmission
Atmosphere
Reflection over a panel
Panel radiation
Organ that doesn't require UV
Vortices
Panel
Panel
Panel
How does an **agrivoltaic system impact the micro-climate and the agricultural production?**
Wind
Soil radiation
Evapo-transpiration
on the plant
Interaction plant/plant
Convection
shadow
Soil reachabale by the plant
Exchanges with the Soil
Heat conduction
Soil not reachabale by the plant

Study question

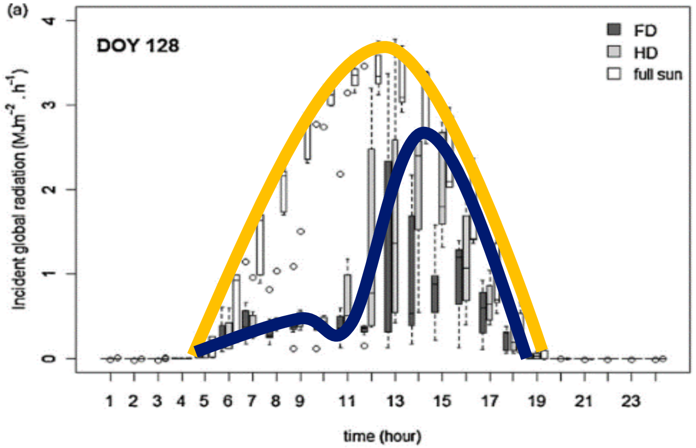
How does an **agrivoltaic system impact the micro-climate and the agricultural production?** **1. Radiation**

Effect on **shortwave radiation**:

- **-35%, depending on the agrivoltaic system** (Edouard et al., 2022)

Effect on **longwave radiation**:

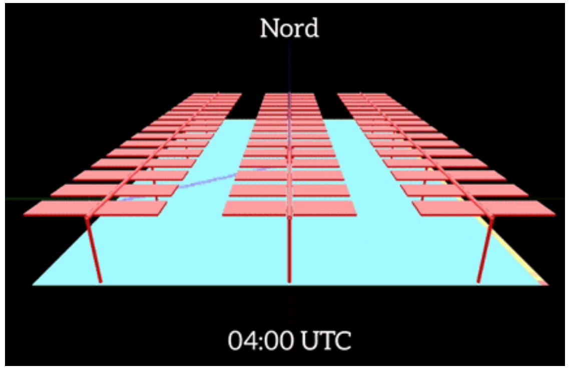
- **Greenhouse effect** during cold nights (Juillion et al., 2022)



(Marrou et al., 2013)

Consequences:
→**Risk** of **lower farming yields** (Marrou et al., 2013)
→**Lower evaporative demands** (Esmail et al., 2017 ; Juillion et al., 2022)

Simulation softwares:
Shading is easily captured by radiation codes: Pvnov, Caribu…
BUT **no links with micro-climate and crops**.

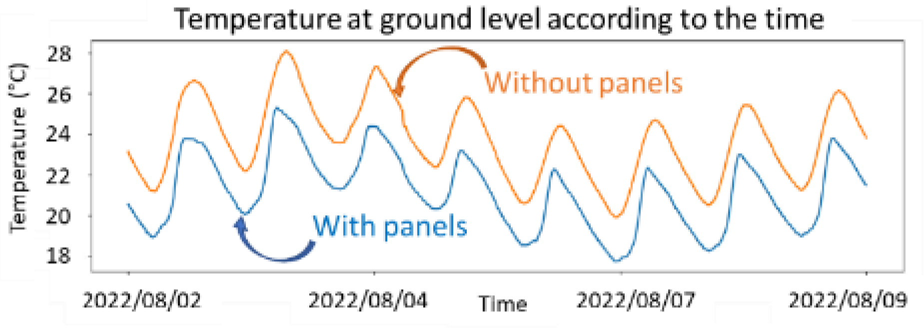


Study question

How does an **agrivoltaic system impact the micro-climate and the agricultural production?** **2. Temperature**

Effect on **air temperature**:

- **-1,2°C** (Barron-Gafford et al., 2020 ; Weselek et al., 2021)



Effect on surface **temperature**:

- Of the **crop, -3°C** during daytime (Marrou et al., 2013)
- Of the **soil, -1,3°C** (Weselek et al., 2021)

Consequences:

→ **Delay on the phenological stages** (Edouard et al., 2022)

→ **Lowe**

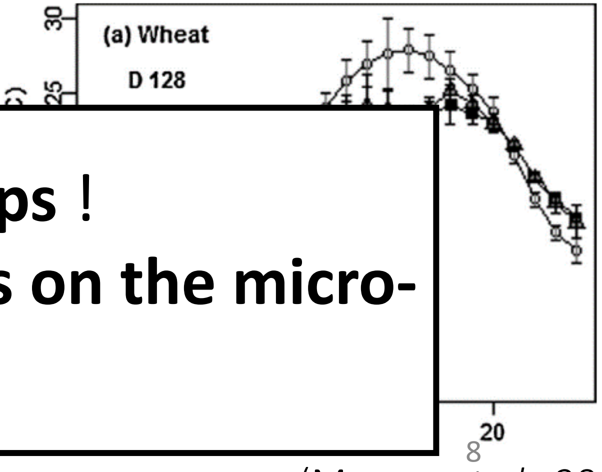
Simulat

Many c

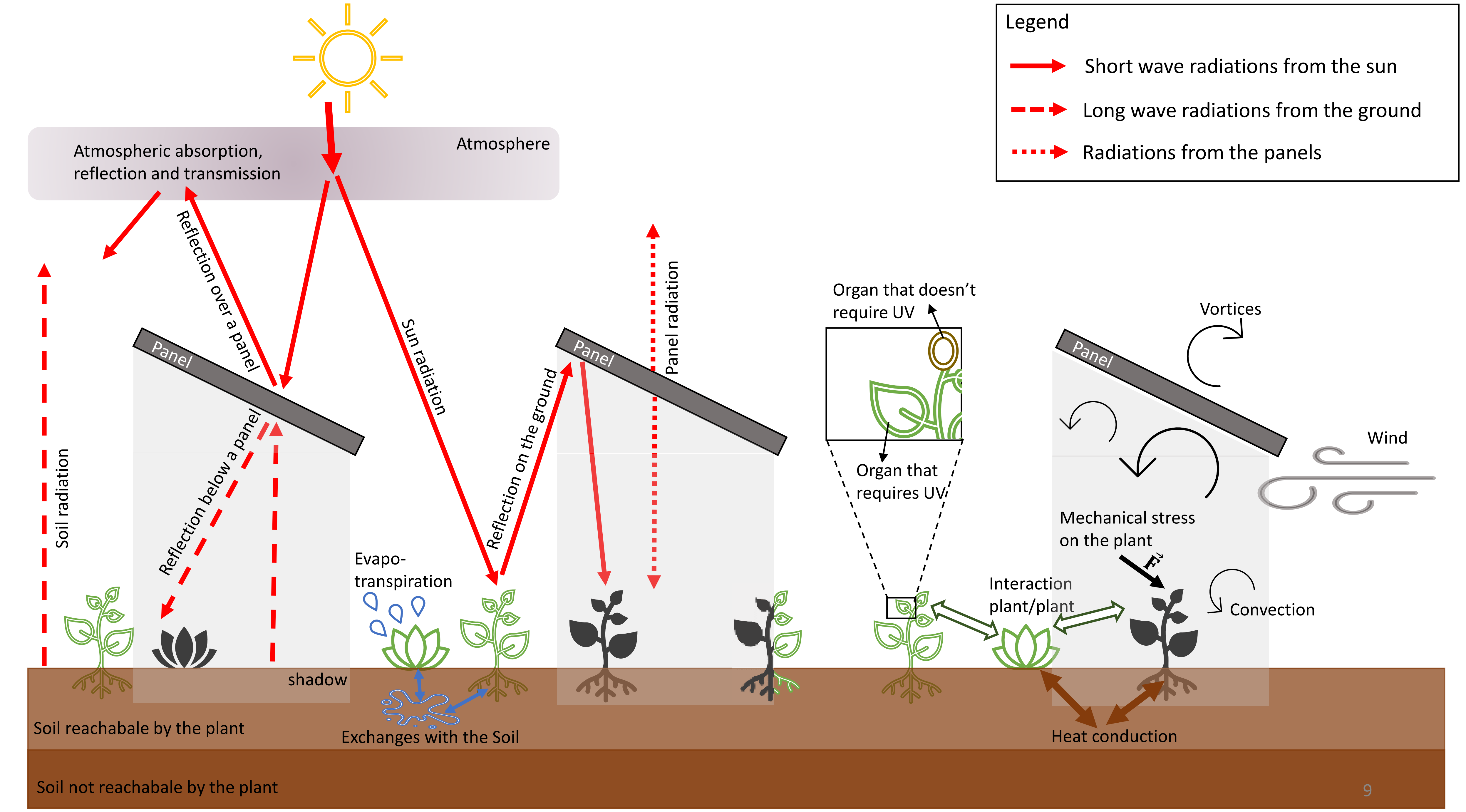
BUT **no**

Design studies are crucial not to **harm the crops** !

Need a software that considers **the impact of solar panels on the micro-climate and the crops.**



(Marrou *et al.*, 2013)



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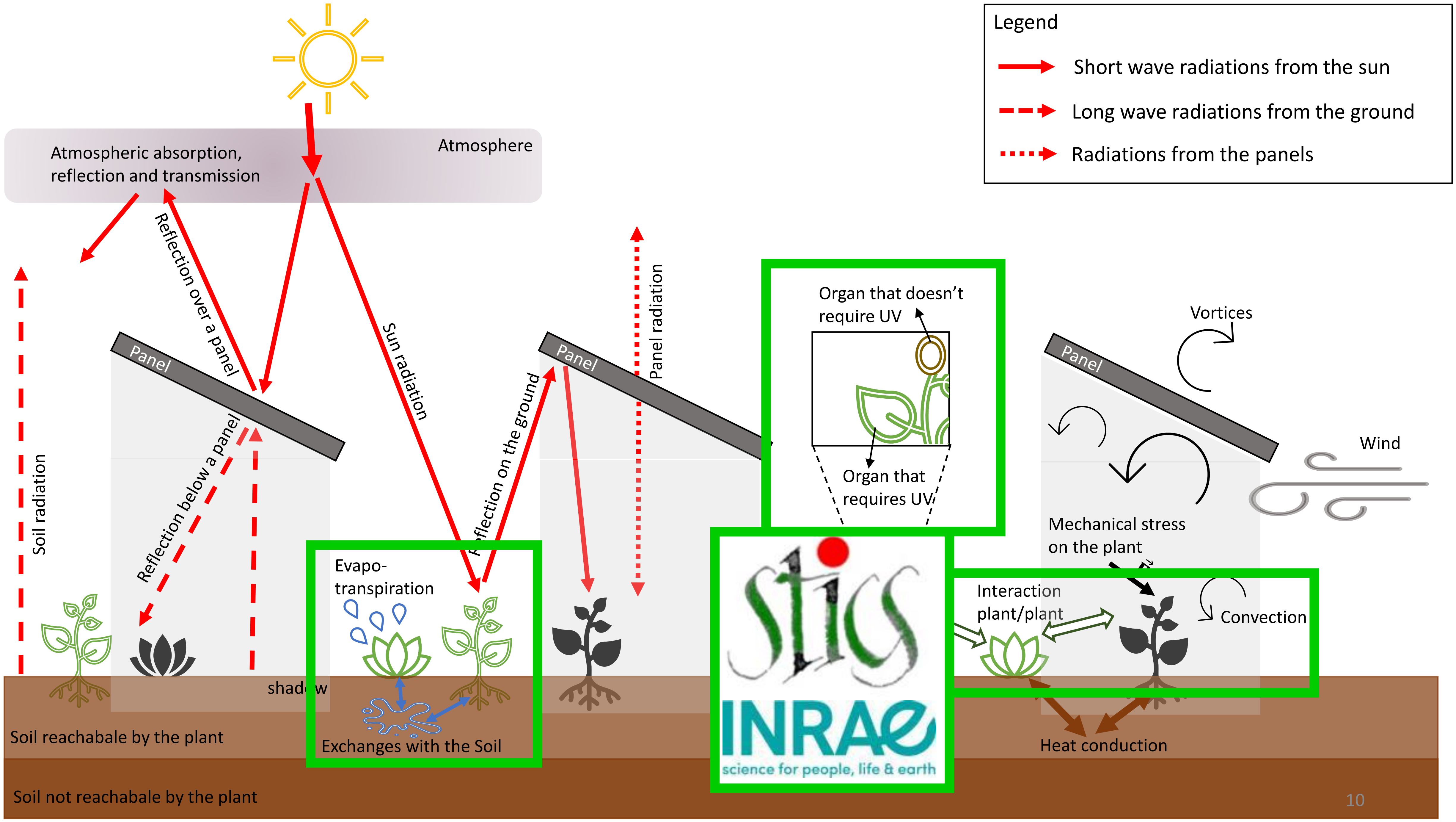

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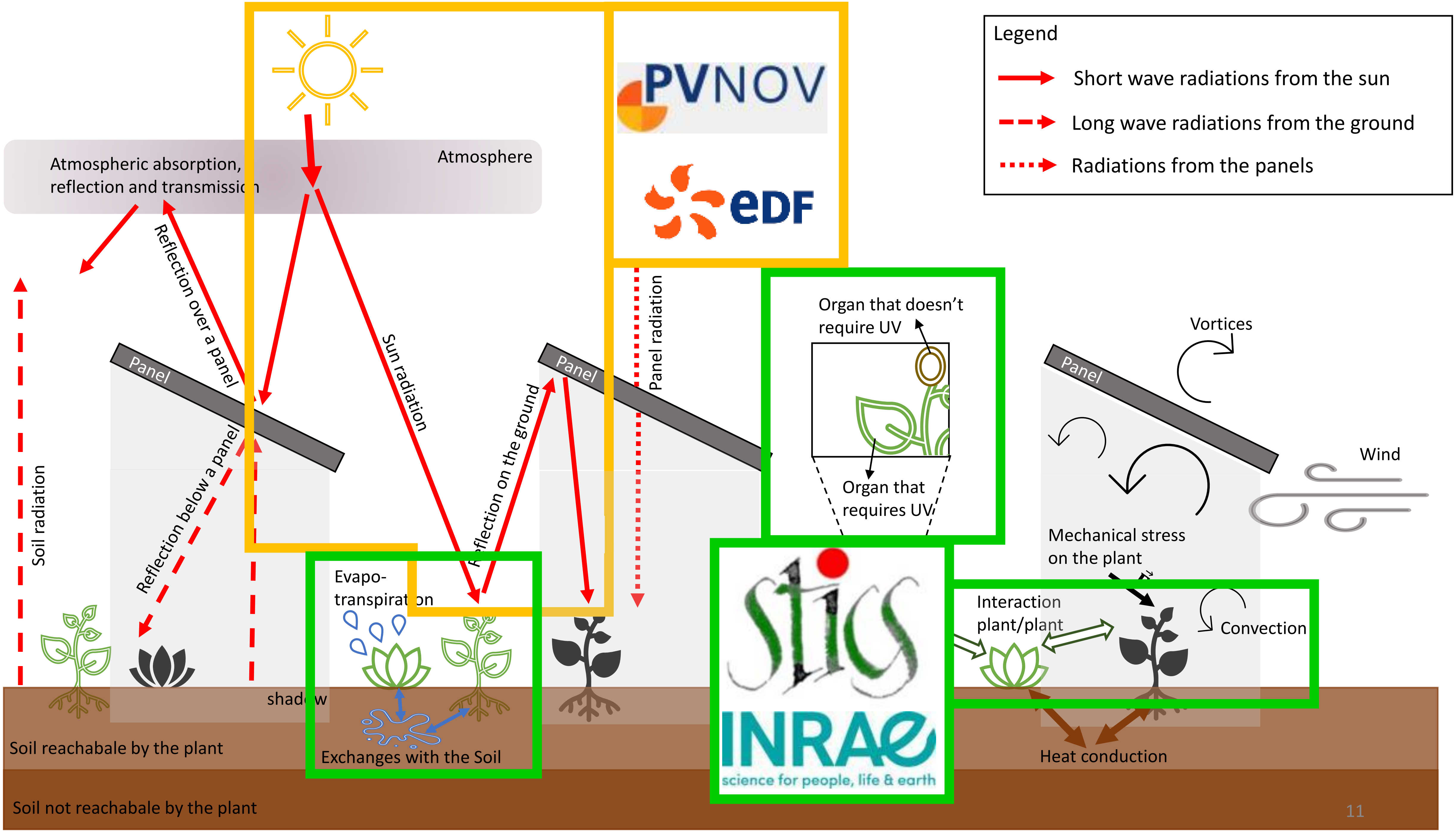

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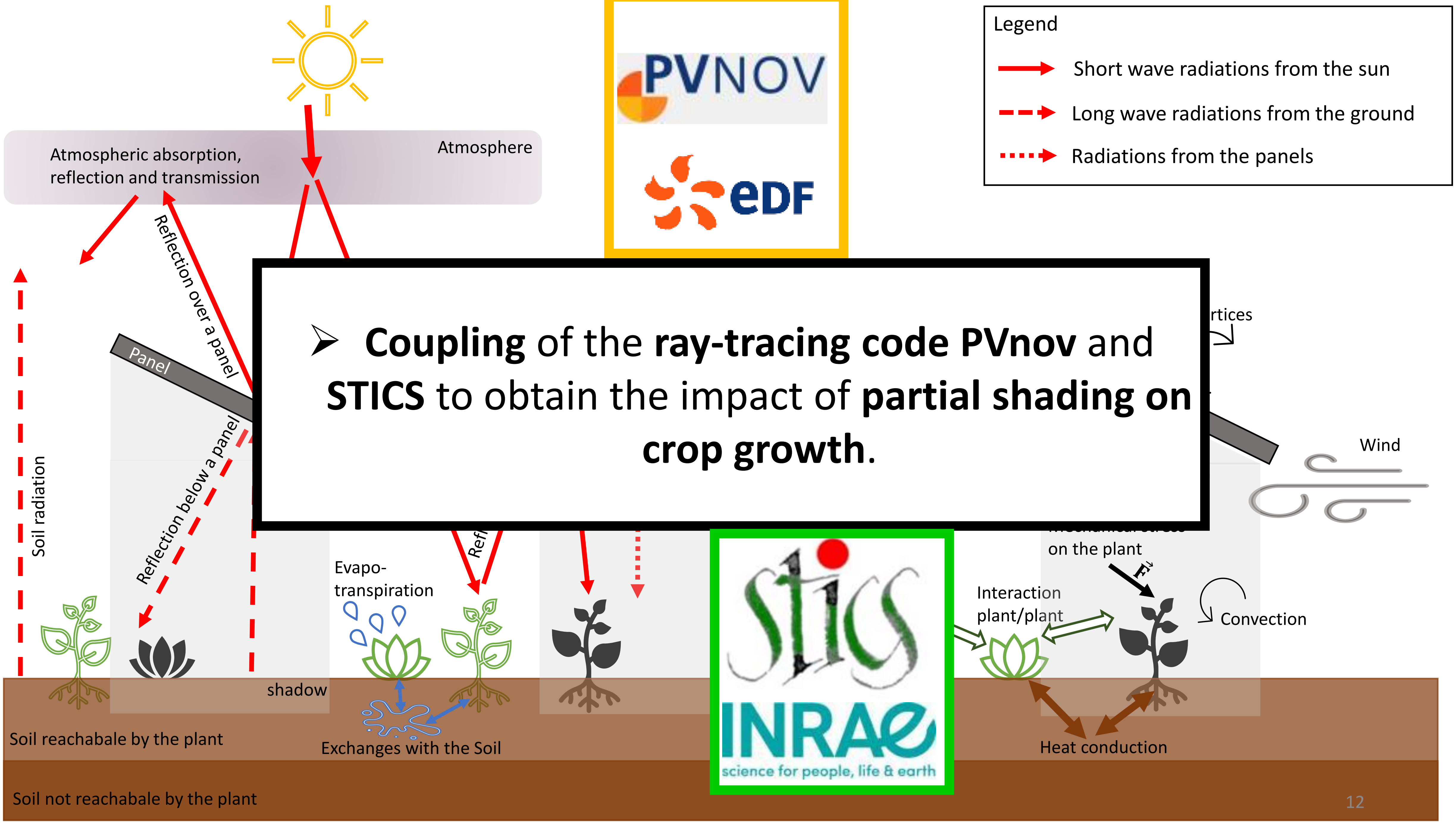


- **Coupling** of the **ray-tracing code PVnov** and **STICS** to obtain the impact of **partial shading on crop growth**.

Simulations VS Experiments

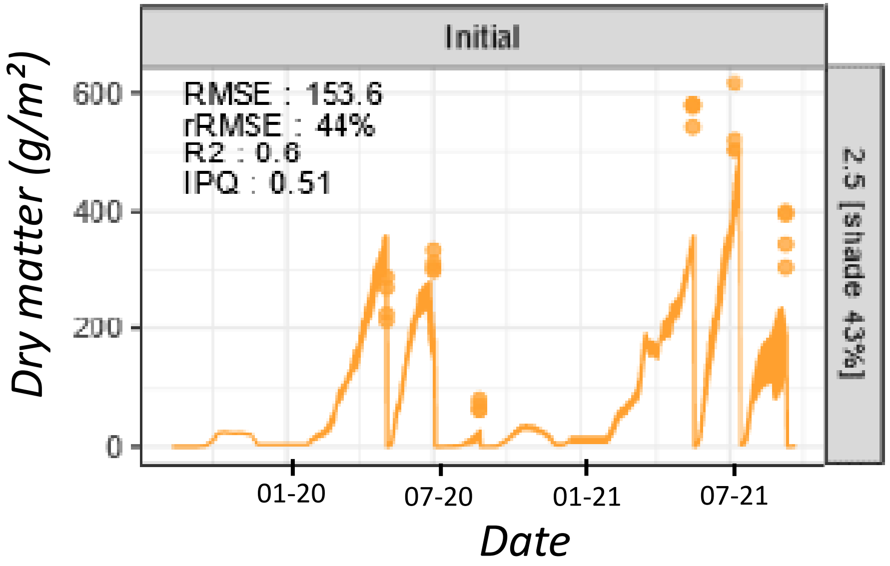
Coupling of the **ray-tracing code PVnov** and **STICS** to obtain the impact of **partial shading on crop growth**

Application case : 1. **study of alfalfa**

Alfalfa experiment conducted over 2 years (2020-2021)

Difference between experiments and coupling models:

Yield → difference of **44% Experiment** VS **STICS**



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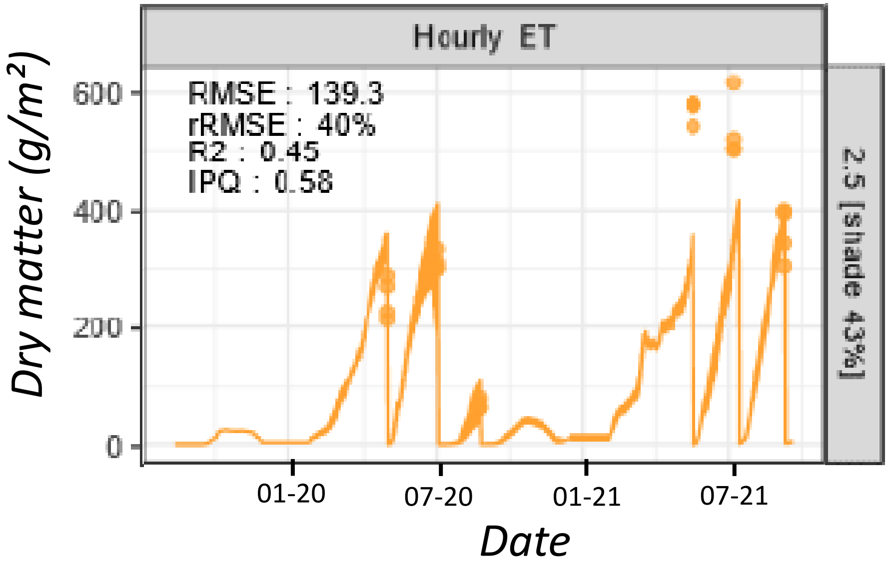
Evapotranspiration improvement → **40% Experiment** VS **STICS**

Hourly evapotranspiration is more coherent



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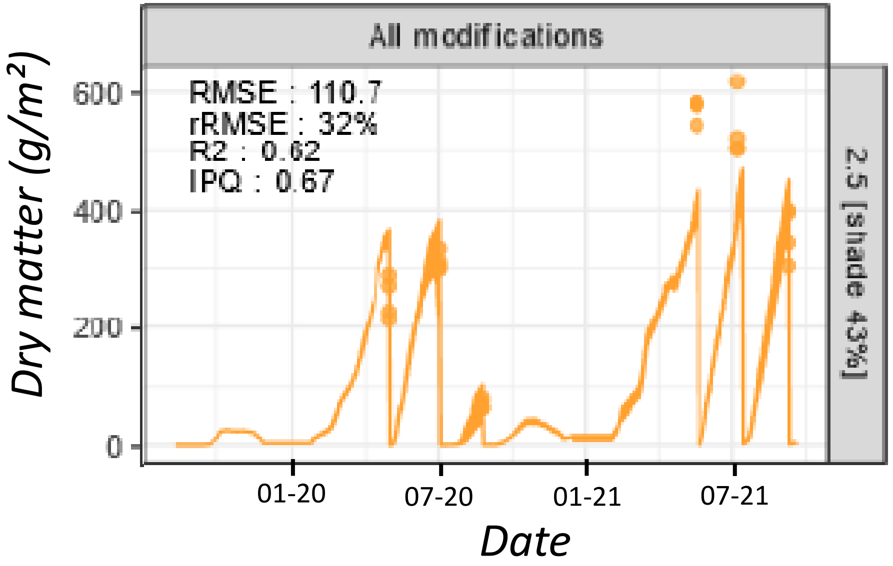
Hourly evapotranspiration computation is more precise

ET + **Frost** deactivation → **32% Experiment** VS **STICS**

STICS wrongly predicted frost below the panels



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Simulations VS Experiments

Coupling of the **ray-tracing code PVnov** and **STICS** to obtain the impact of **partial shading on crop growth**

Application case : 2. **study on wheat**

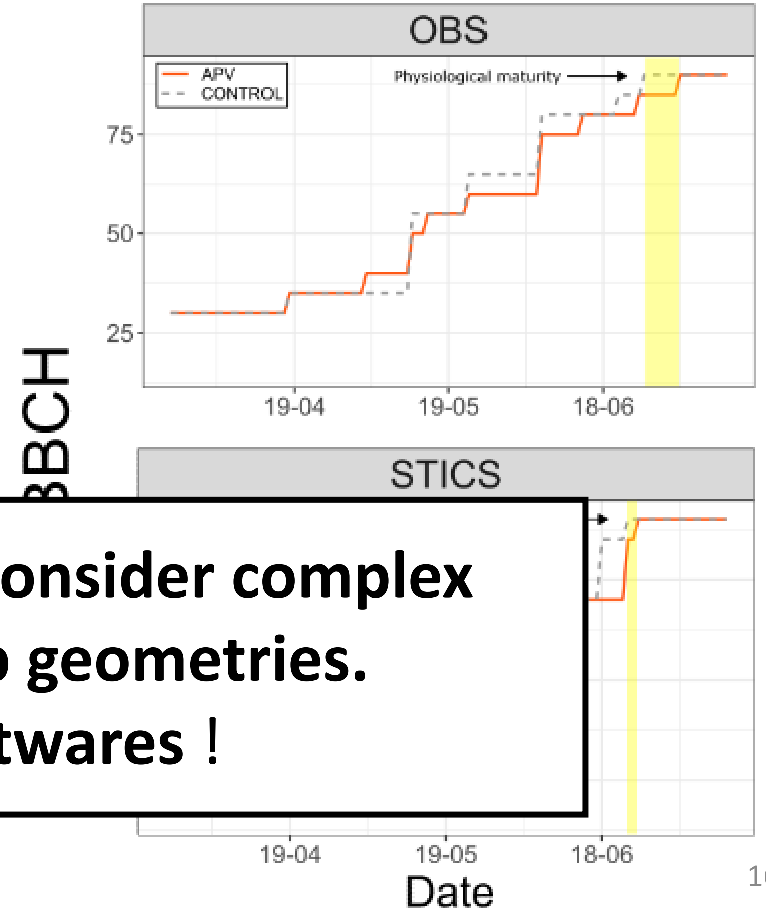
Winter wheat experiment conducted during the 2022-2023 season

Difference between experiments and coupling models:

Growth delay → Experiment 8 days VS **STICS 2 days**

delay in wheat growth under the agrivoltaic, from early bolting (BBCH 30) to physiological maturity (BBCH 89)

same result observed



Lack of flexibility when it comes to **consider complex micro-climate** and **complex crop geometries.**
Need other simulation softwares !

Back to crop modeling

What are the **main phenomena** that drive the **crop temperature and how to model it**?

By an energy balance:

$$\boldsymbol{G = (1 - \alpha)R_{sun} + R_{therm} + E_s + E_l}$$

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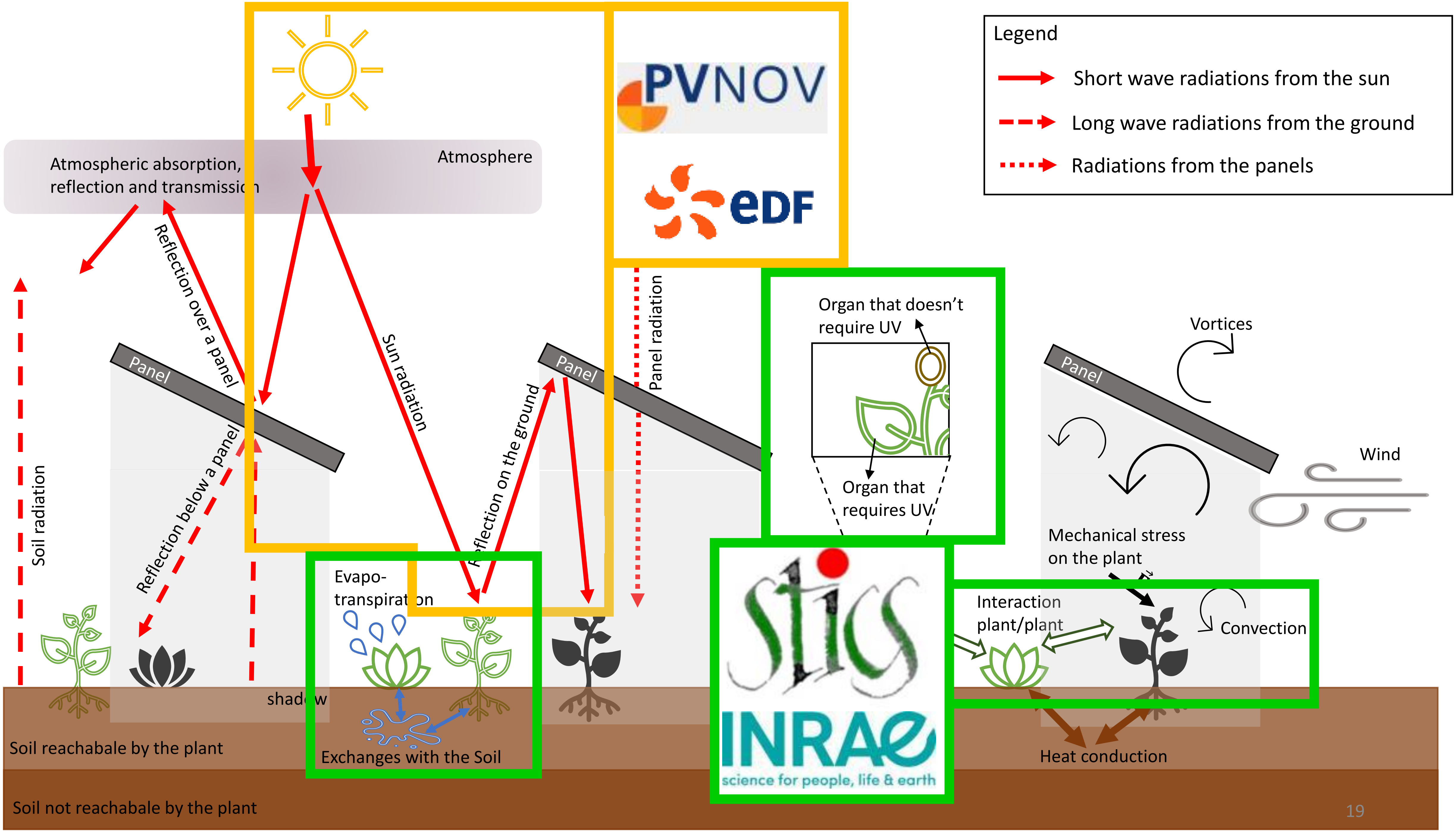
Open source codes

stics

code_saturne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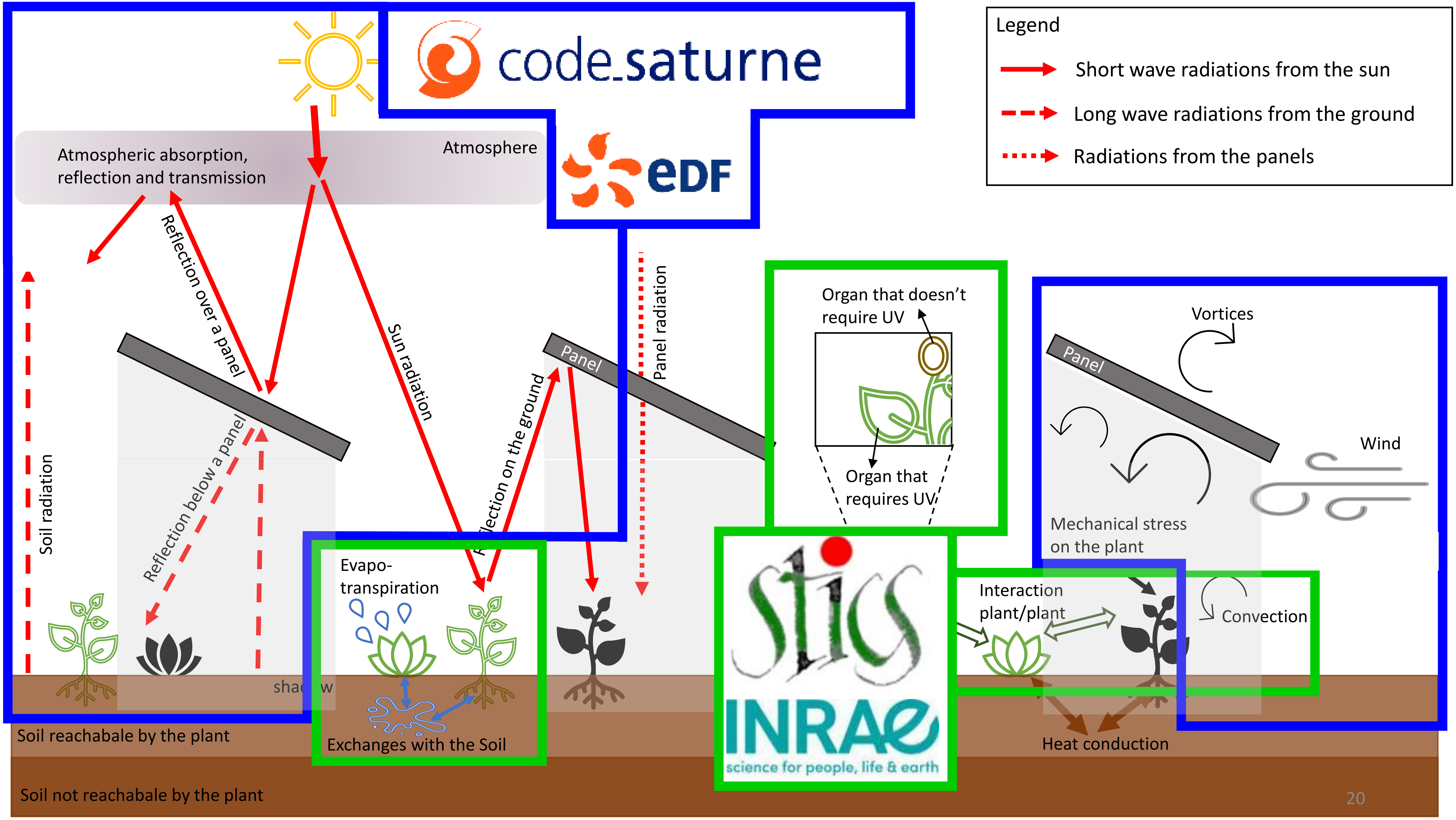
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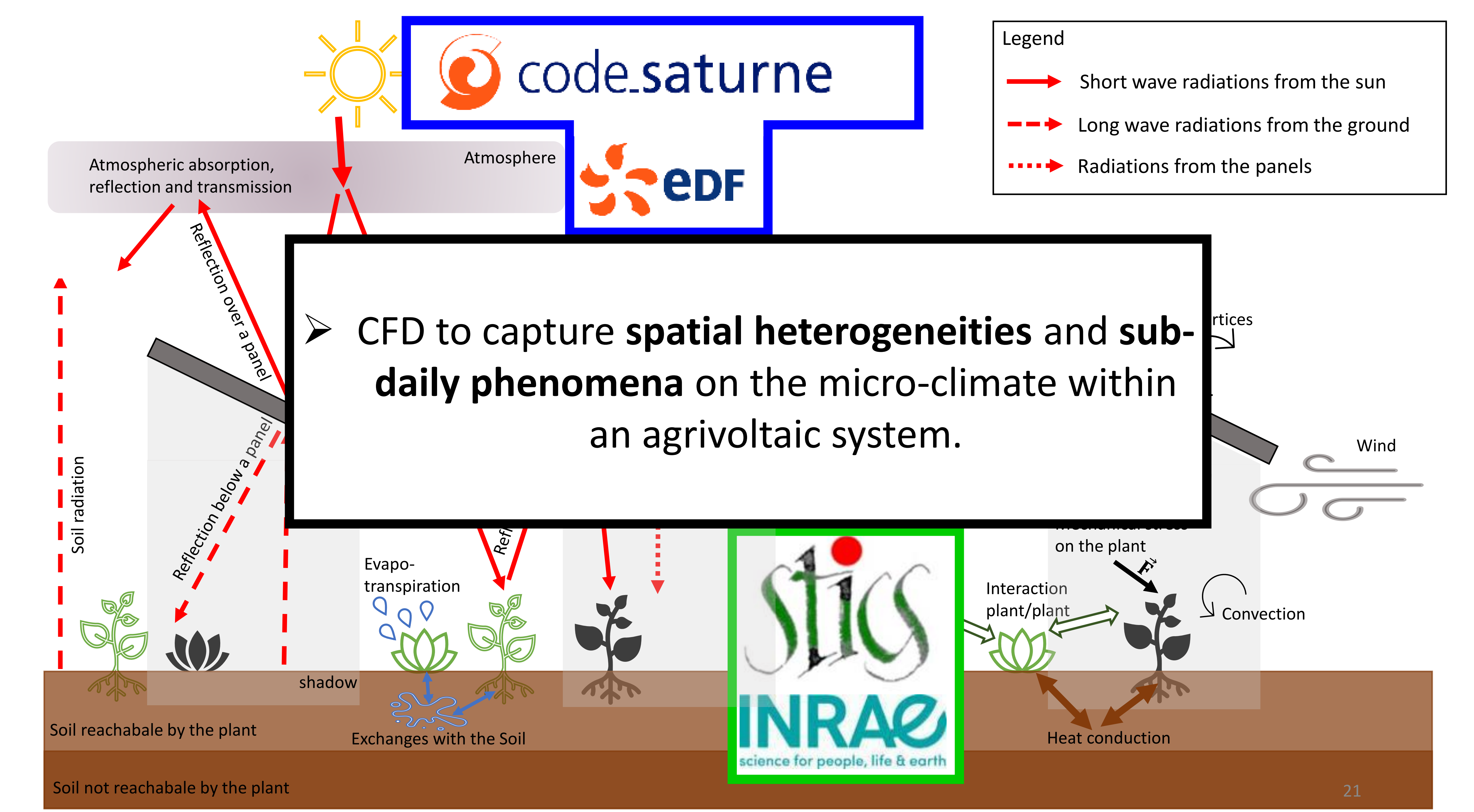
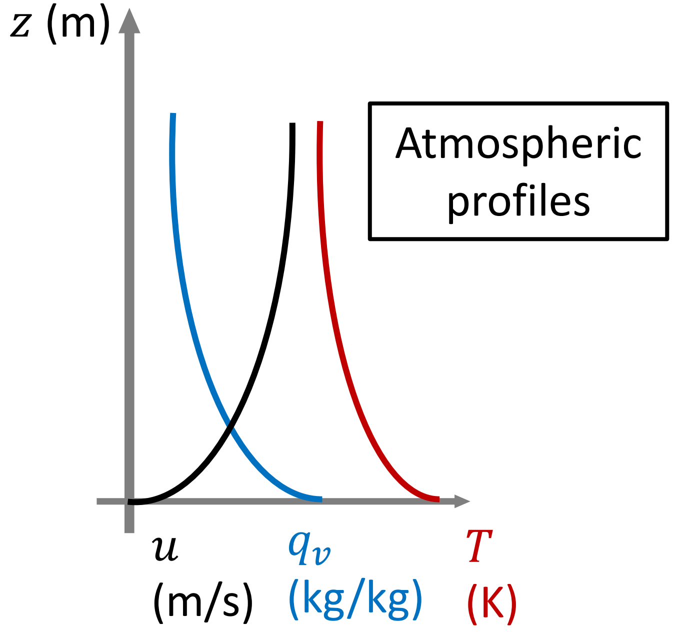
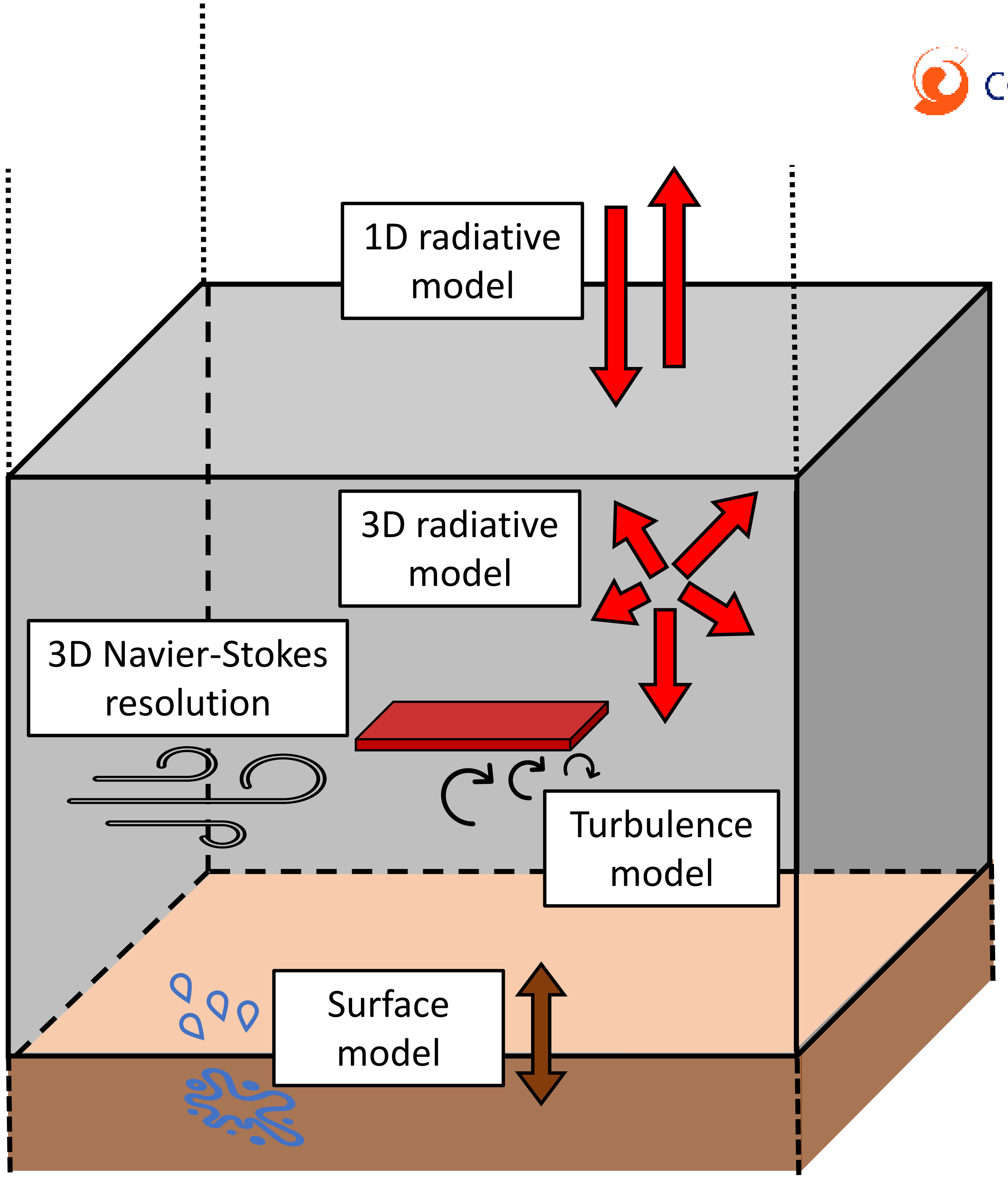


- CFD to capture **spatial heterogeneities** and **sub-daily phenomena** on the micro-climate within an agrivoltaic system.

CFD – Models



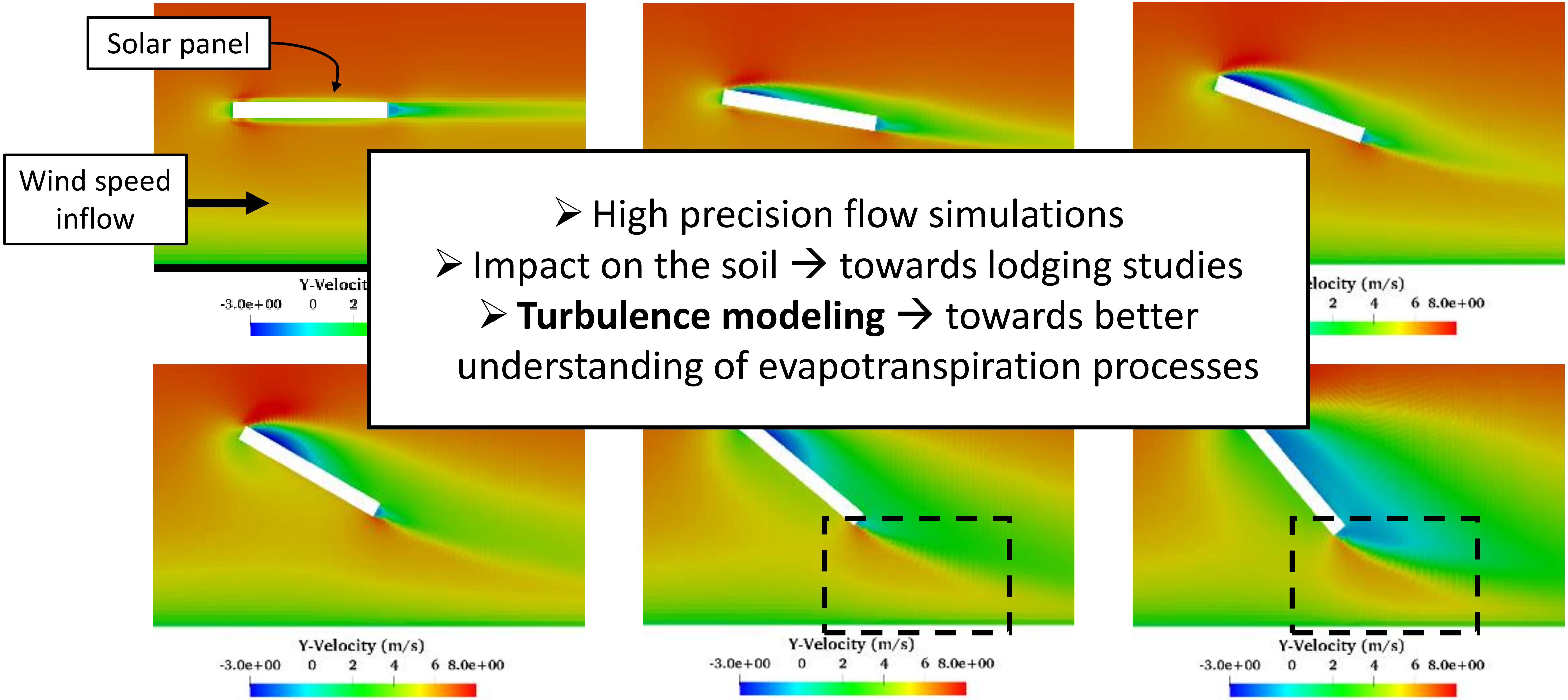
z (m)
Atmospheric profiles
u (m/s)
q_v (kg/kg)
T (K)



1D radiative model
3D radiative model
3D Navier-Stokes resolution
Turbulence model
Surface model

(Flow simulation in case of an obstacle)

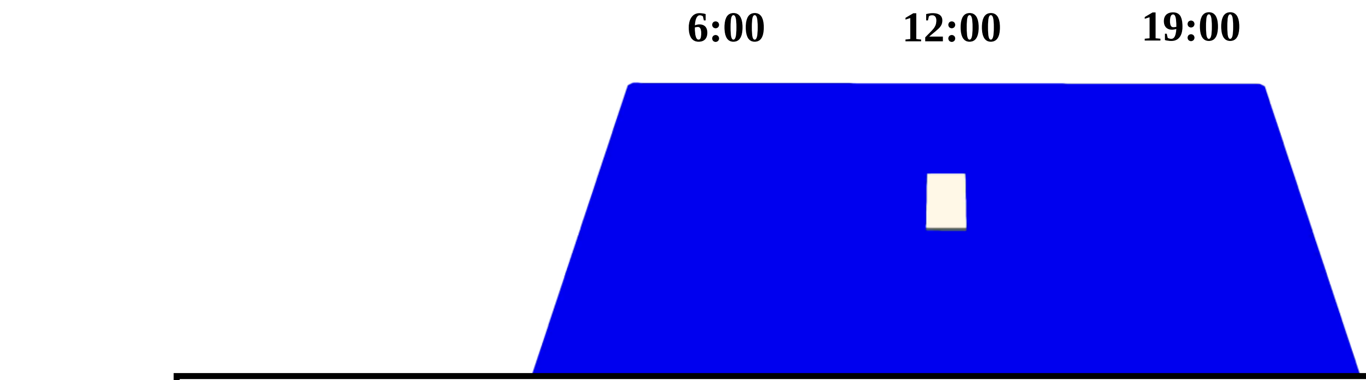
CFD – Results



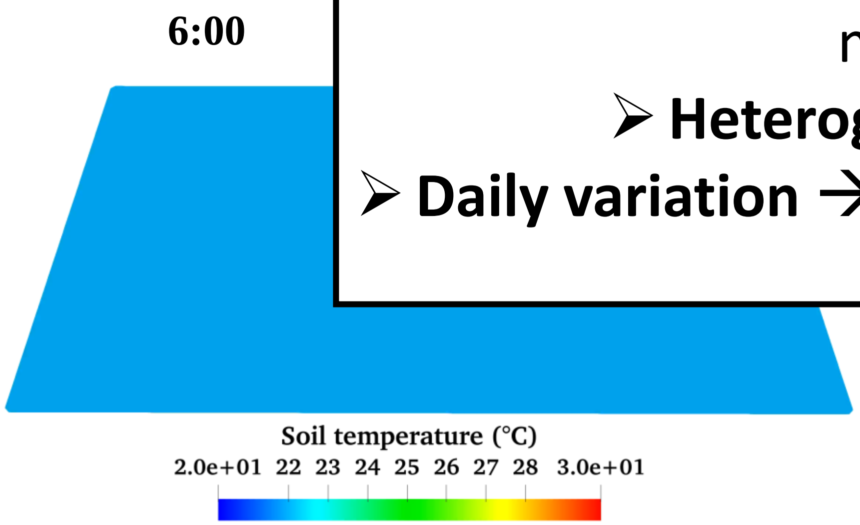
- ➢ High precision flow simulations
- ➢ Impact on the soil → towards lodging studies
- ➢ **Turbulence modeling** → towards better understanding of evapotranspiration processes

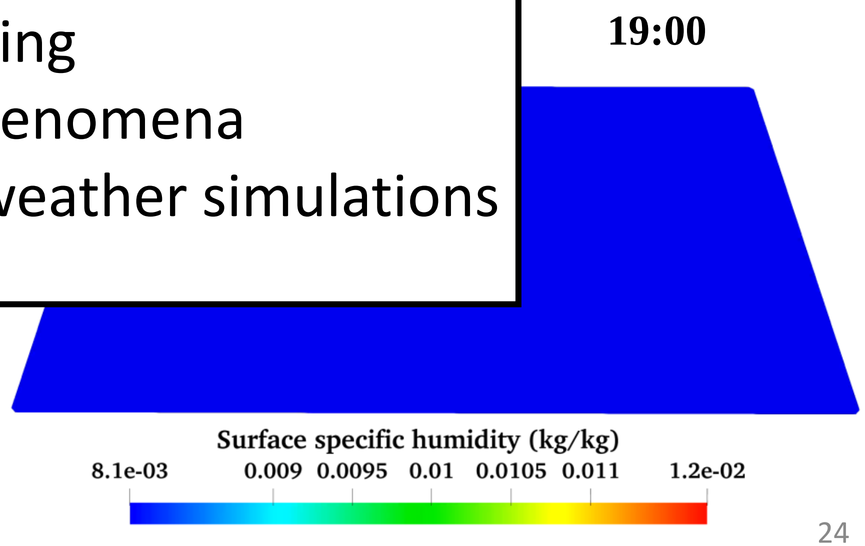
(Micro-climate simulation in case of an obstacle, 13-hours simulation « summer » conditions)

CFD – Results



- **Impact of obstacles** well captured → towards improved micro-climate modeling
- **Heterogeneous** physical phenomena
- **Daily variation** → towards extreme weather simulations





Conclusions

Agrivoltaics latest research findings

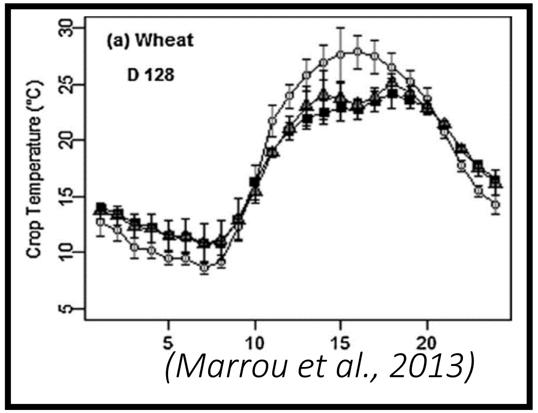
- Experimental studies showed strong impacts of solar panels on crops
- Simulations pointed out STICS limits
- STICS lacks of flexibility to simulate agrivoltaic micro-climate → Need of CFD

CFD – Spatial heterogeneity

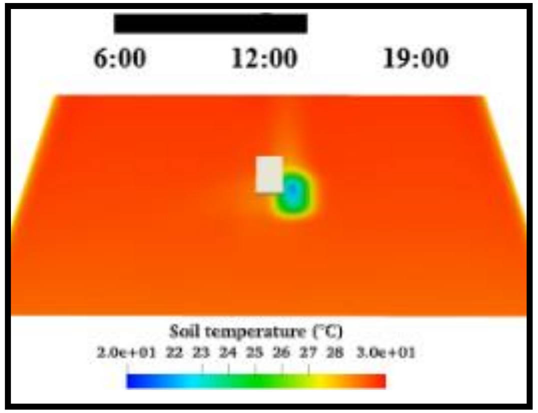
- Of the radiation fields
- Of the temperature and the moisture
- Of the wind speed

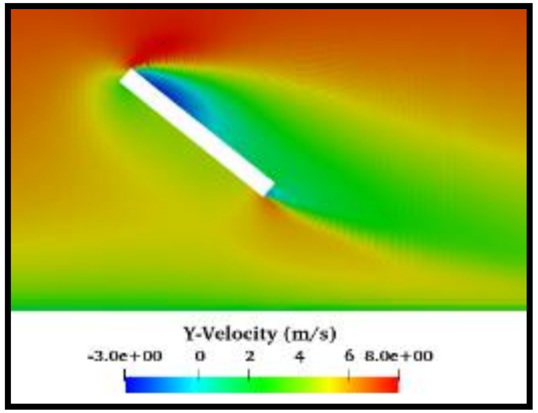
CFD – Sub-daily time step

- Turbulence impact
- Intermittent shading
- Extreme weather modeling



(Marrou et al., 2013)





Perspectives – Linking CFD and STICS

- Towards precise **extreme micro-climate phenomena**

STICS → code_saturne: *Crop formalisms* → $\begin{cases} h_{crop} \\ T_{crop} \\ LAI \end{cases}$

- ❖ Night simulations for **frost**
- ❖ Daytime simulations for **scalding**
- ❖ Wind flow simulations for **lodging**

⋮

- Towards **improved long-term farming yields**

code_saturne → STICS: *Micro-climate studies* → $\begin{cases} R_{solar} \\ R_{therm} \\ wind \end{cases}$

- ❖ **Agrivoltaic module** in STICS
- ❖ **Enhanced STICS micro-climate** considerations through code_saturne studies

Thank you for your attention !

Any questions ?