

On the use of evapotranspiration resistive models in agrivoltaics modeling

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How to model simply evapotranspiration of a crop ?



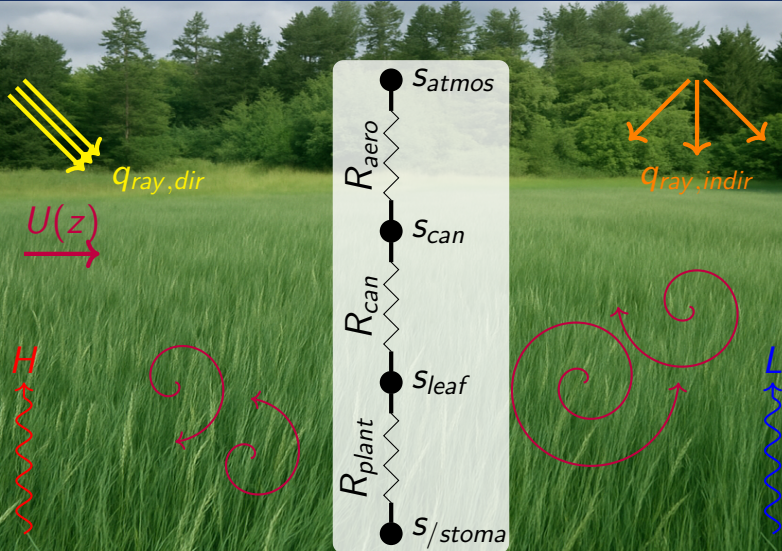
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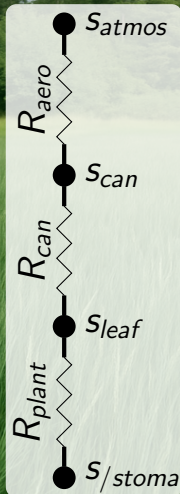
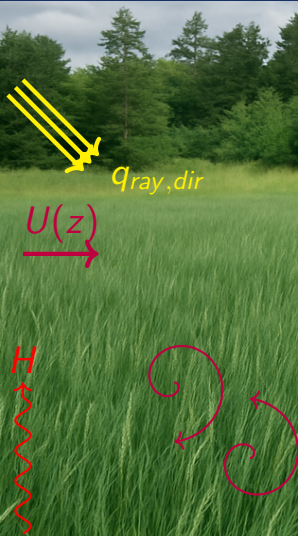
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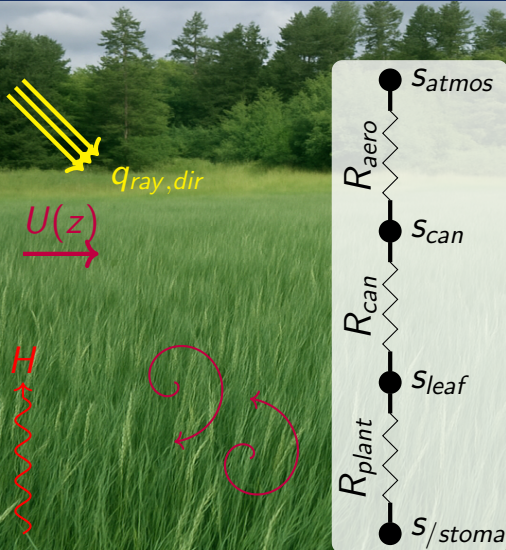


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Resistive models family

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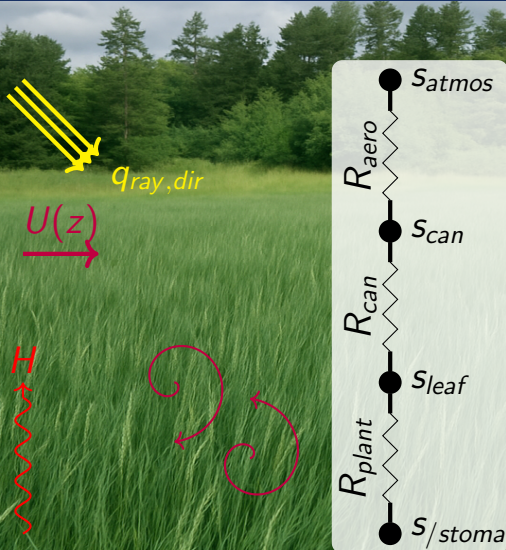
Resistive models family

- Electrical analogy [1–3]

$$L = \frac{S_{stoma} - S_{atmos}}{R_{plant} + R_{can} + R_{aero}}$$

- Water concentration s [kg m^{-3}]
- Resistance R [s m^{-1}]
- Evapotranspiration L [$\text{kg m}^{-2} \text{s}^{-1}$]

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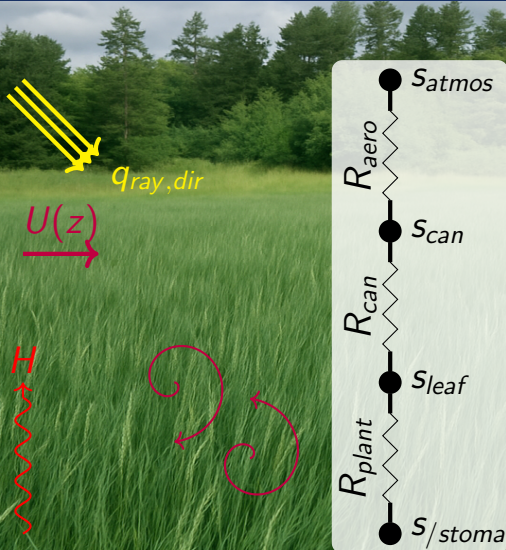
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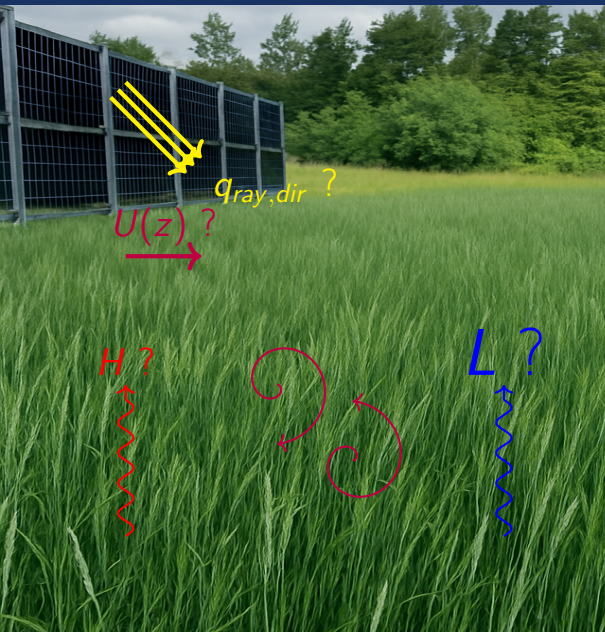
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- Aerodynamic resistance [1]: $R_{aero} = \frac{\kappa^2}{u(z) \ln^2\left(\frac{z}{z_0}\right)}$

... and with solar panels ?



Resistive model validity ?

Some strong assumptions
[1]

... and with solar panels ?



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- Horizontal homogeneity
⇒ 1D transport
⇒ Radiative patterns

H?



L?



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Resistive model validity ?

Some strong assumptions [1]

- Horizontal homogeneity
⇒ 1D transport
⇒ Radiative patterns
- Logarithmic velocity profile
Where measure the velocity and s_{atmos} in AgriPV configuration ?

H ?



L ?



Objectives

Implement **simple** CFD model of vertical agrivoltaics farms

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Implement **simple** CFD model of vertical agrivoltaics farms

- to model the **wind** inside AgriPV structures
- to give a first flavour of the **water transport** mechanism in AgriPV
- to give some insight on the use of the **resistive model** to evaluate evapotranspiration

Numerical model: Momentum equations

Reynolds Averaged Navier-Stokes Equations (**RANS**)

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- Time derivative
- Convection
- Pressure stress
- Shear stress
- Other source/sink of momentum
- Reynolds stress

$$\cancel{\frac{\partial \bar{u}}{\partial x}} + \nabla \cdot (\bar{u} \otimes \bar{u}) = -\frac{1}{\rho} \nabla p^* + \nu \Delta \bar{u} - \nabla \cdot (\overline{u' \otimes u'}) + f$$

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Reynolds stress tensor

It's a symmetric tensor that add 4 unknowns in 2D and 6 in 3D. Linked to the turbulence. We have to add a turbulence closure model to solve it.

$k - \omega$ SST model [4]

- 2 equations model: k and ω

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- new variable: ν_t
- Works well with adverse pressure and flux separation

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- Convection/Advection
 - Molecular diffusion
 - Turbulence transport
 - Source/sink of water vapour
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Water vapour source: S_s

Source from the crops and modelled through a simplistic resistive relation between the **substomatal cavity** and the external leaf surface.

$$S_s = \frac{s^* - s_{ext}}{R_{plant}}$$

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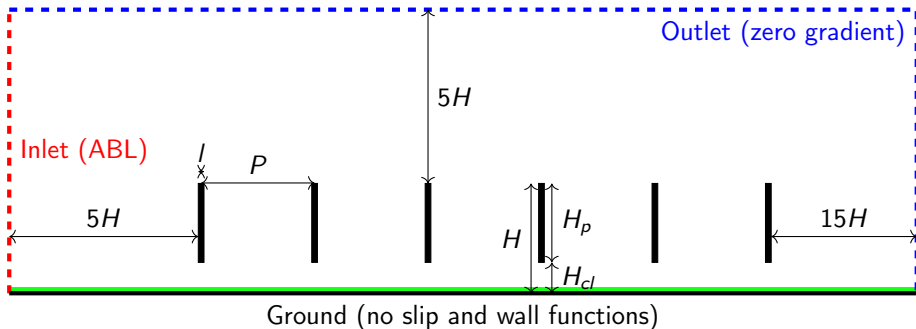
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Turbulence

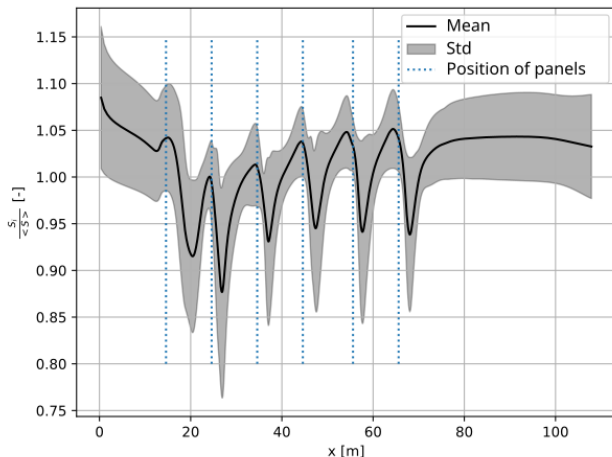
Source in the ω and k equations.
Break the mean flow and big whirls into turbulence and dissipate more the small structures [5, 7, 8].

Simulation domain and boundary conditions

- 6 rows facing the flow
- non-cartesian structured mesh
- 80000 cells based on a mesh convergence analysis
- $H = 2.914$ m, $l = 0.15$ m, $H_{cl} = 0.817$

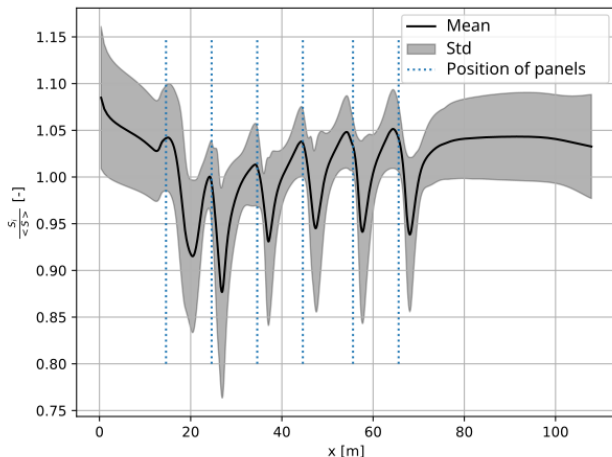


Evapotranspiration transect



Evapotranspiration
profile under the
AgriPV plant

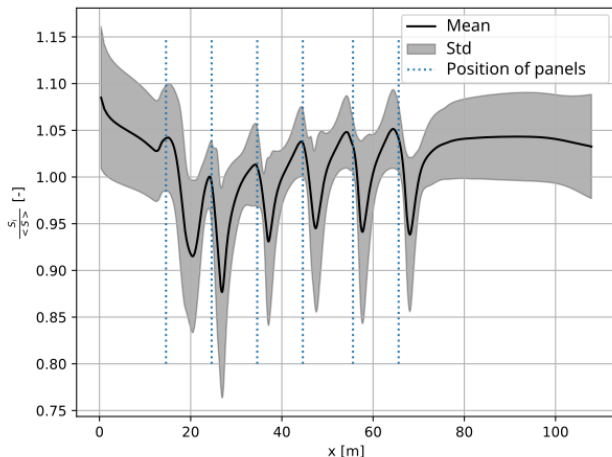
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Evapotranspiration profile under the AgriPV plant

- Average of situation with velocity from 2 to 10 m s^{-1}
- Uniform crop

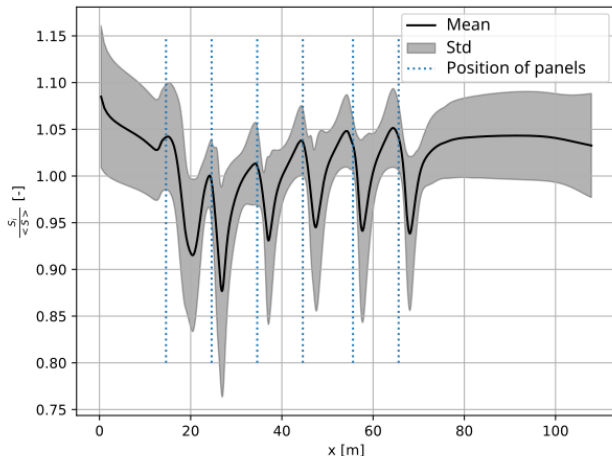
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- S_i : flux at the location, $\langle S \rangle$: spatial average flux

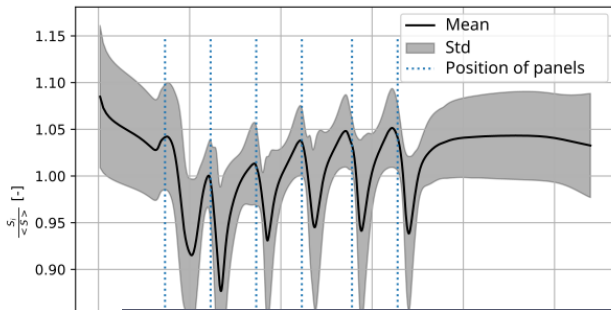
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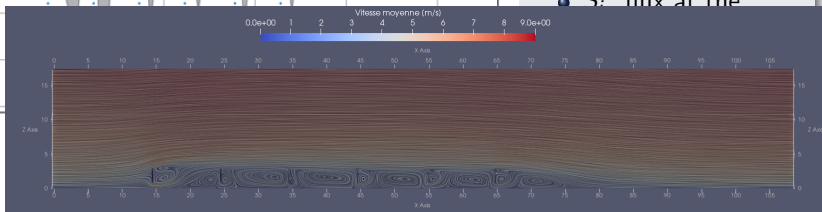
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- Maxima located below each panel

Evapotranspiration transect

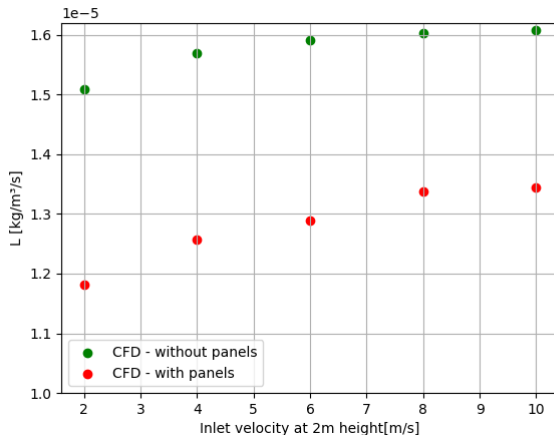


Evapotranspiration profile under the AgriPV plant

- Average of situation with velocity from 2 to 10 m s^{-1}
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- S_z : flux at the



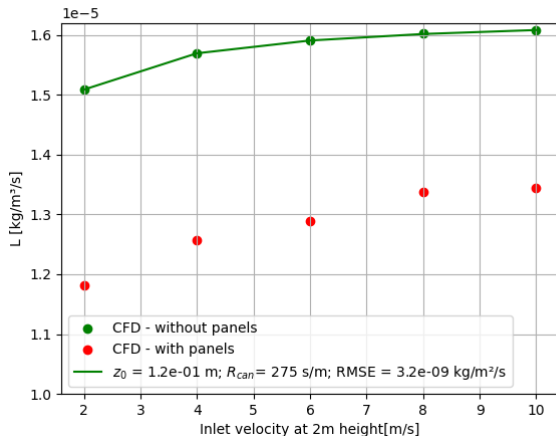
How the panels modify the resistive model?



Evolution of the water flux with the inlet velocity

- 2 configurations: with and without solar panels.
- Same plant canopy and same inlet conditions.
- The panels reduced the turbulent flux between the plant canopy and the atmosphere.

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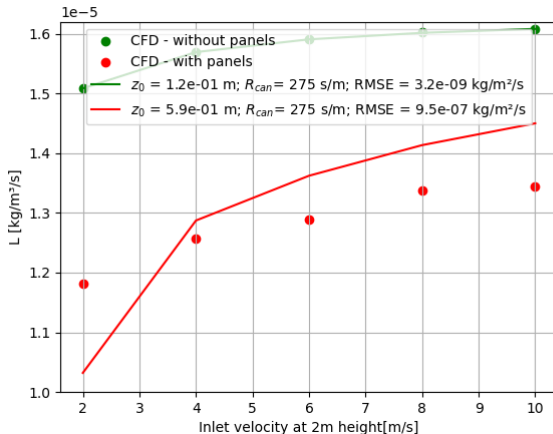


$$L = \frac{\Delta s}{R_{can} + \ln^2 \left(\frac{z}{z_0} \right)} \kappa^2 u$$

Resistive model for a flat uniform plant canopy

- R_{can} combination of the stomatal resistances and blockage effect.
- Velocity probe at 2m height.

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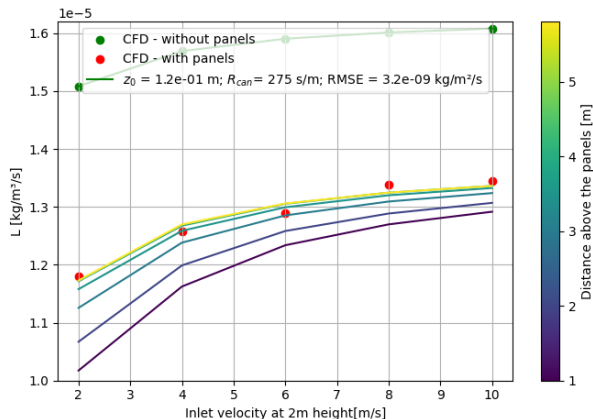
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Velocity probe
behind the panels (in
the middle of the
power plant)

Assumptions:

- The Agri-PV structures doesn't modify the canopy effect
- Modification of the aerodynamic resistance

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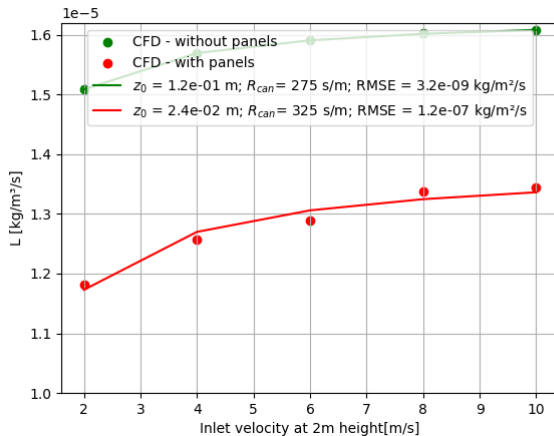


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Velocity probe above the panels

- Good agreement when measured 1 to 2 times H above the panels

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Velocity probe in the reference zone

- Measurement of the inlet background influence
- Good agreement - The panels act as a second canopy
- R_{can} increase of 50 s/m

Conclusions and perspectives

Conclusions:

- Agri-PV structures act as a second canopy and increase the R_{can} .
- Inhomogeneity of the evapotranspiration due to recirculation zones.

Perspectives:

- Limitation of the models: 2D and RANS $\Rightarrow$ more precise models (e.g. LES)
- Validation: lysimeters
- Scale effect and geometry

$\Rightarrow$ create a chart or a function that take the geometry parameters as an input to get the additional resistance

References I

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