PALM's Canopy Model

PALM group

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Notes

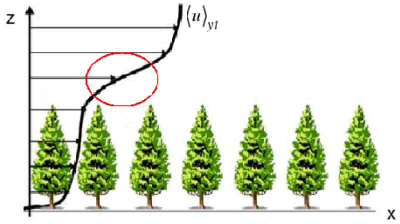
Overview

- The canopy model embedded in PALM can be used to study the effect of a plant canopy on e.g.:
  - mean flow field,
  - development of coherent turbulence structures,
  - scalar exchange processes between canopy and atmosphere.
- Within the canopy model, the plant canopy acts as a sink for momentum and as a source/sink for active (e.g. temperature) and passive (e.g. tracer) scalars.
- The canopy model does not account for each plant element, but rather accounts for a volume averaged effect on the flow and scalar concentration, depending on:
  - leaf area density,
  - drag coefficient.

Notes

Theory (I)

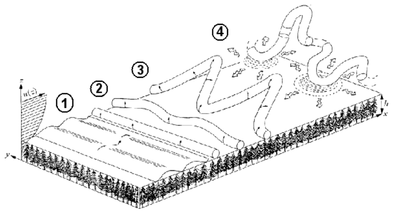
- A plant canopy affects the flow by acting as a momentum sink due to form and viscous drag forces.
- The effectiveness of momentum absorption depends on the amount of leaf area per unit volume and the aerodynamic drag.
- Due to the aerodynamic drag, the flow is decelerated within the canopy, leading to an inflection point in the vertical profile of the horizontal velocity at the canopy top.



Notes

Theory (II)

- The inflection point in the velocity profile introduces instabilities to the flow, leading to the formation of Kelvin-Helmholtz waves near the canopy top (①).
- Wave breaking induces further instabilities, whereby a longitudinal component is added to the developing turbulence structures (② & ③).
- Due to the persistent instabilities the turbulence structures develop a distinct three-dimensionality (④).
- The large turbulence structures developing due to the inflection point instability significantly contribute to the vertical mixing of in-canopy and above-canopy air.



Notes

Methods (I)

- The canopy model in PALM is based on the models used by Shaw and Schumann (1992) and Watanabe (2004).
- The aerodynamic effect of the canopy on the turbulent flow is accounted for by an additional term in the momentum equations:

$$\frac{\partial \bar{u}_i}{\partial t} = \ldots - c_d a U \bar{u}_i$$

  - c_d : drag coefficient
  - a : leaf area density $[m^2 m^{-3}]$
  - U : $(u^2 + v^2 + w^2)^{1/2}$ $[ms^{-1}]$
  - u_i : velocity component $(u_1 = u,\ u_2 = v,\ u_3 = w)$

Note: The canopy model does not resolve the effect of single plant elements.

Notes

Methods (II)

- The effect of the canopy on the subgrid scale turbulence is accounted for by adding a sink term to the prognostic equation for the subgrid scale turbulent kinetic energy:

$$\frac{\partial e}{\partial t} = \ldots - 2 c_d a U e$$

- It is assumed that the subgrid scale turbulent kinetic energy is dissipated by the canopy due to the rapid dissipation of wake turbulence in the lee of canopy elements (e.g. Watanabe, 2004).

Notes

Methods (III)

- If desired, the effect of the canopy on the sensible heat transport can be considered. A source term is added to the prognostic equation for potential temperature:

$$\frac{\partial \bar{\theta}}{\partial t} = ... + S_\theta$$

- It is assumed that the foliage is warmed by the penetrating solar radiation and, in turn, warms the surrounding air.
- The source strength S_θ is defined as the vertical derivative of the upward kinematic vertical heat flux Q_θ, given by (Shaw and Schumann, 1992):

$$Q_\theta(z) = Q_\theta(h) exp(-\alpha F) \; , \; Q_\theta(h) : \text{ Heat flux at canopy top}$$

  - $\alpha = 0.6$ (extinction coefficient)
  - $F = \int_z^h a \, dz$ (downward cumulative leaf area index)

Notes

Methods (IV)

- The canopy might act as a sink or source for other scalars q (e.g. humidity, passive tracer). Therefore, an additional term is added to the scalar transport equation:

$$\frac{\partial \bar{q}}{\partial t} = ... - c_q a U (\bar{q} - q_c)$$

  - c_q : scalar exchange coefficient
  - q_c : scalar concentration at leaf surface

Notes

Basics (I)

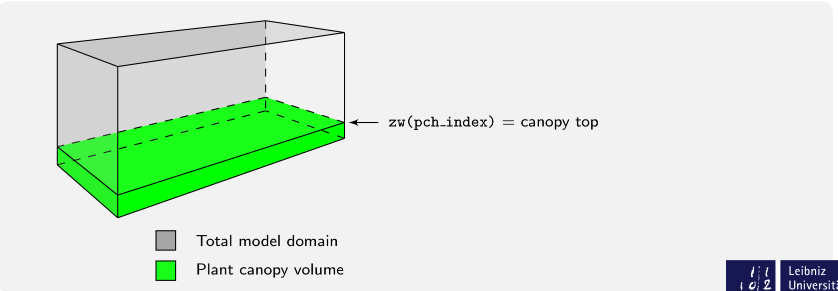
- The canopy model is switched on by setting the parameter `plant_canopy = .TRUE.` within the &inipar `NAMELIST` in the parameter file (`PARIN`).
- All parameters for steering the canopy model are described in: Documentation → Model steering → Parameters → Initialization → Canopy (http://palm.muk.uni-hannover.de)
- The following slides will describe how to set up a simulation with a simple horizontally homogeneous canopy block covering the entire model domain surface. In this case, `canopy_mode = 'block'` must be set in &inipar `NAMELIST`.

Notes

Basic canopy parameter (I)

The parameters for steering the canopy model have to be added to the &inipar `NAMELIST` in the parameter file (`PARIN`).

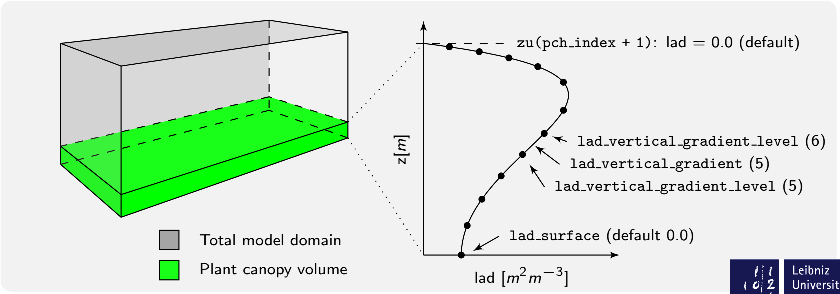
- Step I: Define the upper boundary of the plant canopy layer using the parameter `pch_index (grid point index, default 0)`. `pch_index` specifies the number of grid points resolving the canopy layer in the vertical direction.



Notes

Basic canopy parameter (II)

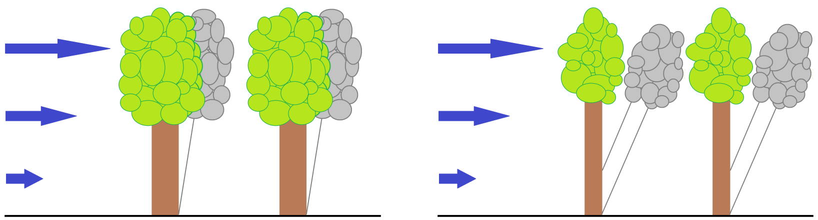
- Step II: Construct the vertical profile of the leaf area density (lad) to prescribe the distribution of leaf area within the plant canopy volume.
  The canopy top is located between `zu(pch_index)` and `zu(pch_index + 1)` because this is the transition between the in-canopy grid point and the above-canopy grid point.



Notes

Basic canopy parameter (III)

- Step III: Prescribe a value for the parameter `drag_coefficient` `(default 0.0)`. The drag coefficient is a dimensionless factor describing the magnitude of the form drag by the canopy working against the flow. A larger form drag results in a greater momentum reduction.



Strong trees offer a larger form drag to the flow.

Young / small trees offer a smaller form drag to the flow because they are more flexible.

Notes

Basic canopy parameter (IV)

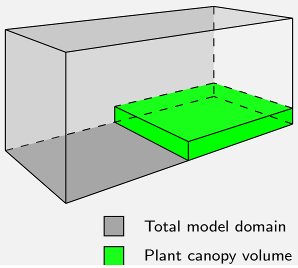
- For steering the effect of the canopy sensible heat transfer, prescribe a value for the sensible heat flux at the canopy top, using the parameter `cthf` (see Methods (III)).
- The sink/source effect of the canopy on other scalar quantities, such as humidity or a passive tracer can be steered by the parameters `leaf_surface_concentration` and `scalar_exchange_coefficient` (see Methods (IV)).

Notes

User-defined canopy

Do you want to simulate a more customized canopy, which e.g. covers only half the model surface?

- Step I: Copy the file `user_init_plant_canopy.f90` from `trunk/SOURCE` to the directory `$Home/palm/current_version/USER_CODE/<enter job name>` and make the desired changes for `CASE ('user_defined_canopy_1')`.
- Step II: In your parameter file set: `canopy_mode = 'user_defined_canopy_1'`



Note: You might have to make changes in other parts of your `USER_CODE` according to the changes / used parameters in: `user_init_plant_canopy.f90`

Notes