Giorgio Crasto
DiMeCa - University of Cagliari - ITALY

windsim

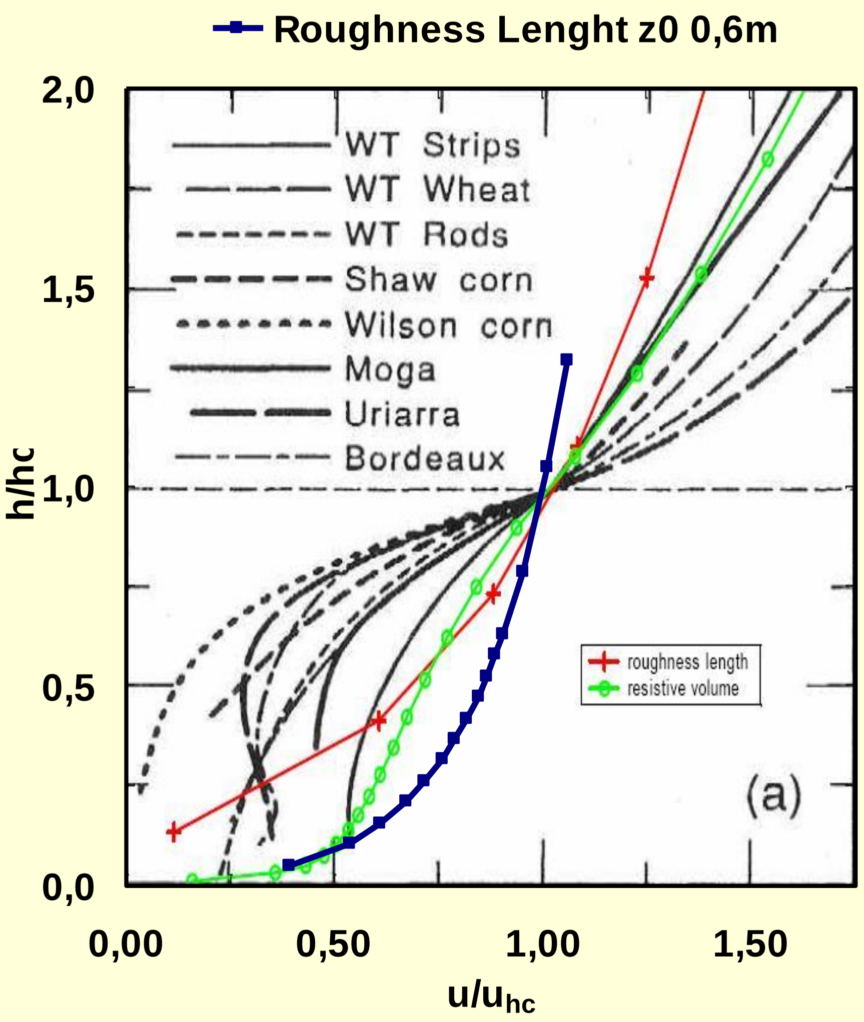
Forest Modeling

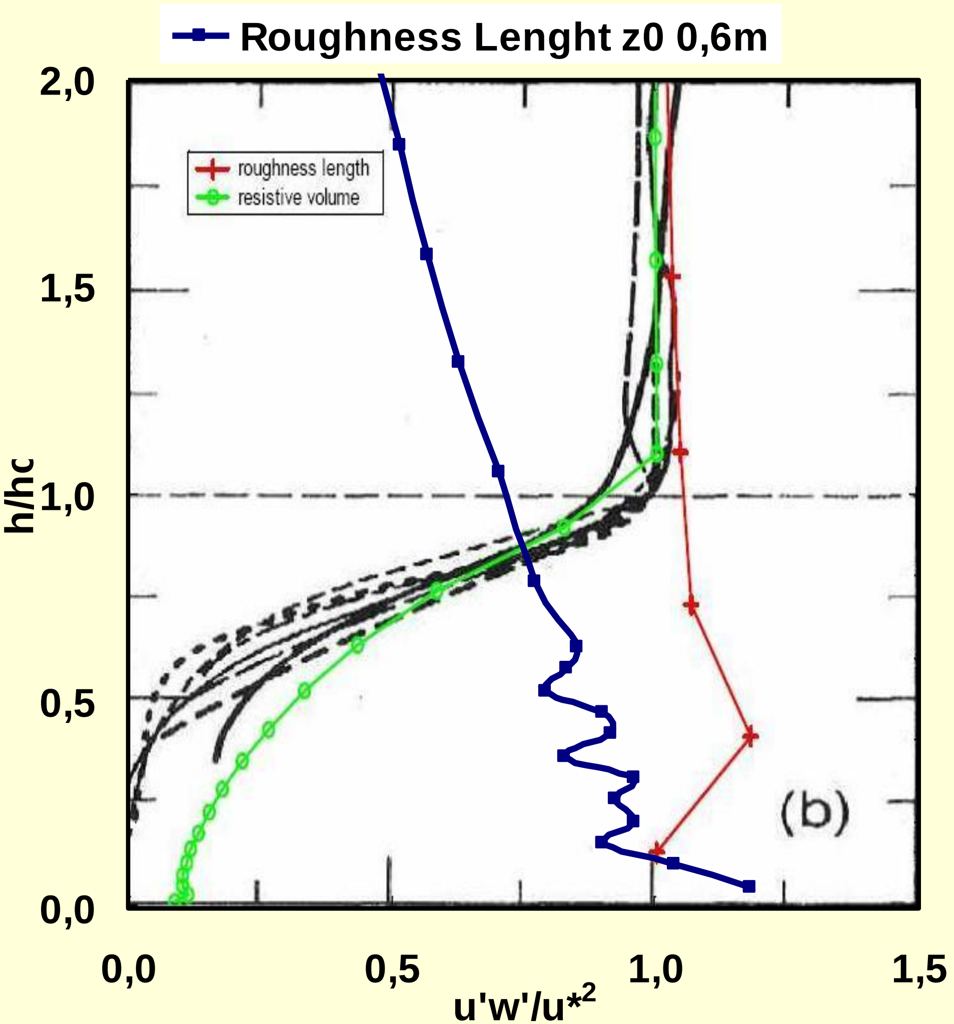
A canopy model for WindSim 4.5

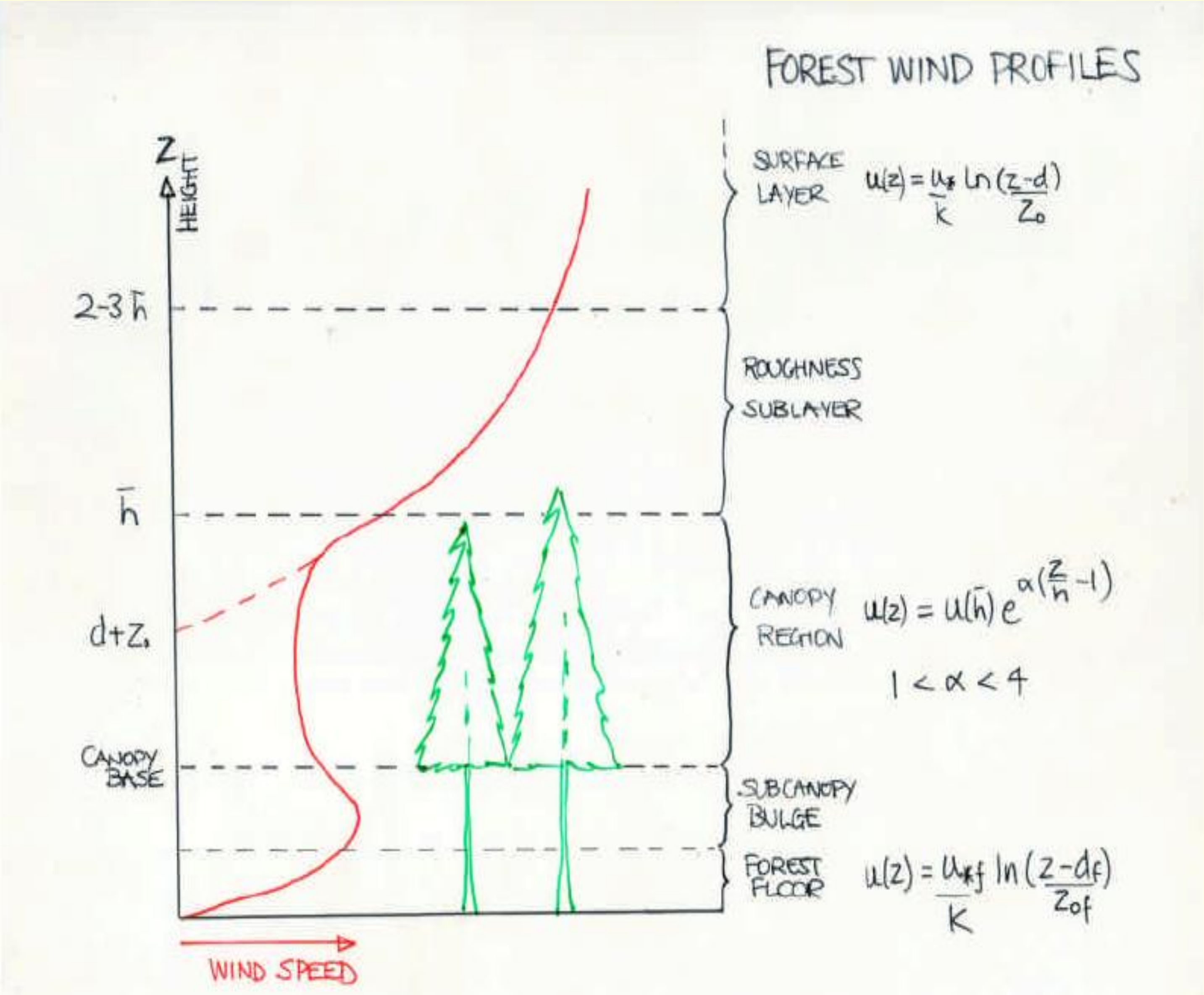
Kassel, 13rd February 2006 – WindSim Workshop

Giorgio Crasto
DiMeCa - University of Cagliari - ITALY

Why the need for a canopy model






FOREST WIND PROFILES
Z
HEIGHT
2-3 h̄
h̄
d+Z₀
CANOPY BASE
WIND SPEED
SURFACE LAYER
$u(z) = \frac{u_*}{k} \ln\left(\frac{z-d}{z_0}\right)$
ROUGHNESS SUBLAYER
CANOPY REGION
$u(z) = u(\bar{h})\, e^{\alpha\left(\frac{z}{\bar{h}}-1\right)}$
$1 < \alpha < 4$
SUBCANOPY BULGE
FOREST FLOOR
$u(z) = \frac{u_{*f}}{k} \ln\left(\frac{z-d_f}{z_{0f}}\right)$

- In the new canopy model of WindSim the Canopy Layer is solved by the use of porosity and drag forces (sinks of momentum)
- The canopy is described by:
  - Height of the canopy – h_c
    - The canopy is discretized with a certain number of cells (uniform grid)
  - Underwood roughness length – z_0
  - Porosity – β
  - Drag coefficients – C1 and C2

Concept of Porosity

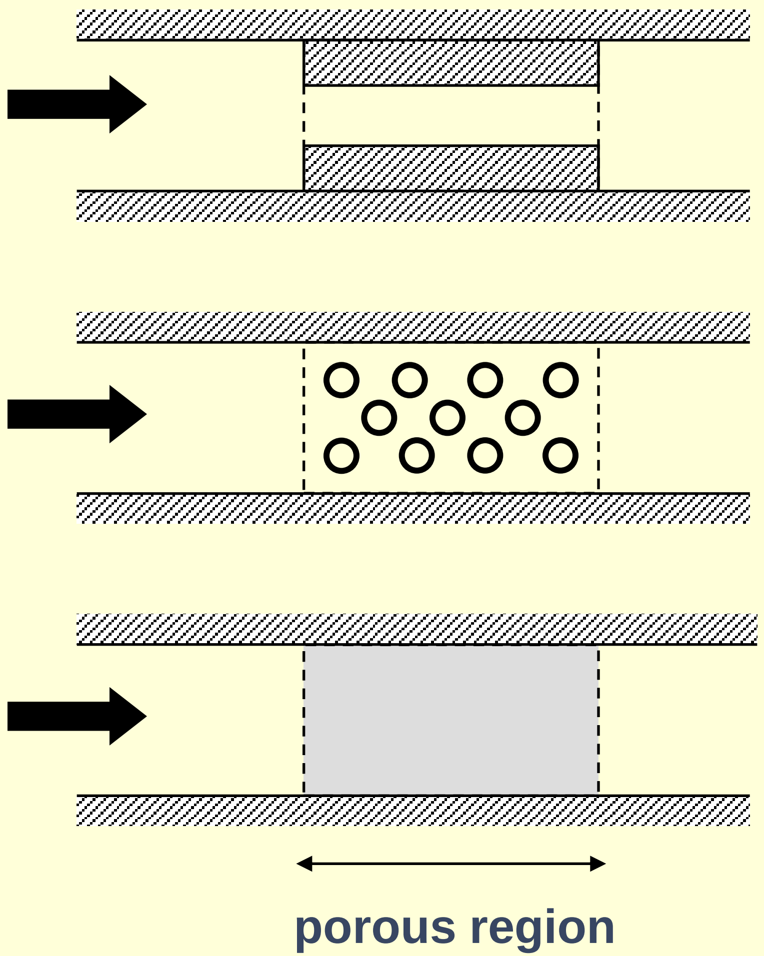
- Given a generic volume occupied by fluid and solid phases, its porosity β is defined as the ratio

$$\beta = \frac{\text{volume of fluid phases}}{\text{total volume}}$$

Giorgio Crasto
DiMeCa - University of Cagliari - ITALY

windsim

On the concept of Darcy's velocity



- The Darcy's velocity is the velocity that would occur if the whole volume was occupied by the fluid

$$U_D = U\,\beta$$

Giorgio Crasto
DiMeCa - University of Cagliari - ITALY

Every element of the canopy introduces in the flow a sink of momentum

- So inside the canopy the momentum RANS equations present an additional term S_j

$$\rho U_i \frac{\partial U_j}{\partial x_i} = \frac{\partial}{\partial x_i}\left[\mu_t \frac{\partial U_j}{\partial x_i}\right] - \frac{\partial P}{\partial x_j} + \rho f_j + S_j \qquad [S_j] = \frac{N}{m^3}$$

Advection — **Diffusion**

- $-\frac{\partial P}{\partial x_j}$: **pressure gradient**
- ρf_j: **body forces (gravity)**
- S_j: **additional sources/sinks**

Giorgio Crasto
DiMeCa - University of Cagliari - ITALY

The sinks of momentum depend upon porosity and velocity

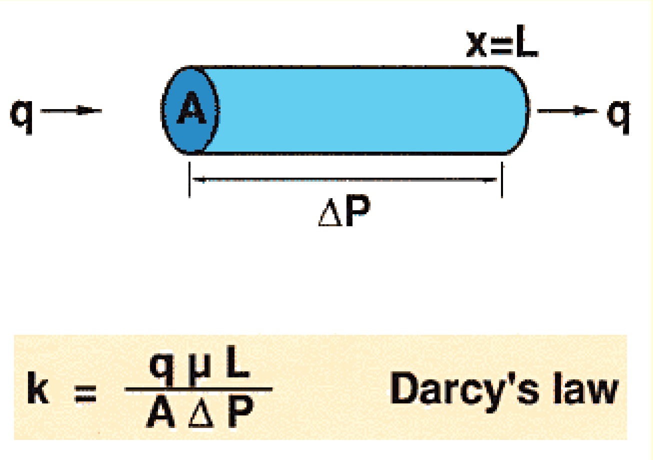
- A classical approach (for high porous materials) is to consider the sinks of momentum proportional to the velocity
- In the Darcy's law the advective and diffusive terms are neglected, so the gravity

$$S_U = C_V U$$

$$C_V = \frac{\mu}{k}$$

Darcy's law

$$\vec{\nabla} P = -C_V \vec{U}_D$$



Sinks of momentum implemented in WindSim 4.5

- Sinks of momentum [N/m^3]: two terms

$$\vec{S} = -\rho C1 \vec{U} - \rho C2 \left|\vec{U}\right| \vec{U}$$

viscous force

pressure force

Since the high Reynolds numbers

pressure >> viscous forces

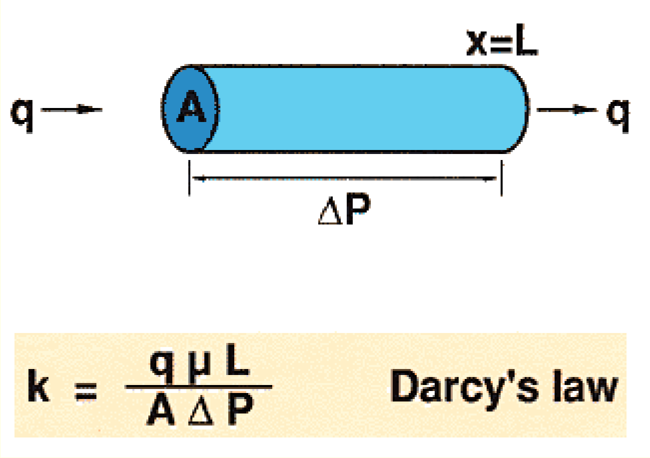
Present model

- In the canopy model of WindSim is possible to set the drag coefficients C1 and C2 where
  - C1 is the ratio of kinetic viscosity to permeability
  - C2 is a drag coefficient multiplied by the ratio of total frontal area to volume

$$[C1] = \frac{1}{s} \qquad [C2] = \frac{1}{m} = \frac{m^2}{m^3}$$

$$C1 = \frac{\mu}{\rho k} = \frac{\upsilon}{k}$$

$$k\,[m^2]\,\text{permeability}$$



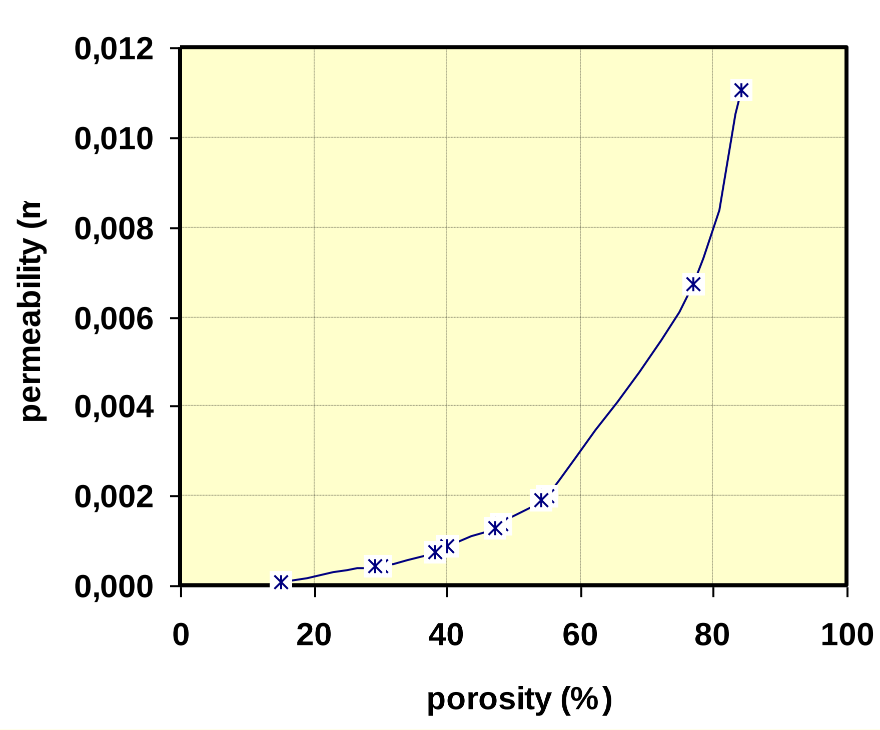
How to estimate the porosity k?

- The relation k vs. β is proposed:

$$k = C\frac{\beta^2}{1-\beta^2} \quad [m^2]$$

$$C = 0{,}0046215\,m^2$$

In this way it's possible to estimate the value of the drag coefficient C1 starting from a given value of porosity β



Giorgio Crasto
DiMeCa - University of Cagliari - ITALY

windsim

As regards the porosity

- Please visit the site: http://www.sbe.hw.ac.uk/research/buildingeng/wind_modelling/gui_windbk.html

(Estimates of porosities obtained from 2d windbreaks)

Case C → Beech

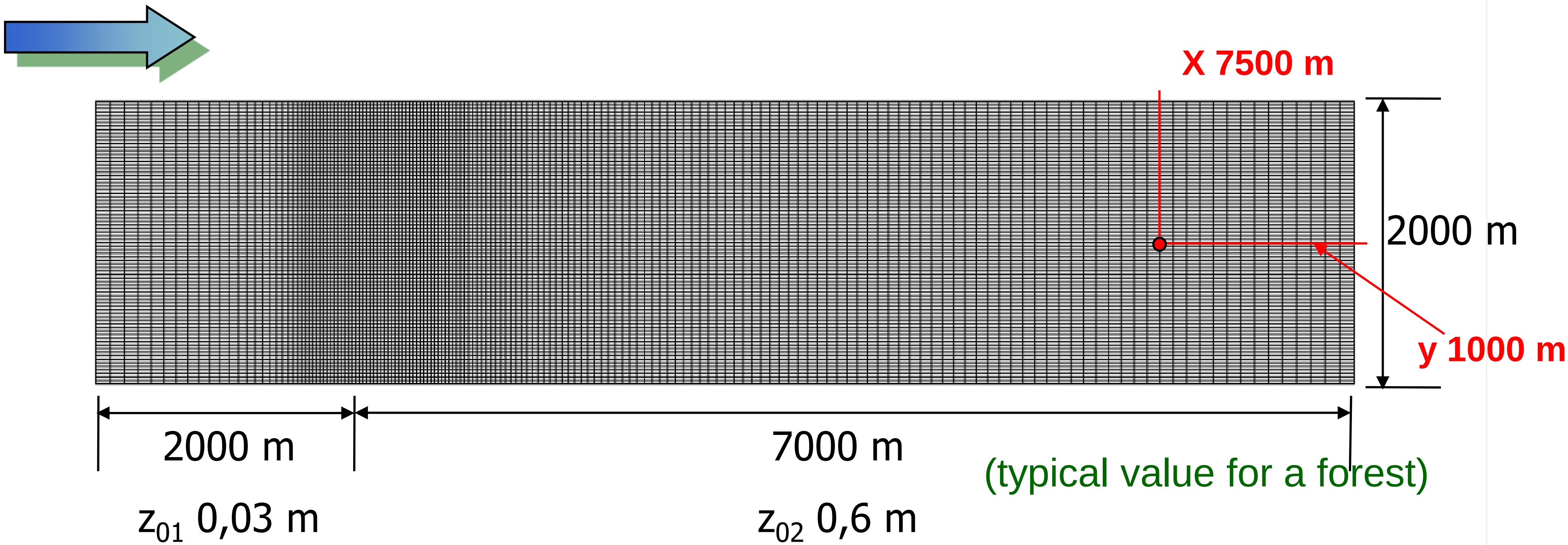
Case B → 50

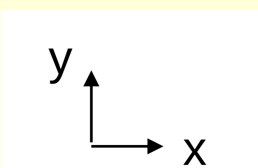
Case A → Cypresses

Species of tree	β [%]	k [m²]	C_1 [1/s]
Fluid	100	-	-
Beech	84	1,108E-02	1,394E-03
Black cherry	77	6,731E-03	2,294E-03
Birch	55	2,004E-03	7,703E-03
Lime	54	1,902E-03	8,116E-03
	50	1,541E-03	1,002E-02
Ash	48	1,384E-03	1,116E-02
Mature maple	47	1,310E-03	1,178E-02
Scots pine	38	7,800E-04	1,980E-02
Firs	30	4,571E-04	3,378E-02
Spruce	29	4,244E-04	3,638E-02
Cypresses	15	1,064E-04	1,451E-01
Solid	0	-	-

Giorgio Crasto
DiMeCa - University of Cagliari - ITALY

First test case: Step change in roughness (top view)

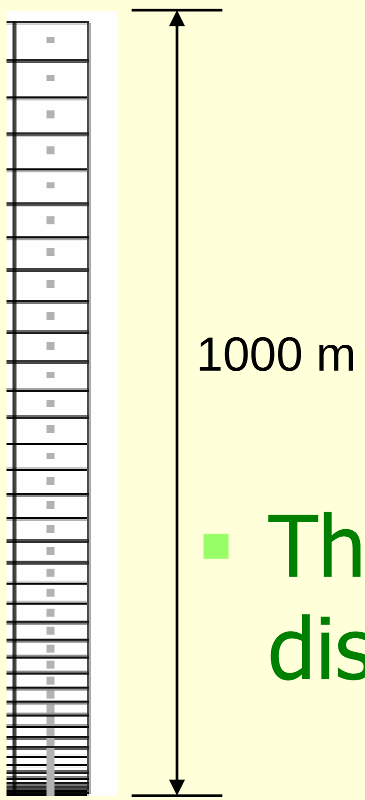




Cells	x	y	z	Tot.
	124	61	38	287432

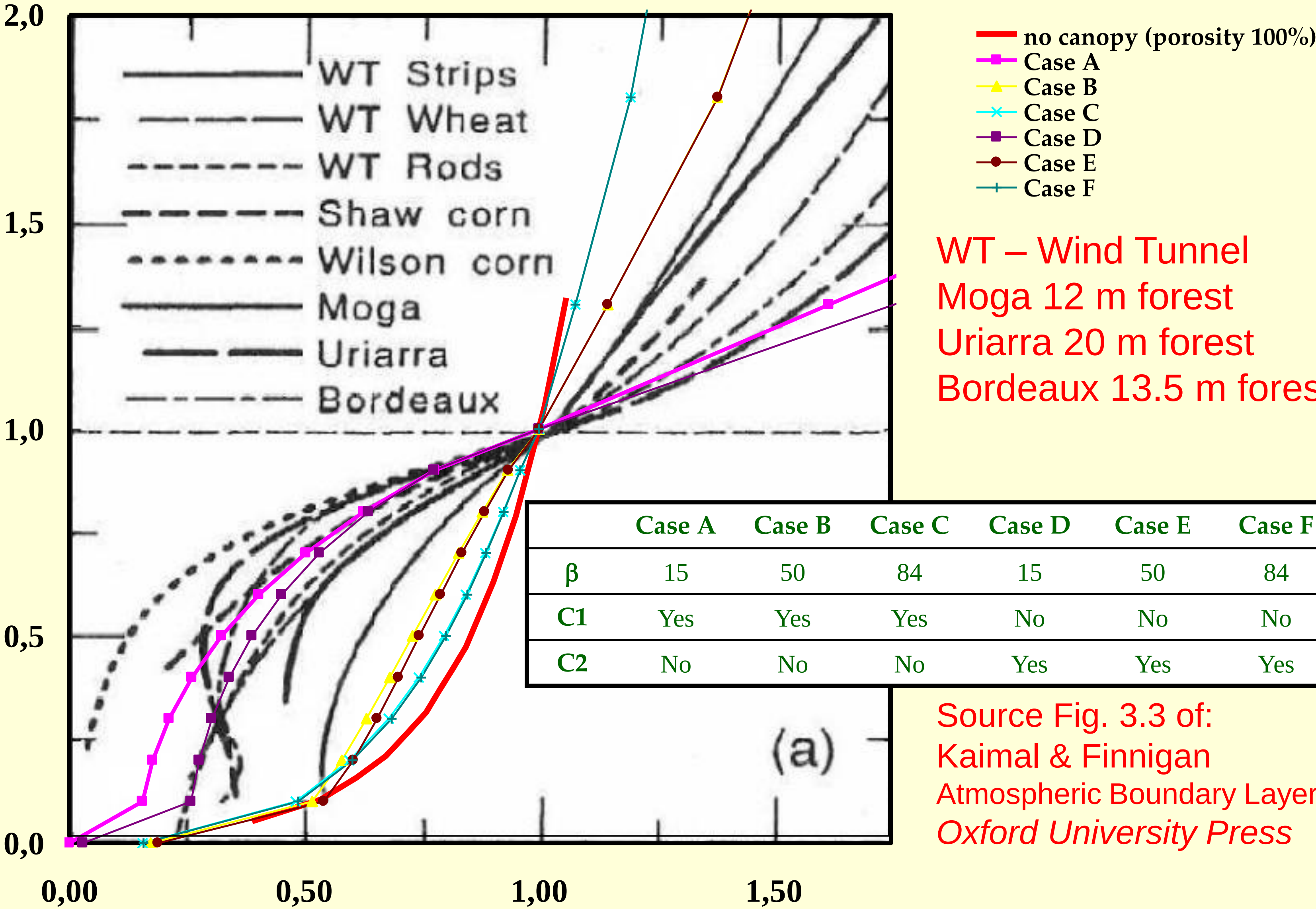
Vertical discretization

	Case A	Case B	Case C	Case D	Case E	Case F	
β	15	50	84	15	50	84	
C1	0,1451	0,01002	0,001393	0	0	0	1/s
C2	0	0	0	0,8535294	0,0055978	0,0004313	m^2/m^3
u_{5m}	0,17	1,79	3,23	0,15	1,73	3,21	m/s
S	2,93E-02	2,13E-02	5,35E-03	2,93E-02	2,13E-02	5,35E-03	N/m^3



- The forest, 10 m height, has been discretized with 10 cells equally spaced.

Giorgio Crasto
DiMeCa - University of Cagliari - ITALY



WT – Wind Tunnel
Moga 12 m forest
Uriarra 20 m forest
Bordeaux 13.5 m forest

	Case A	Case B	Case C	Case D	Case E	Case F	
β	15	50	84	15	50	84	
C1	Yes	Yes	Yes	No	No	No	1/s
C2	No	No	No	Yes	Yes	Yes	m^2/m^3

Source Fig. 3.3 of:
Kaimal & Finnigan
Atmospheric Boundary Layer Flows
Oxford University Press

Conclusions

- With the proposed canopy model is possible to estimate properly the dissipation of momentum and the production of turbulence inside a forest
- Further validations are needed in order to state more precise guidelines for the choice of the parameters C1 and C2 used together
  - Masts inside forests (SgurrEnergy)
  - Wind farms close to forests