

# Edge flow in inhomogeneous canopy

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# Edge flow in inhomogeneous canopy

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- Most of knowledge on forest edge flows : numerical and wind-tunnel experiments where canopy horizontally homogeneous
- Differences in inhomogeneous canopy ? (3D tree-scale heterogeneities)





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Edge site

#### Helicopter-based high resolution scans (>10 $m returns/m^2$ ) ightarrow LES input





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## Neutral flow

#### Domain



2m

#### LES model

- Spatially-filtered NS eqns.
- 1.5-order SGS model
  (Deardoff, 1980)
- Modified for canopy flow
  (Dupont & Brunet, 2008, 2009; Dupont et al., 2011)
- Solved with ARPS code

(Xue et al., 1995; 2000; 2001)



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### Case description





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## Flow averaging framework

Time + spatial averaging :

$$\begin{array}{l} \phi_i' = \phi_i - \bar{\phi}_i \\ \bar{\phi}_i'' = \bar{\phi}_i - \langle \bar{\phi}_i \rangle & (\langle \bar{\phi}_i \rangle_y \text{ or } \langle \bar{\phi}_i \rangle_{xy}) \end{array}$$

Inhomogeneous canopy : dispersive fluxes important?

$$\frac{\partial \langle \bar{u}_i \rangle}{\partial t} = -\langle \bar{u}_j \rangle \frac{\partial \langle \bar{u}_i \rangle}{\partial x_j} - \frac{1}{\rho} \frac{\partial \langle \bar{p} \rangle}{\partial x_i} - \frac{\partial \langle T_{ij}^{tot} \rangle}{\partial x_j} - \langle F_{\mathcal{D}}^{tot} \rangle$$

Second-order moments :

$$\langle T_{ij}^{tot} \rangle = \underbrace{\langle \overline{u'_i u'_j} \rangle}_{turbulent} + \underbrace{\langle \overline{u_i}'' \overline{u_j}'' \rangle}_{dispersive}$$

Third-order moments (skewness) :

$$\langle T_{iii}^{tot} \rangle = \underbrace{\langle \overline{u_i' u_i' u_i'} \rangle}_{turbulent} + \underbrace{3 \langle \overline{u_i u_i''} \overline{u_i''} \rangle - 6 \langle \overline{u_i} \rangle \langle \overline{u_i''} \overline{u_i''} \rangle + 2 \langle \overline{u_i''} \overline{u_i''} \overline{u_i''} \rangle}_{dispersive}$$



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# Half-canopy height view

#### Heterogeneous edge-case





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## Two-dimensional view : streamwise velocity

#### Heterogeneous



#### Homogeneous





## Two-dimensional view : turbulent kinetic energy

#### Heterogeneous







## Two-dimensional view : turbulent flux

#### Heterogeneous







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## Two-dimensional view : correlation coefficient

Heterogeneous







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## Two-dimensional view : skewness of streamwise velocity

Heterogeneous







## Two-dimensional view : skewness of vertical velocity

#### Heterogeneous







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#### Two-dimensional view : ratio of dispersive to total flux





### Two-dimensional view : ratio of dispersive to total flux





# 1D u-velocity/TKE





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## 1D u-budget







#### Impacts of tree-scale heterogeneities in edge flow analysed

Inside the canopy :

- 1. Faster flow penetration
- 2. Higher TKE
- 3. Lower efficiency
- 4. Higher skewness (gusts)
- 5. Lower drag
- 6. Important dispersive fluxes at the edge (10-80% of total flux), up to 50% at canopy top for u-variance

Above the canopy :

1. Slightly higher wind speed / same level of  $\mathsf{TKE}$ 





#### Consequences :

- 1. Important to picture well the edge vertical foliage distribution in numerical simulation of homogeneous canopy
- 2. Underestimation of gust occurence in homogeneous canopy (skewness local)
- 3. Lower loads on trees / higher production for wind turbines

Thank you for your attention !

