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Modelling the water flow in presence of small and flexible seagrass *Zostera noltii*

F. GANTHY[1,2], R. VERNEY[2] and A. SOTTOLICHIO[1]

1. University of Bordeaux1, UMR 5805 CNRS - EPOC, Avenue des Facultés, 33405 Talence cedex, France. Email: florian.ganthy@gmail.com
2. IFREMER, Centre of Brest, BP70, 29280 Plouzané, France.

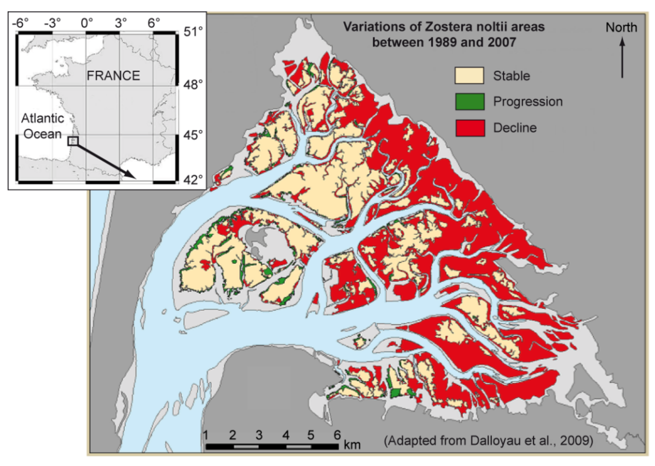
The Arcachon lagoon (French Atlantic Coast)

- Extensive seagrass beds of *Zostera noltii* on intertidal flats
- Drastic regression of meadows since 20 years : -33% of surface area from 1988 to 2007 (Plus et al., 2010)
- Infilling of Eastern shallow channels

What are the consequences of seagrass regression on sediment dynamics and morphological evolutions of the lagoon?

→ Study of the interactions ***Vegetation – Hydrodynamics – Sediment dynamics*** through :

- Field surveys
- Flume study
- Process-based numerical modelling



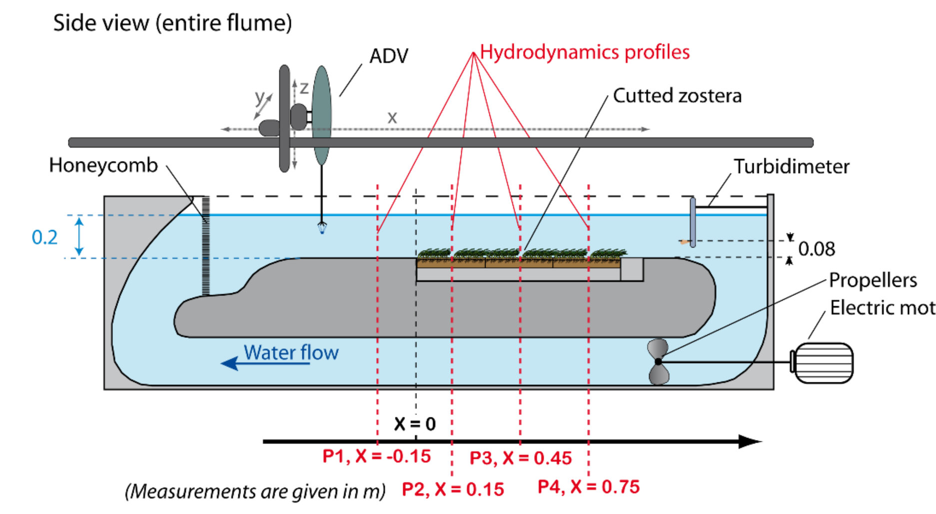
Flume experiments

- Real seagrass at contrasted development stages

→ Quantification of flow velocity and turbulence in presence of seagrass

→ Quantification of sediment erosion and deposition fluxes

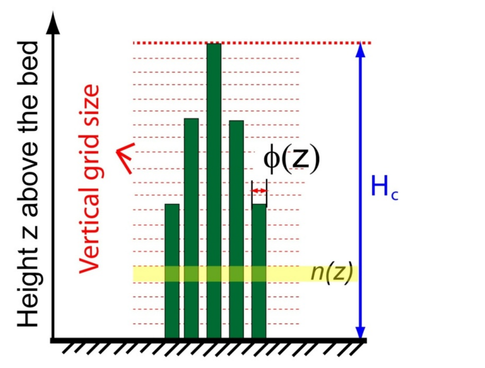
→ Reliable data for model calibration



Model description (implemented within MARS model; Lazure and Dumas, 2008)

• Vegetation description

Vegetation is described as cylindrical structures defined by their **height (*Hc*), diameter (*ϕ*)** and **density (*n*)**



Horizontal cross-sectional surface area of elements per unit area

$$A(z)=\frac{\pi}{4}\cdot\phi(z)^2\cdot n(z)$$

• Model Equations

3D impacts of vegetation on drag and turbulence using k-ε closure scheme

(Uittenbogaard, 2003; Temmerman et al., 2005)

- Momentum equation:

$$\int_{z=0}^{z=h_w}\frac{\partial\tau_{xz}}{\partial z}\cdot dz+\int_{z=0}^{z=h_w}\frac{\partial P}{\partial x}\cdot dz+\int_{z=0}^{z=H_c}F(z)\cdot dz=0$$

- Turbulent kinetic energy equation:

$$\left(\frac{\partial k}{\partial t}\right)_{veg}=\frac{1}{1-A(z)}\cdot\frac{\partial}{\partial z}\left\{(1-A(z))\cdot\frac{\upsilon+\upsilon_t}{\sigma_k}\cdot\frac{\partial k}{\partial z}\right\}+T(z)$$

- Turbulent dissipation equation:

$$\left(\frac{\partial \varepsilon}{\partial t}\right)_{veg}=\frac{1}{1-A(z)}\cdot\frac{\partial}{\partial z}\left\{(1-A(z))\cdot\frac{\upsilon+\upsilon_t}{\sigma_\varepsilon}\cdot\frac{\partial \varepsilon}{\partial z}\right\}+T(z)\cdot\tau_\varepsilon^{-1}$$

- F(z) - Resistance force imposed by vegetation:

$$F(z)=-\frac{1}{2}\cdot Cd\cdot\rho\cdot\phi(z)\cdot n(z)\cdot|u(z)|\cdot u(z)$$

- T(z) - The work spent by the fluid: $T(z)=F(z)\cdot\frac{u(z)}{\rho}$

- L(z) - The typical size of eddies (smallest distance between structures): $L(z)=0.3\cdot\left\{\frac{1-A(z)}{n(z)}\right\}^{1/2}$

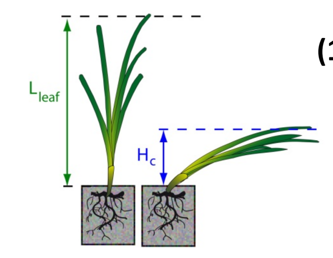
- τ_ε - The minimum between the dissipation timescale of free turbulence (τ_{free}) and the dissipation timescale of eddies between plants (τ_{veg}):

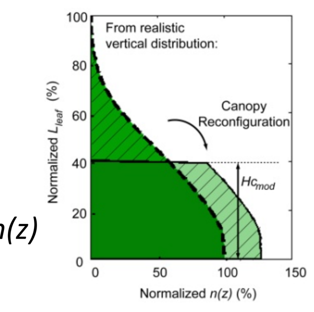
$$\tau_{free}=\frac{1}{c_{2\varepsilon}}\cdot\left(\frac{k}{\varepsilon}\right)\qquad \tau_{veg}(z)=\frac{1}{c_{2\varepsilon}\cdot\sqrt{c_\mu}}\cdot\left(\frac{L(z)^2}{T(z)}\right)^{1/3}$$

• Introduction of seagrass flexibility

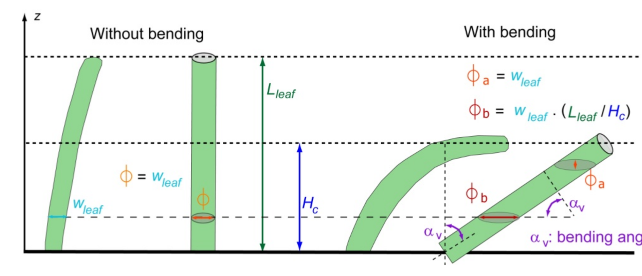
Semi-empirical method

(1) Empirical parameterization of the canopy height, *Hc*





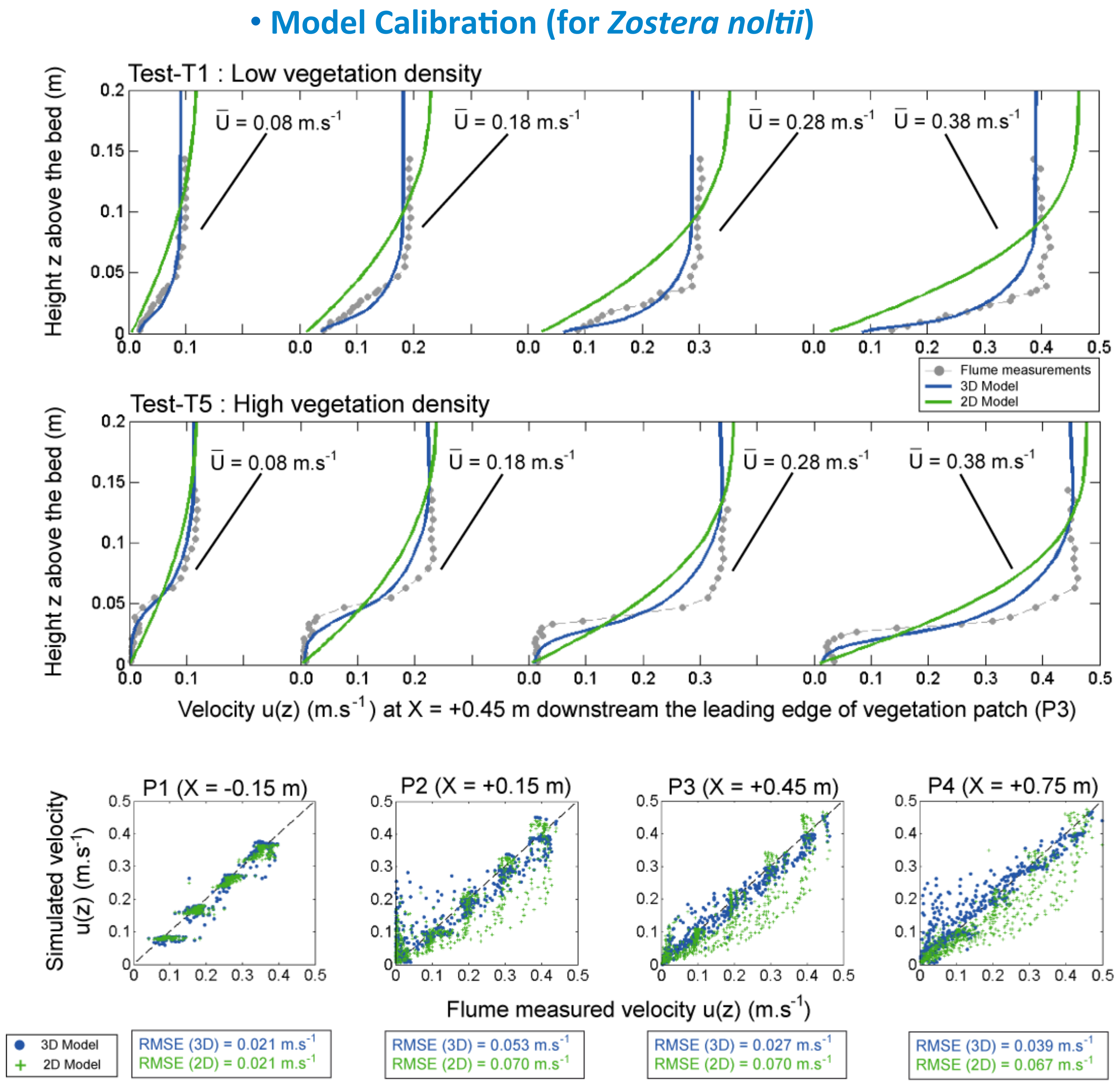
(2) Geometrical correction for canopy reconfiguration, *n(z)*



(3) Geometrical anisotropic correction of the diameter, *ϕ(z)*

Modelling Seagrass – Flow Interactions

• Model Calibration (for *Zostera noltii*)



➢ **Total RMSE over the four velocity profiles:**

- ✓ **For the 3D model RMSE = 0.037 m.s-1**
- ✓ **For the 2D model RMSE = 0.061 m.s-1**

- **For the 2D Model:**
  - The **source term F(z)** within momentum equation is **depth-averaged**
  - The **roughness length z_0** is set to the **vegetation height (Hc)**

✓ Good simulation of flow velocity along the vegetation patch using the 3D model

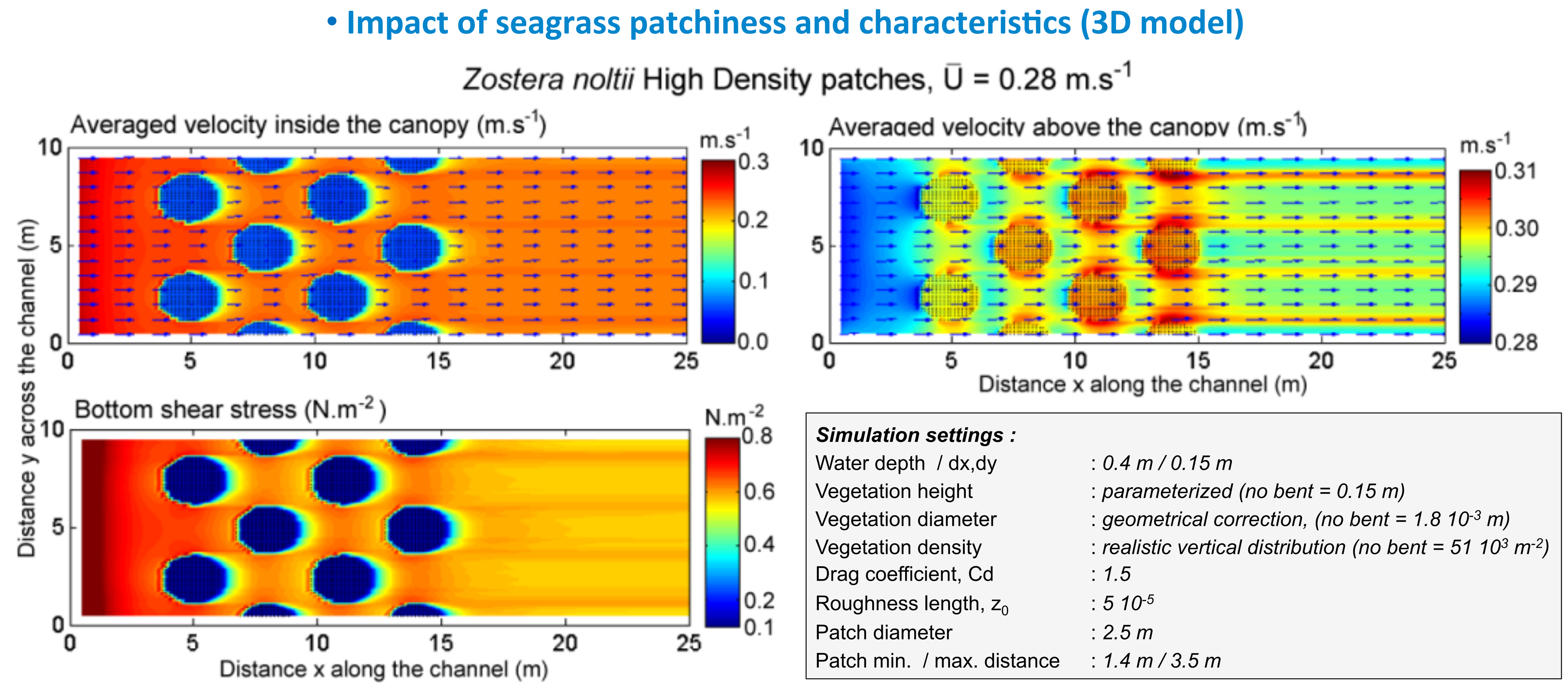
✓ Satisfactory simulation of near-bed flow along the vegetation patch using the 2DH model considering simplifications

✓ The use of 2D model allowed computation times 2 to 3 times shorter than using the 3D model

✓ Both the 2 models provide good simulations of the bottom shear stress

• Impact of seagrass patchiness and characteristics (3D model)

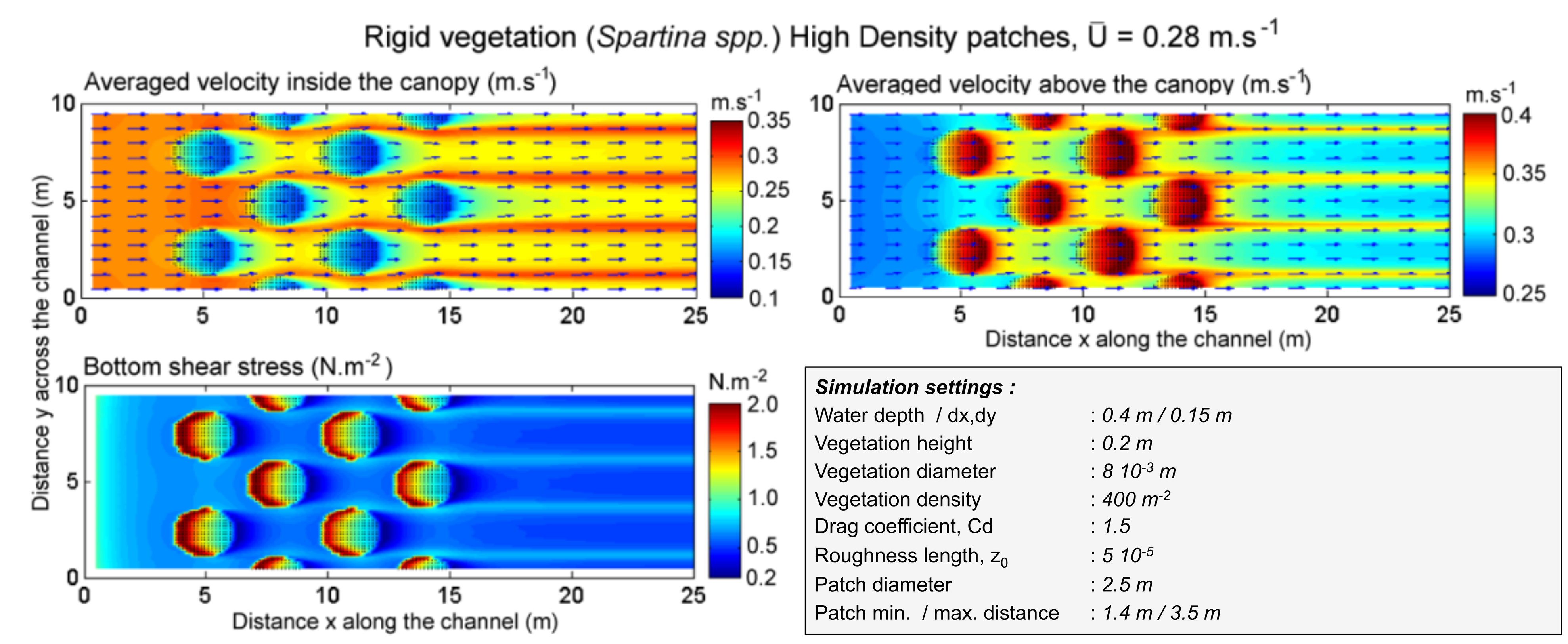
Zostera noltii High Density patches, $\bar{U}$ = 0.28 m.s-1



Simulation settings :

Water depth / dx,dy	: 0.4 m / 0.15 m
Vegetation height	: parameterized (no bent = 0.15 m)
Vegetation diameter	: geometrical correction, (no bent = 1.8 10^{-3} m)
Vegetation density	: realistic vertical distribution (no bent = 51 10^{3} m^{-2})
Drag coefficient, Cd	: 1.5
Roughness length, z_0	: 5 10^{-5}
Patch diameter	: 2.5 m
Patch min. / max. distance	: 1.4 m / 3.5 m

Rigid vegetation (*Spartina spp.*) High Density patches, $\bar{U}$ = 0.28 m.s-1



Simulation settings :

Water depth / dx,dy	: 0.4 m / 0.15 m
Vegetation height	: 0.2 m
Vegetation diameter	: 8 10^{-3} m
Vegetation density	: 400 m^{-2}
Drag coefficient, Cd	: 1.5
Roughness length, z_0	: 5 10^{-5}
Patch diameter	: 2.5 m
Patch min. / max. distance	: 1.4 m / 3.5 m

✓ For the two types of vegetation, strong velocity attenuation is simulated, associated with a velocity enhancement above the canopy

✓ The larger the ratio between canopy heigth and water depth is, the more the flow is deflected around vegetation patches with substantial impacts on the bottom shear stress

✓ Considering bottom shear stress as a proxy for sediment resuspension, *Zostera noltii* appears to be more efficient to protect bed sediment from erosion than rigid vegetation such as *Spartina spp.*

Conclusions

✓ **The introduction of the balance between turbulence production and dissipation, associated with a semi-empirical method for integrating the seagrass flexibility allowed us to simulate a wide range of flows through flexible vegetation. In all cases, the agreement between the simulated and measured velocity and bottom shear stress was satisfactory. Despite a less accuracy of the 2D model compared with the 3D model, the 2D formulation appears 2-3 folds less expensive in computational time.**

✓ **The comparison of the impacts of *Zostera noltii* and rigid vegetation such as *Spartina spp.* patchiness on bottom shear stress (as a proxy of sediment resuspension) highlights strong differences of erosion/deposition patterns within and around vegetation patches.**

✓ **Our model appears suitable for modelling impacts of differents kinds of vegetation at a regional scale. It will be used to investigate the consequences of *Zostera noltii* decline on the sediment dynamics and morphological evolutions of the Arcachon lagoon.**

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References

-Dalloyau S., Trut G., Plus M. and Auby I. (2009). Caractérisation de la qualité biologique des Masses d'Eau Côtières : Cartographie des herbiers de *Zostera noltii* et *Zostera marina* du Bassin d'Arcachon. Rapport Ifremer RST /LER/AR/09-003: 51.
- Lazure P. And Dumas F. (2008). An external-internal mode coupling for a 3D hydrodynamical model for application at regional scale (MARS). Advances in Water Ressources, 31:233-250.
- Plus M., Dalloyau S., Trut G., Auby I., de Montaudouin X., Emery E., Noël C. and Viala C. (2010). Long-term evolution (1988-2008) of Zostera spp. Meadows in Arcachon Bay (Bay of Biscay). Estuarine, Coastal and Shelf Science, 87:357-366.
- Temmerman S., Bouma T.J., Govers G., Wang Z.B., De Vries M.B. and Herman P.M.J. (2005). Impact of vegetation on flow routing and sedimentation patterns: three-dimensional modeling for a tidal marsh. Journal of Geophysical Research, 110:F04019.
- Uittenbogaard R. (2003). Modelling turbulence in vegetated aquatic flows. International Workshop on Riparian Forest Vegetated Channels : Hydraulic, Morphological and Ecological Aspects, RIPFOR, Trento, Italy, 17pp.