



# Inauguration du supercalculateur « Austral »

Le HPC au service du développement des énergies marines  
renouvelables

Gregory PINON & pleins de collaborateurs

Université Le Havre Normandie / CNRS (UMR 6294 LOMC)



Normandie Université



LE HAVRE  
NORMANDIE



RÉGION  
NORMANDIE



Ifremer

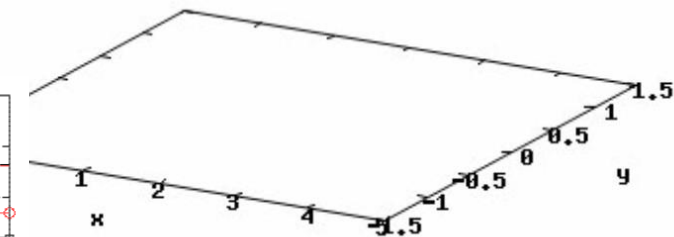
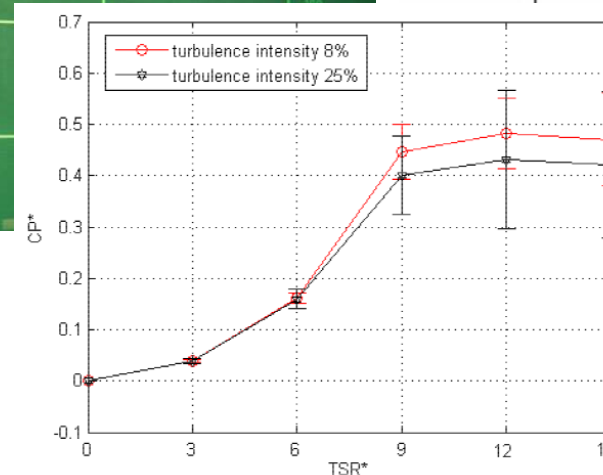
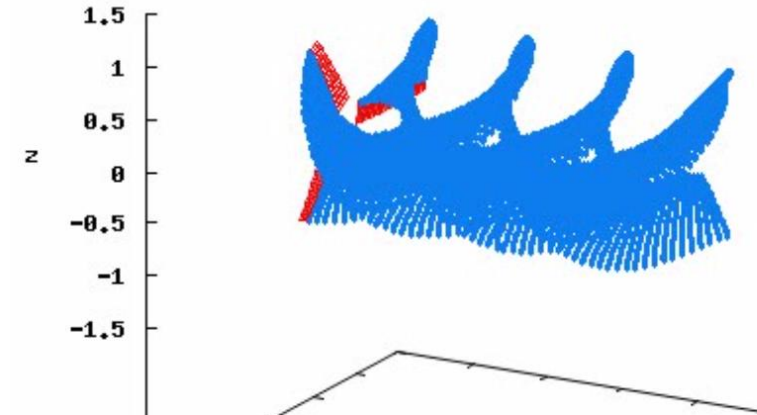
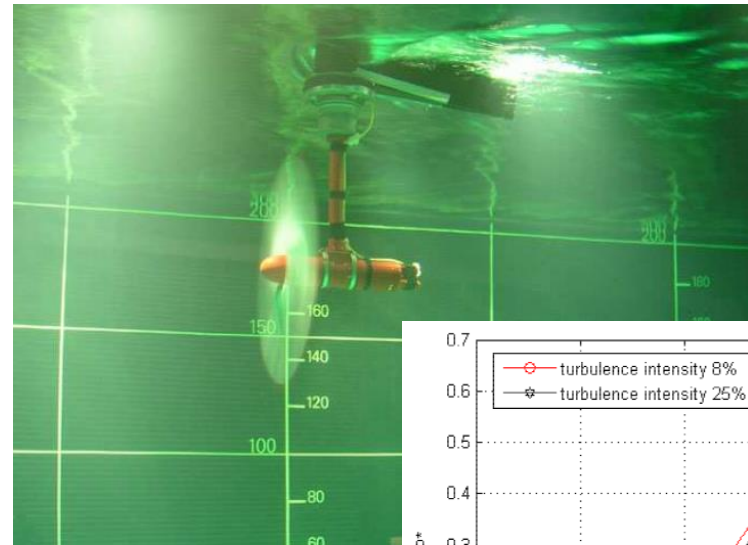
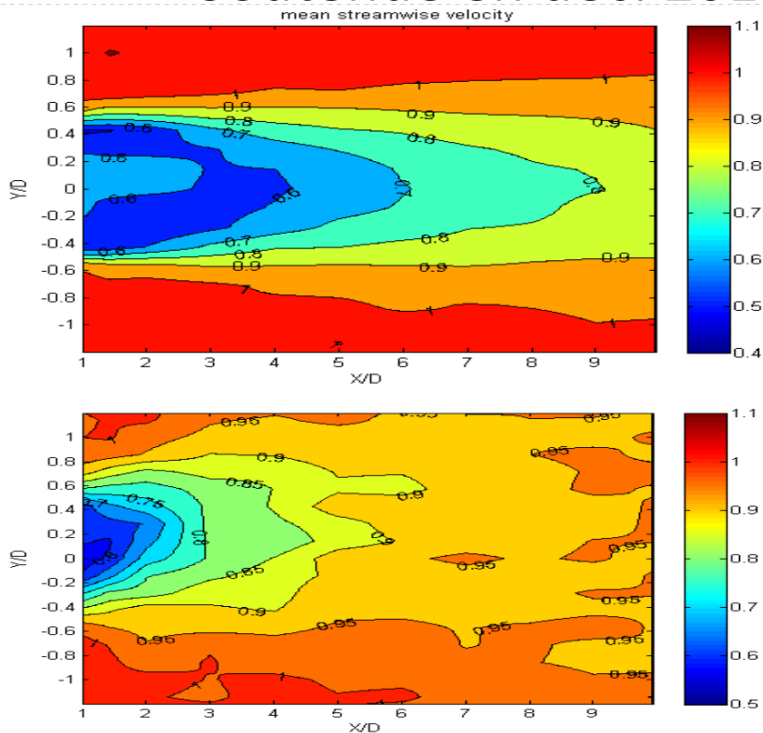
# Plan de l'exposé

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- **Introduction - Les premières thèses**
- Vers des configurations de plus en plus réaliste
- Conclusions et perspectives

- *Caractérisation numérique et expérimentale des effets d'interactions entre une hydrolienne et le milieu marin*

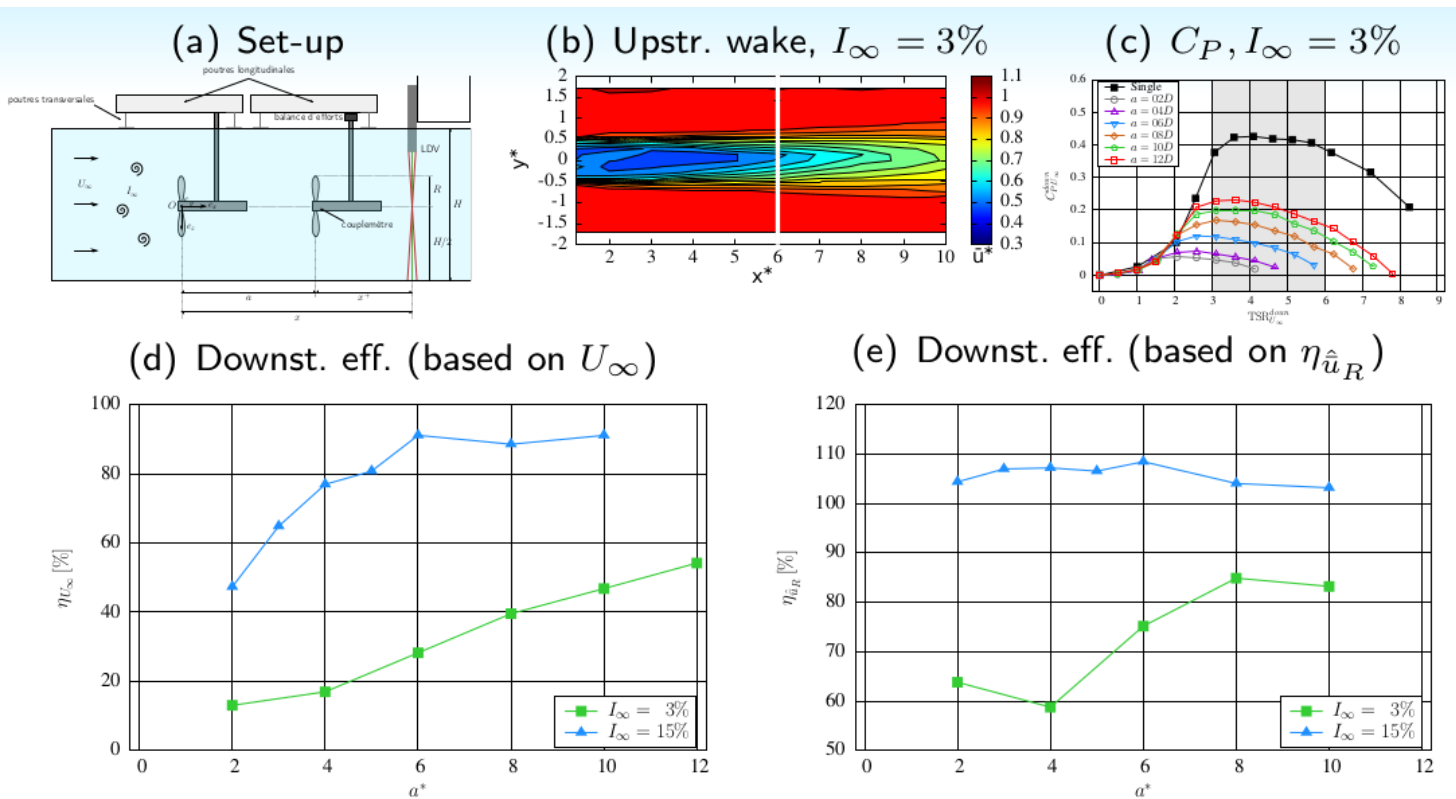
- Direction: Elie Rivoalen & Grégory Germain
- Soutenue en déc. 2011



# Thèse de Paul Mycek

## De l'expérimental et un peu plus de numérique

### • Étude numérique et expérimentale du comportement d'hydroliennes



Paul Mycek, Benoît Gaurier, Grégory Germain, Grégory Pinon, and Elie Rivoalen.

Experimental study of the turbulence intensity effects on marine current turbines behaviour. part II : Two interacting turbines.

Renewable Energy, 68(0) :876 – 892, 2014.

**MODÉLISATION NUMÉRIQUE**  
le calcul haute performance

**MÉCANIQUE DES FLUIDES**  
Hydrodynamique marine : simulation du sillage d'une hydrolienne

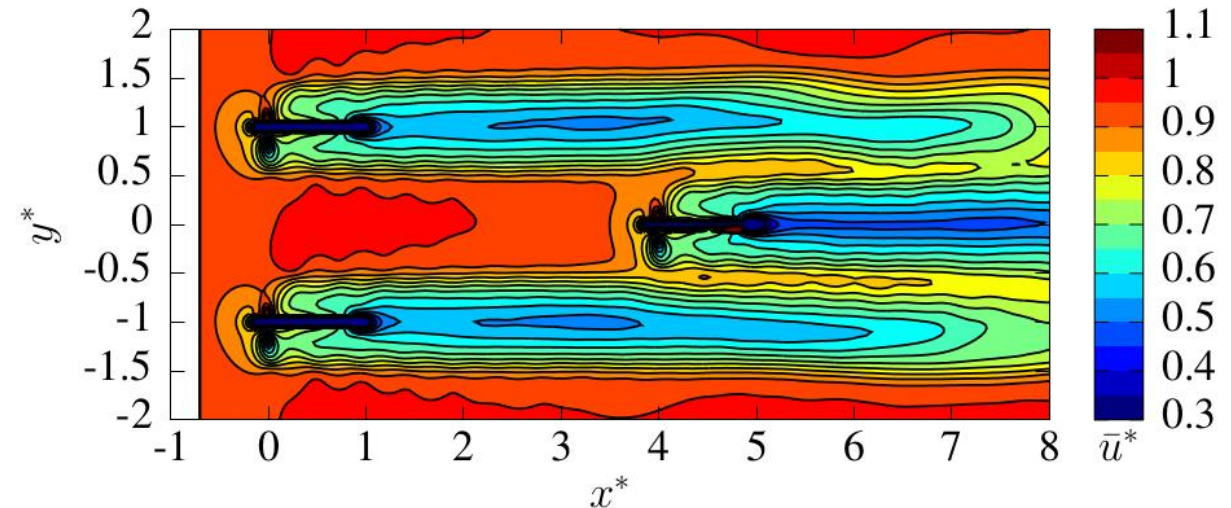
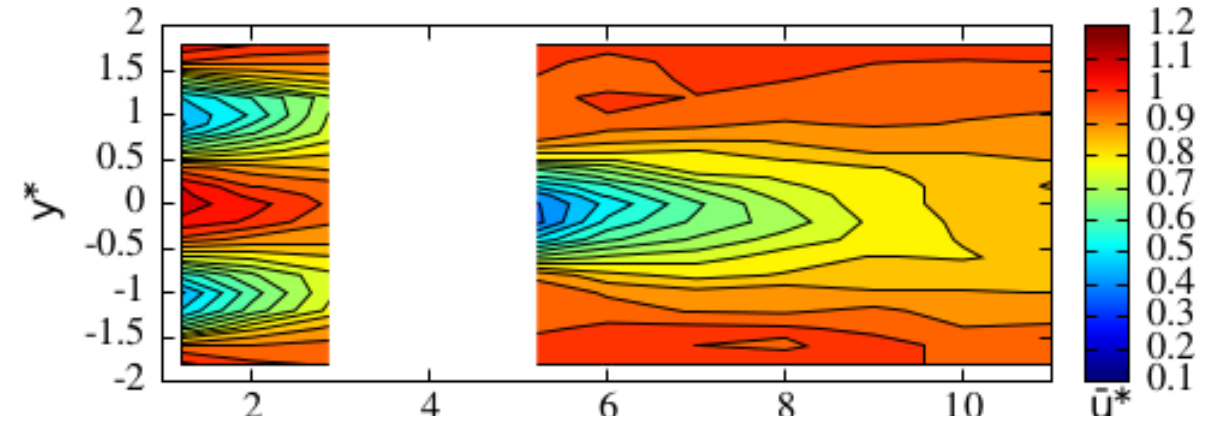
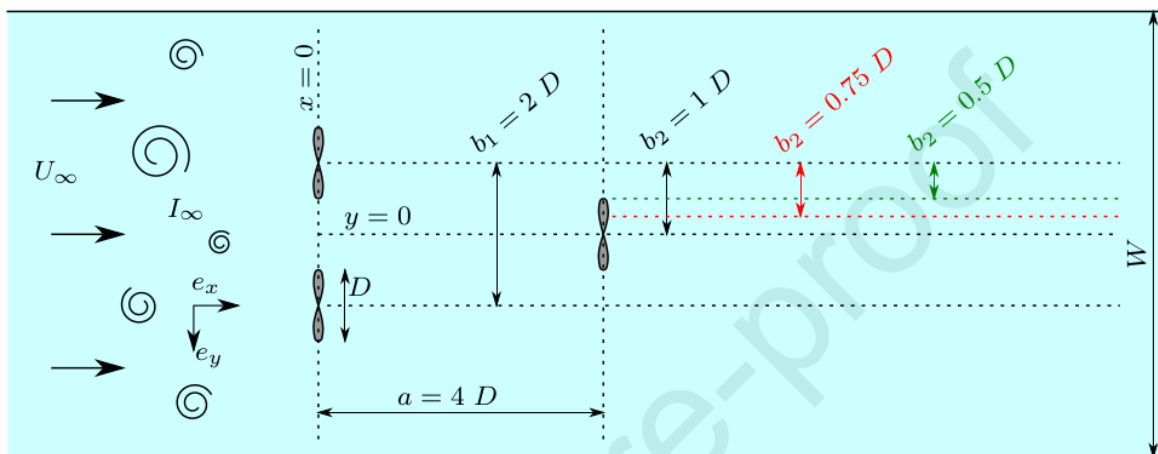
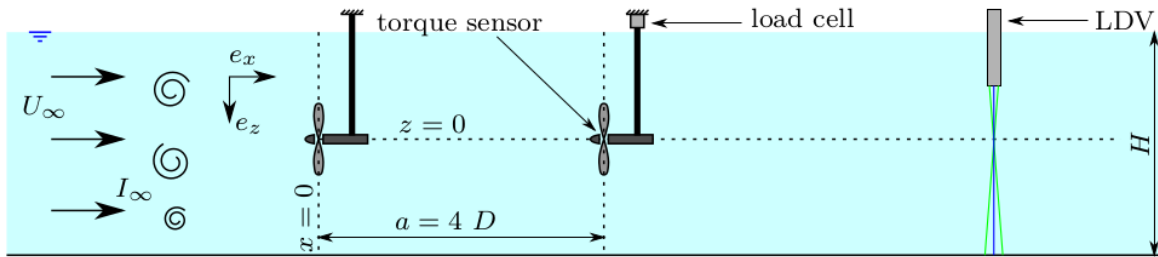
J. M. Étancelin, G. Germain, P. Mycek, G. Pinon, É. Rivoalen | FRE 3102 LOMC - IFREMER, Université du Havre et INSA de Rouen

# Thèse de Clément Carlier

## De l'expérimental et de plus en plus de numérique

- *Simulation du comportement d'hydroliennes : modélisation de l'influence de la turbulence ambiante et des effets d'interaction*

- Direction : Elie Rivoalen & Grégory Germain
- Soutenue en déc. 2017



# Plan de l'exposé

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- Introduction - Les premières thèses
- **Vers des configurations de plus en plus réaliste**
- Conclusions et perspectives

# Vers des configurations de plus en plus réalistes – la méthode numérique

## General framework

### Vortex Particle Method

- ▶ Lagrangian method ;
- ▶ Solid obstacles represented by a surface mesh or stationary particles.

### Governing Equations

Navier-Stokes Equations :

- ▶ Incompressible fluid,
- ▶ Velocity-vorticity formulation  $(\mathbf{u}, \boldsymbol{\omega})$ .

$$\left\{ \begin{array}{l} \nabla \cdot \mathbf{u} = 0 \\ \frac{D\boldsymbol{\omega}}{Dt} = \underbrace{(\boldsymbol{\omega} \cdot \nabla)\mathbf{u}}_{\text{Stretching}} + \underbrace{\nu \nabla^2 \boldsymbol{\omega}}_{\text{Diffusion}} \end{array} \right.$$

$$\text{with } \frac{D\boldsymbol{\omega}}{Dt} = \frac{\partial \boldsymbol{\omega}}{\partial t} + (\mathbf{u} \cdot \nabla)\boldsymbol{\omega}$$

### Fluid particles

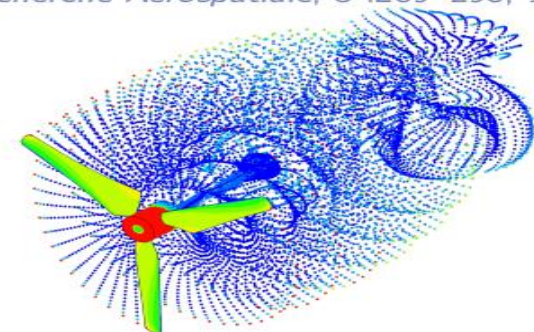
Defined by :

- ▶ Position  $\mathbf{X}$  ;
- ▶ Vorticity ("weight")  $\boldsymbol{\Omega}$ .

**G. Cottet and P. Koumoutsakos.**  
*Vortex methods : theory and practice.*  
Cambridge University Press, 2000.

**A. Leonard.**  
*Vortex methods for flow simulation.*  
*Journal of Computational Physics,*  
37(3) :289–335, 1980.

**C. Rehbach.**  
*Calcul numérique d'écoulements tridimensionnels instationnaires avec nappes tourbillonnaires.*  
*La Recherche Aéronautique,* 5 :289–298, 1977.



# Vers des configurations de plus en plus réalistes – la méthode numérique

## Velocity field

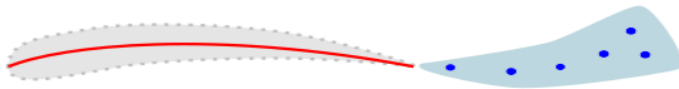
### Helmholtz Decomposition

$$\begin{aligned} \mathbf{u} &= \nabla \times \psi + \nabla \phi + \mathbf{u}^\infty \\ &= \underbrace{\mathbf{u}^\psi + \mathbf{u}^\phi}_{\text{Integral methods}} + \mathbf{u}^\infty \end{aligned}$$

$$\begin{aligned} \nabla^2 \psi &= -\omega \\ \nabla^2 \phi &= 0 \end{aligned}$$

### Velocity components

- ▶  $\mathbf{u}^\psi$  : Rotational component  
⇒ Influence of the wake,
- ▶  $\mathbf{u}^\phi$  : Potential component  
⇒ Influence of the turbines,
- ▶  $\mathbf{u}^\infty$  : Upstream incoming velocity.



Mean camber surface :

- ▶ dipole singularities,
- ▶ loads from dipole distribution.



Full blade surface surface :

- ▶ dipole and source singularities,
- ▶ potential computation and Bernoulli for loads.



Ligting line representation.

G. Pinon, P. Mycek, G. Germain, and E. Rivoalen.

Numerical simulation of the wake of marine current turbines with a particle method. *Renewable Energy*, 46(0) :111 – 126, 2012.

C. Choma Bex.

Développement de modèles numériques Lagrangiens pour la simulation du comportement d'hydroliennes.

PhD thesis, Université Le Havre Normandie, 2021.



# Vers des configurations de plus en plus réalistes – turbulence ambiante

## Integration of SEMs

### Velocity decomposition

$$\mathbf{u} = \mathbf{u}^\psi + \mathbf{u}^\phi + \mathbf{u}_\infty$$

$\mathbf{u}_\infty$  is separated into :

$$\mathbf{u}_\infty = \underbrace{\overline{\mathbf{u}_\infty}}_{\text{average velocity}} + \underbrace{\tilde{\mathbf{u}}}_{\text{fluctuating velocity}}$$

### Integration into the Vortex method

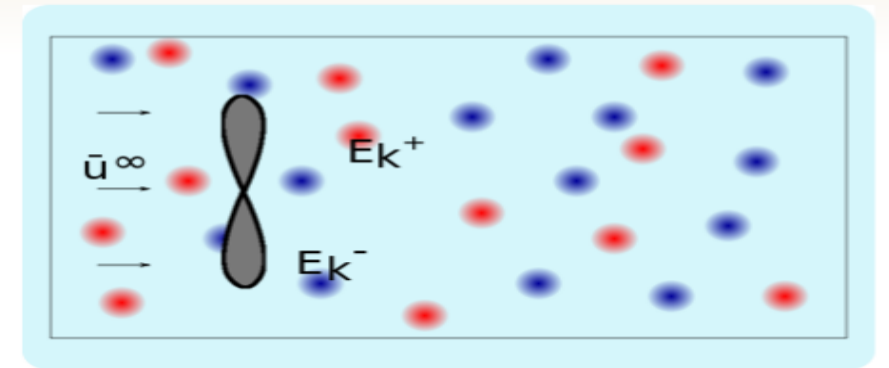
- ▶ Sub-layer of turbulent structures ;
- ▶ Turbulent structures  $\Rightarrow$  Turbines
- ▶ Turbines  $\nRightarrow$  Turbulent structures ;
- ▶ Can be pictured as a "conveyer belt".

**N. Jarrin.**

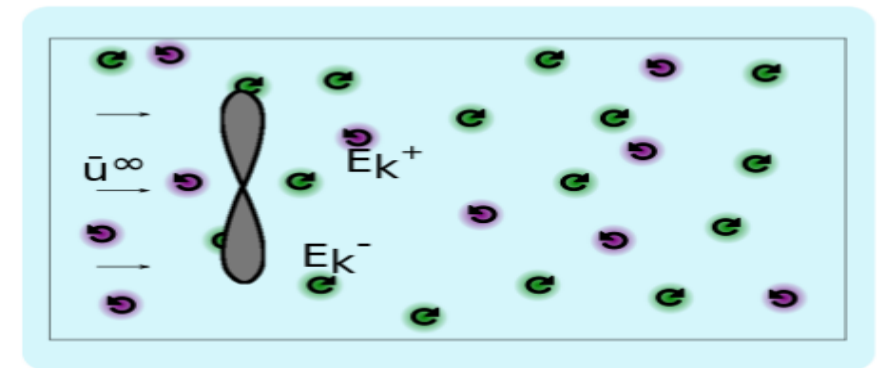
*Synthetic Inflow boundary conditions for the numerical simulation of turbulence.*  
PhD thesis, University of Manchester, 2008.

**R. Poletto.**

*Divergence free development of the Synthetic Eddy Method in order to improve synthetic turbulence for embedded LES simulations.*  
PhD thesis, University of Manchester, 2014.



SEM (Jarrin) : sources/sinks

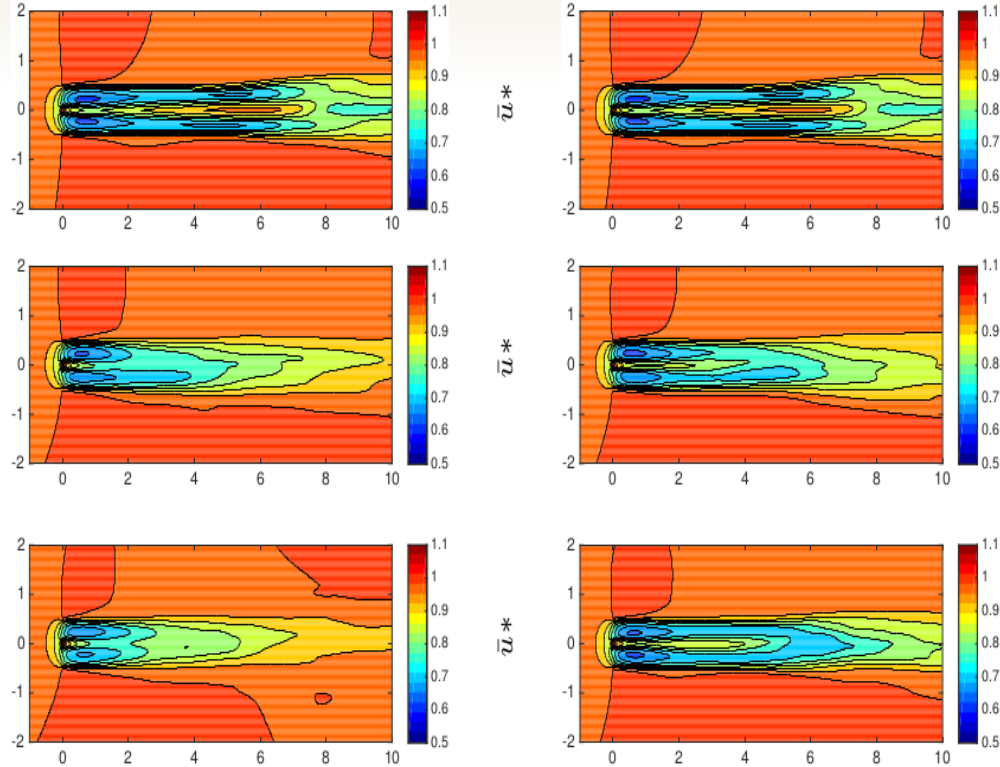


DFSEM (Poletto) : "eddies"

# Vers des configurations de plus en plus réalistes – turbulence ambiante

## Influence on a turbine wake

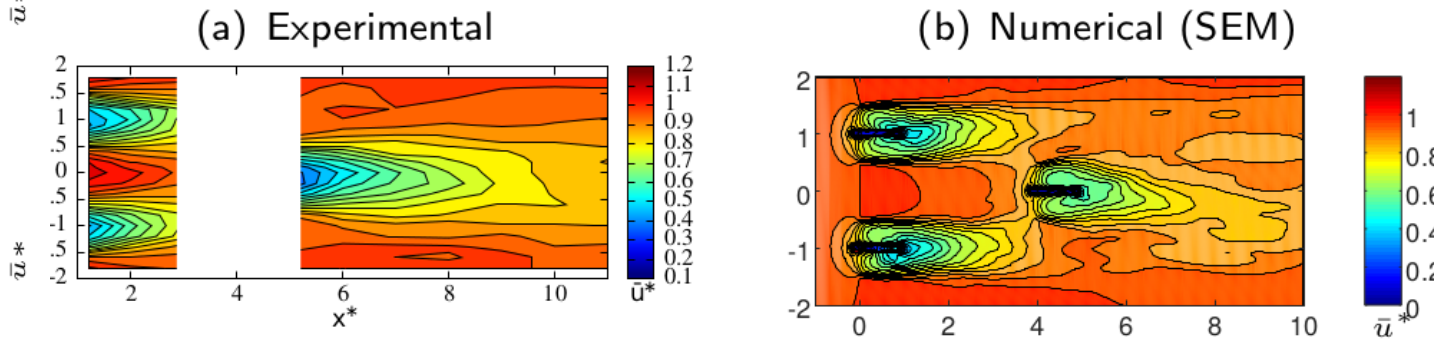
$I_\infty = 0\%$   
 $I_\infty = 5\%$   
 $I_\infty = 10\%$



(a) SEM

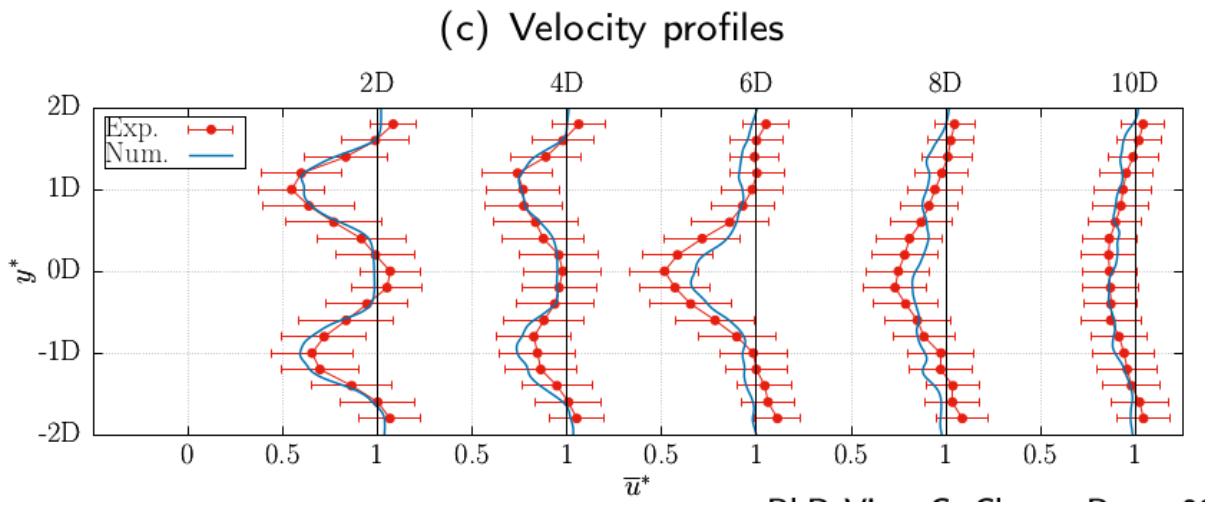
(b) DFSEM

$$I_\infty = 15\%, \text{TSR} = 3.5.$$



(a) Experimental

(b) Numerical (SEM)

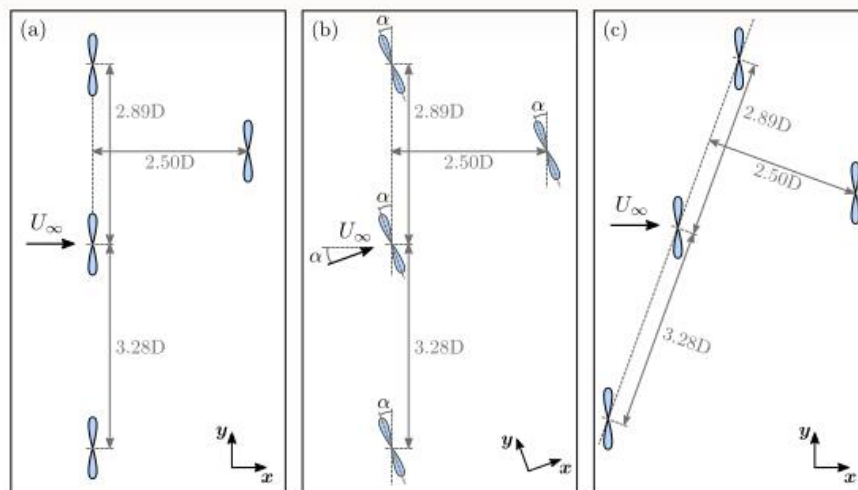


(c) Velocity profiles

# Vers des configurations de plus en plus réalistes – ferme d’hydroliennes

## Normandie-France pilot farm

- General electric / Engie co
- 4 tidal turbines array:
  - Alstom Oceade
  - 18D - 1.4 MW
- The 4<sup>th</sup> turbine is located



$$U_{\infty} = 3.2 \text{ m/s}$$

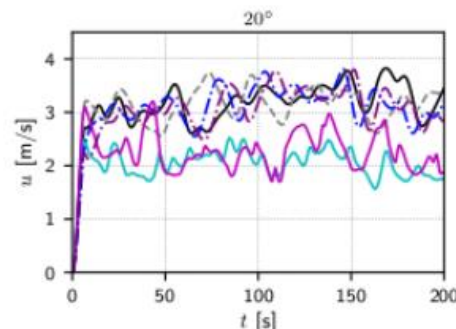
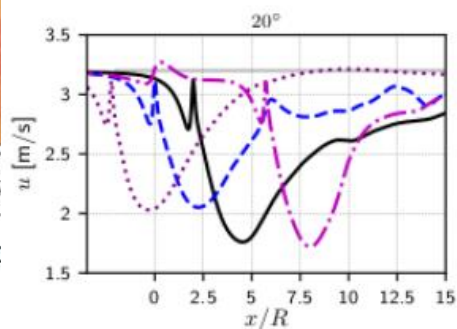
$$I_{\infty} = 10\%$$

$$R_f = 229$$

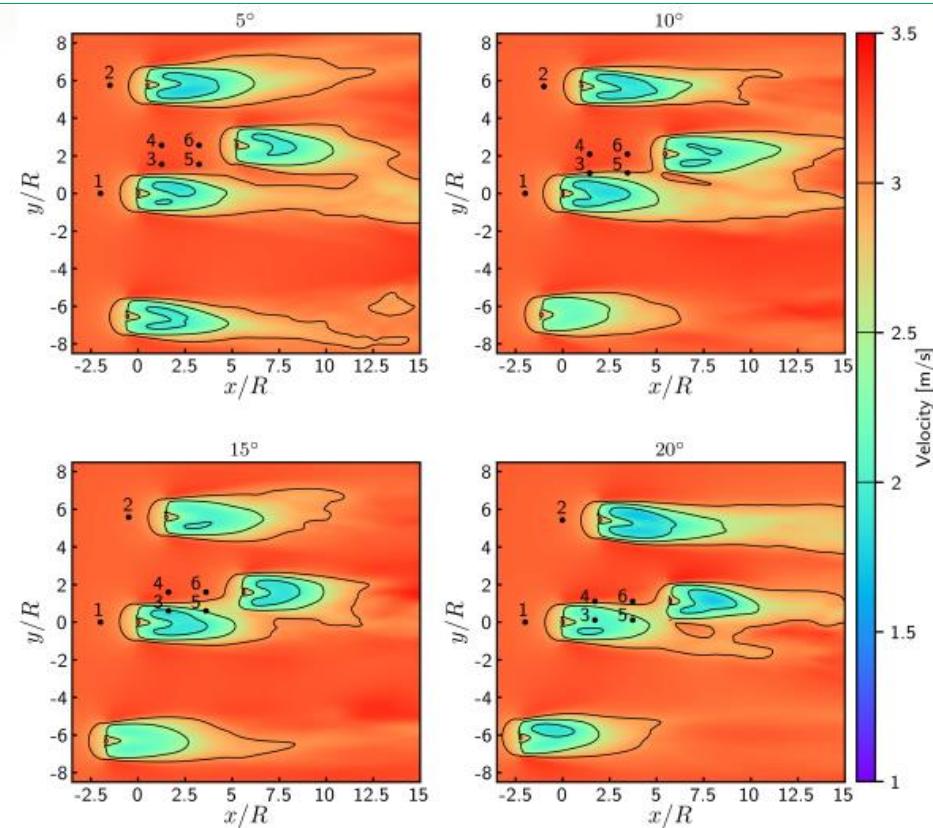
$$TSR = 4.1$$

$$\mathcal{L} = 18 \text{ m} \Rightarrow \lambda = 27.5 \text{ m}$$

$$\sigma(\lambda) = 75\%$$



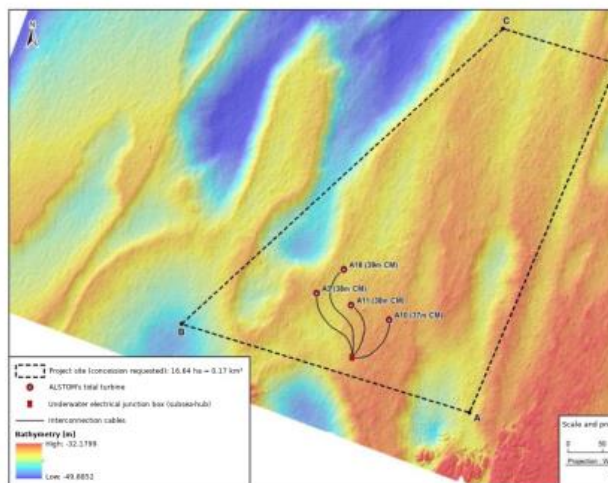
— Upstream top    - - - Upstream middle    — Probe 1    - - - Probe 2    — Probe 3  
 ···· Upstream bottom    ···· Downstream    - - - Probe 4    — Probe 5    - - - Probe 6



M. Slama, C. Choma Bex, G. Pinon, M. Togneri, and I. Evans.

Lagrangian vortex computations of a four tidal turbine array : An example based on the nepthyd layout in the alderney race.

*Energies*, 14 :3826–3839, 2021.



Configuration of the NEPTHYD pilot farm

# Vers des configurations de plus en plus réalistes – performance des machines

## Bound Vortex

$$\Gamma_B(r, t) = \frac{1}{2} c V_{rel} C_L$$

- ▶ Relative velocity :

$$V_{rel} = (U_x, U_\theta - \Omega r)$$

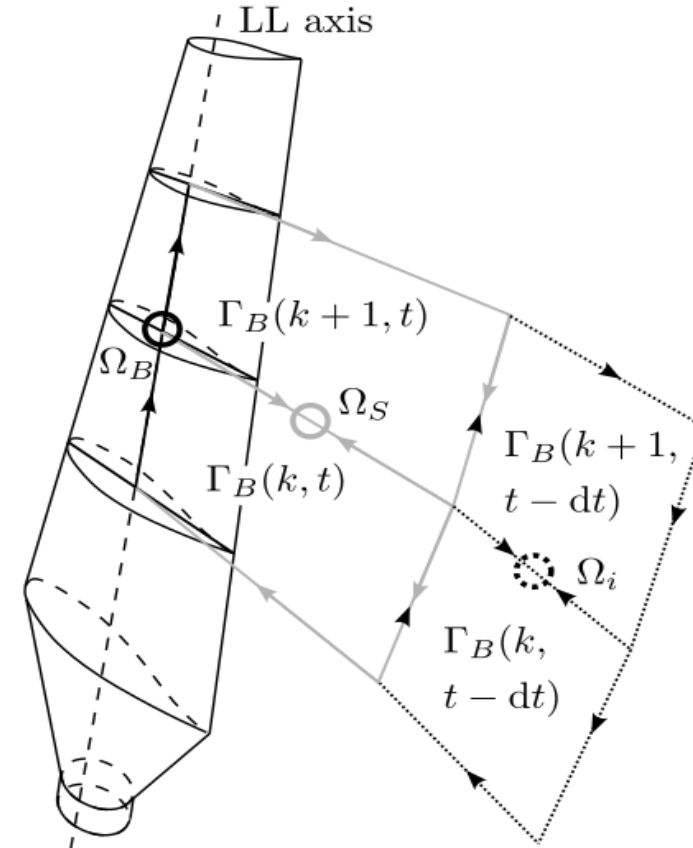
- ▶  $C_L$  : Lift coefficient

$$C_L = C_L(\alpha, Re)$$

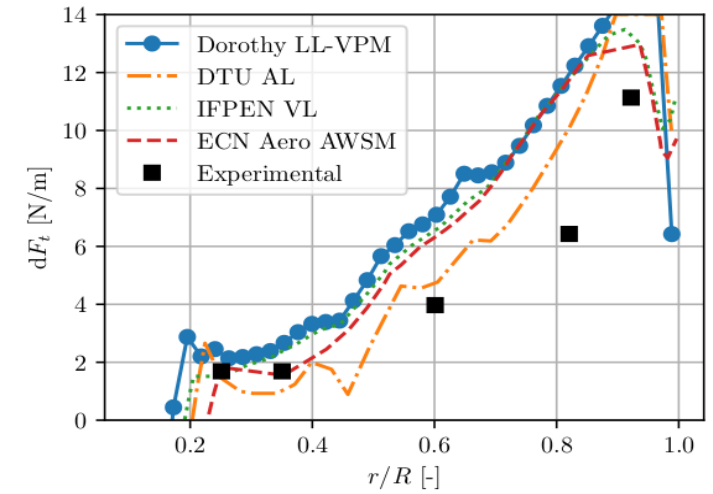
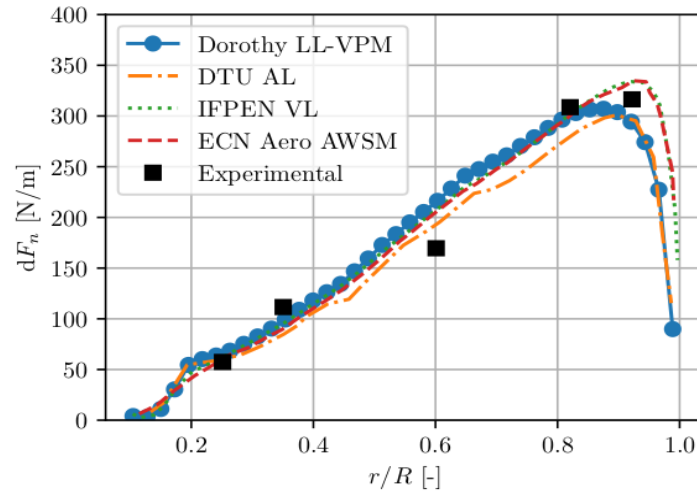
- ▶ Trailing and spanwise vorticity :

$$\Gamma_T\left(r - \frac{dr}{2}, t\right) = \frac{\partial \Gamma_B(r, t)}{\partial r} dr$$

$$\Gamma_S(r, t) = \frac{\partial \Gamma_B(r, t)}{\partial t} dt$$

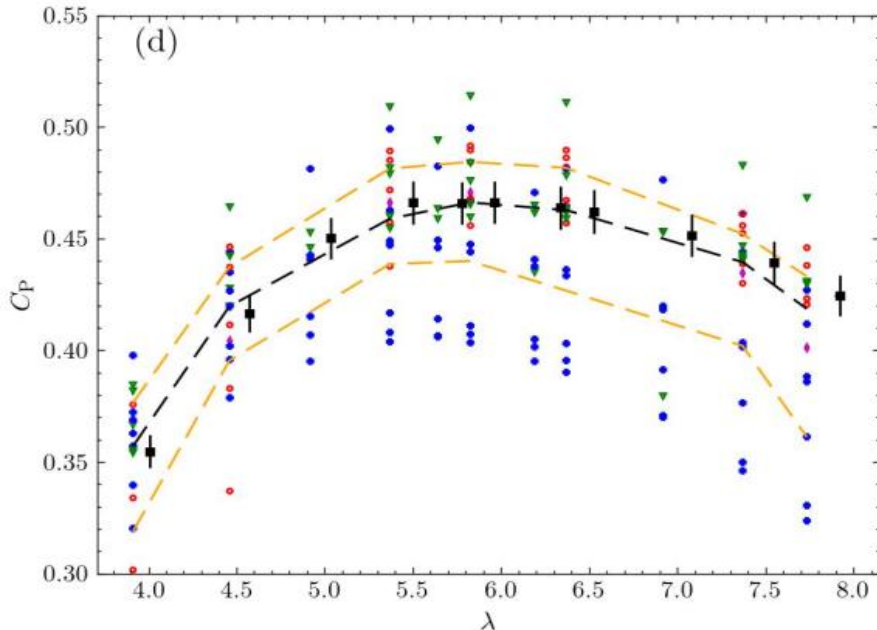


# Vers des configurations de plus en plus réalistes – performance des machines



(a) Normal to chord load  $F_{n,k}$

(b) Tangential to chord load  $F_{t,k}$

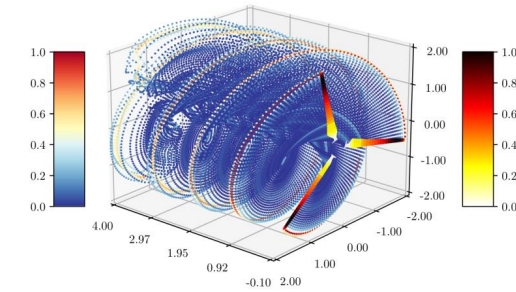


IEA Test case : MexNext III

Bonne performance sur distribution radiales

Benchmark à l'aveugle : Oxford Bench

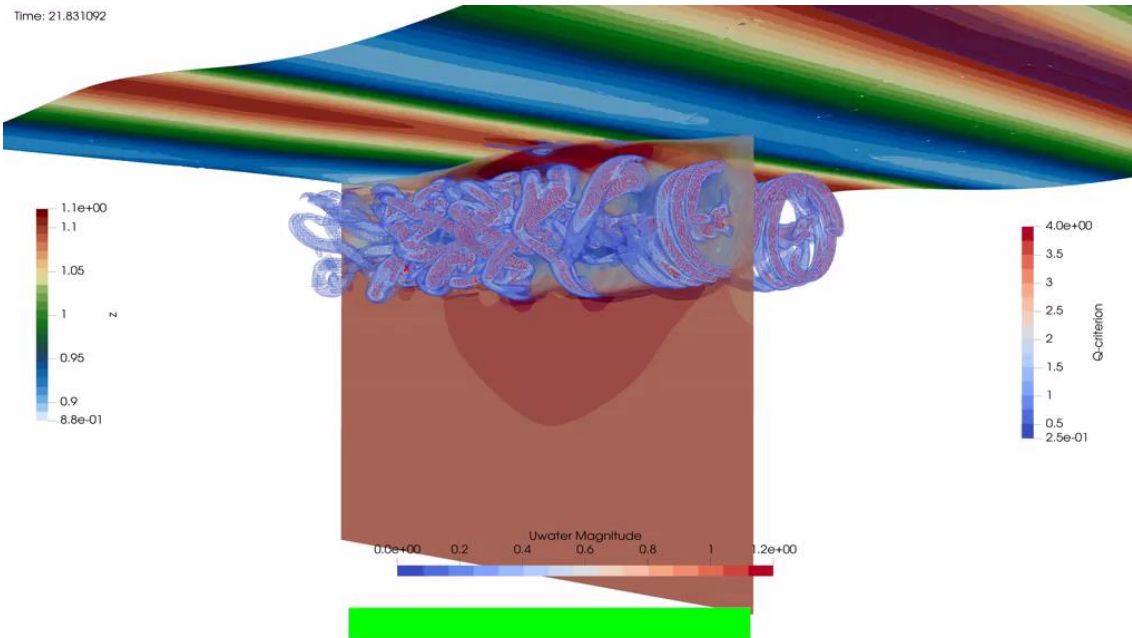
Très bon résultats vis à vis de l'expérience





# Vers des configurations de plus en plus réalistes – turbine / houle

Federico Zilic de Arcos – Post-doc Marie Skłodowska-Curie No 101034329.  
Recipient of the WINNINGNormandy Program supported by the Normandy Region.



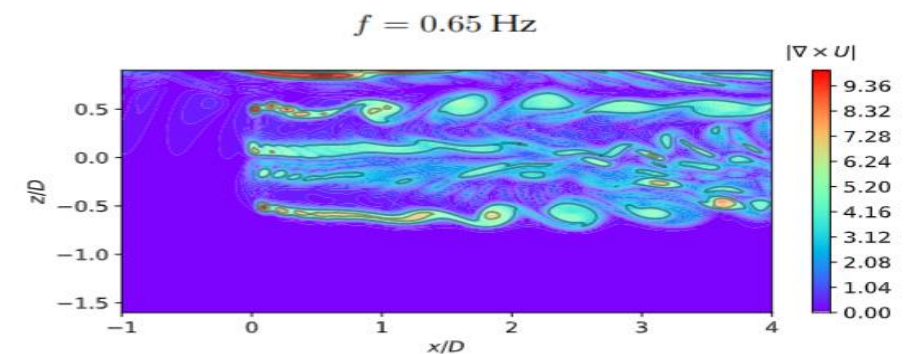
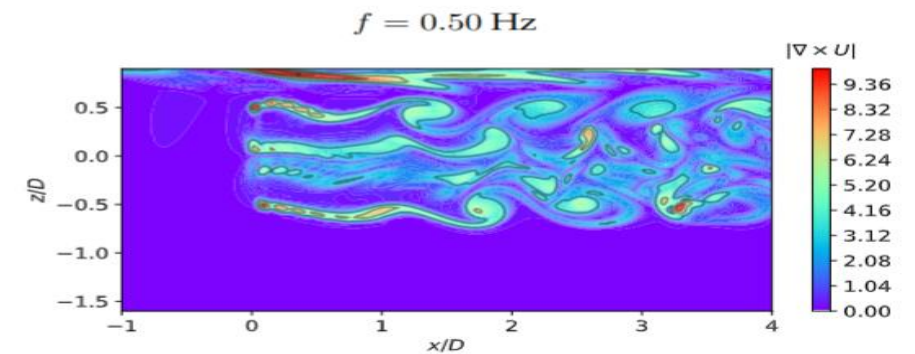
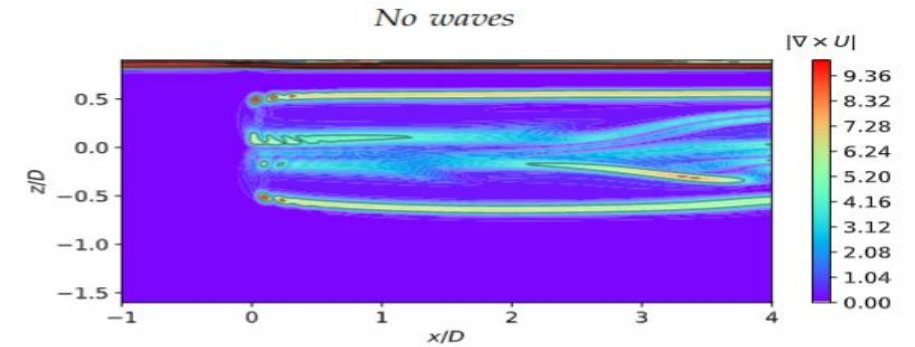
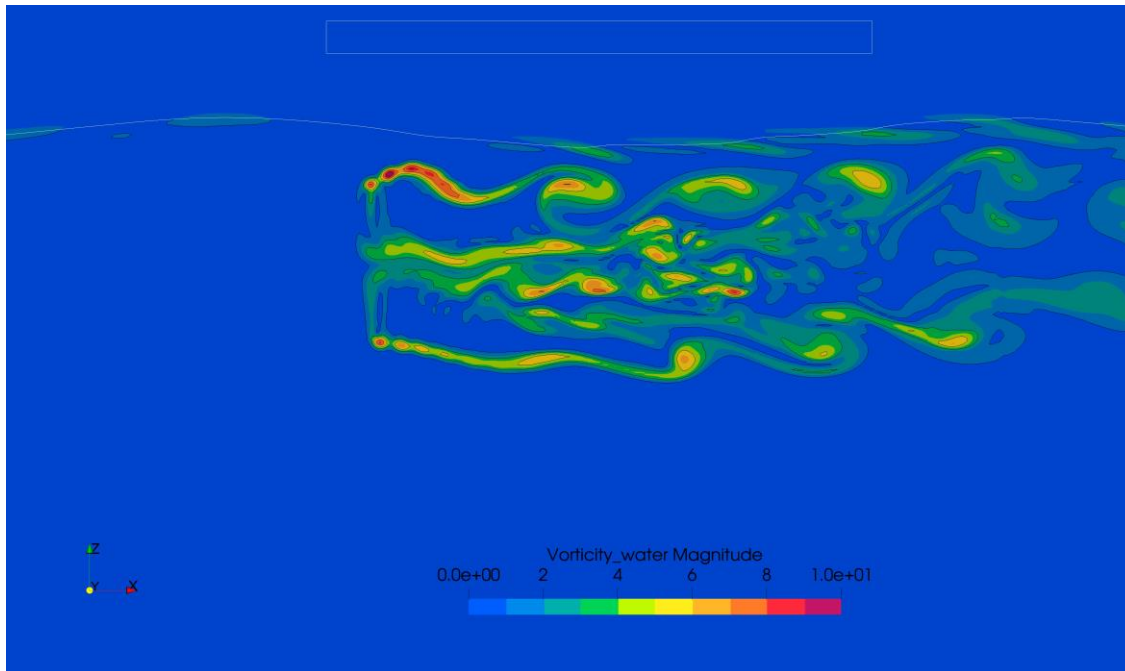
- **OpenFOAM v2012 + Volume-of-Fluid**
- **Stabilised k- $\omega$  SST** turbulence closure (Larsen & Fuhrman, 2018)
- **Waves2Foam** for wave generation/absorption (GABC)
- **Discretisation:**
  - 60 cells over rotor diameter
  - Over 150 cells per wavelength
  - 10 cells per wave height
- **Actuator line** rotor representation
  - Relatively new sampling technique

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 101034329.  
Recipient of the WINNINGNormandy Program supported by the Normandy Region.



# Vers des configurations de plus en plus réalistes – turbine / houle

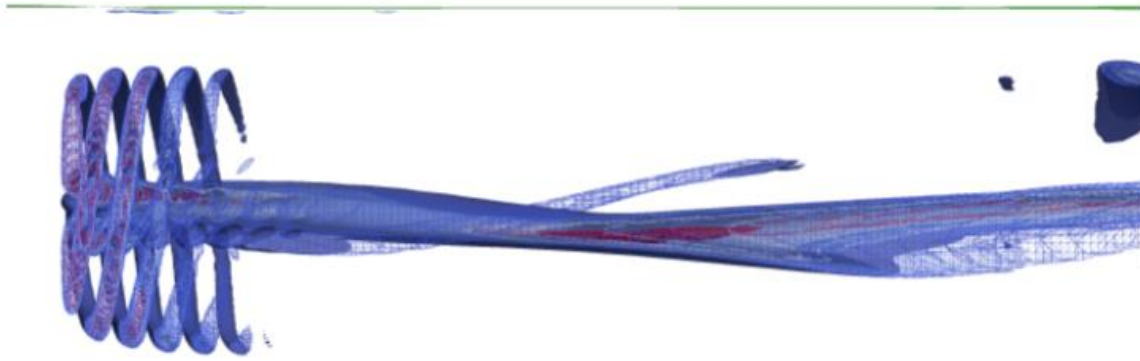
- Formation of large coherent structures due to the interaction between the rotor's wake and waves



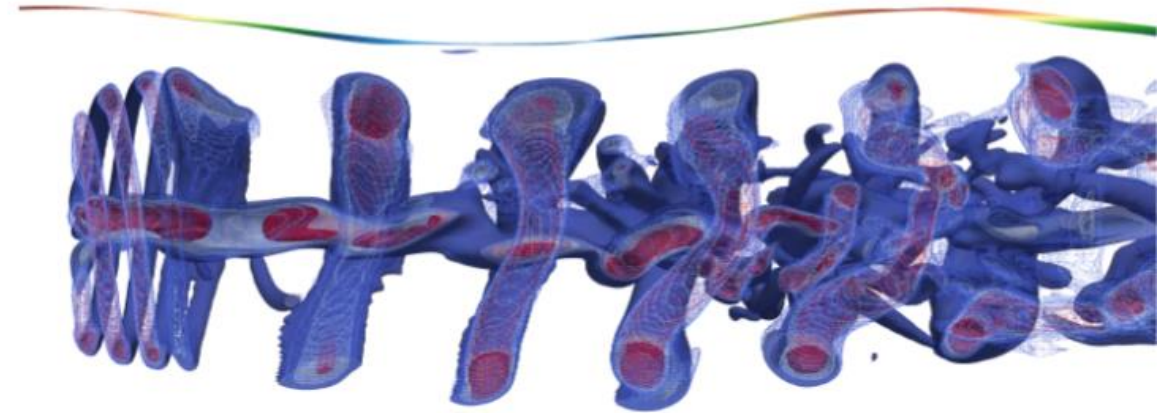


# Vers des configurations de plus en plus réalistes – turbine / houle

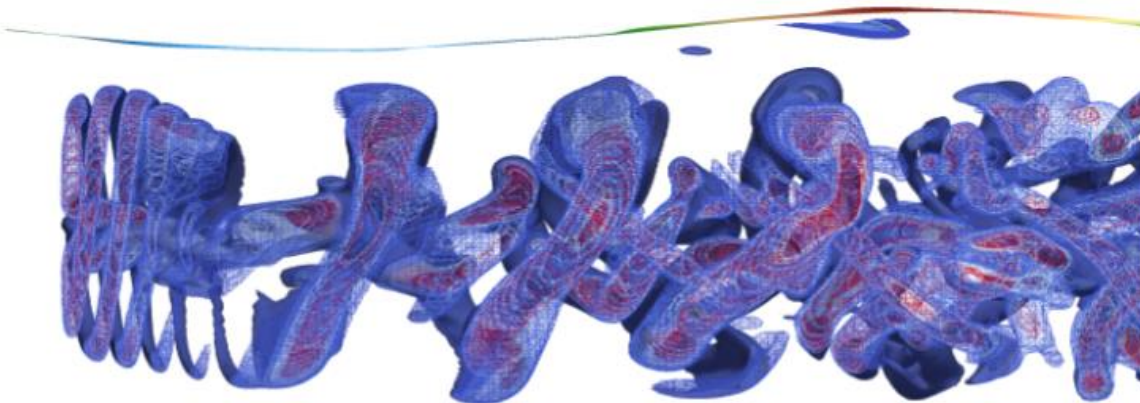
No waves



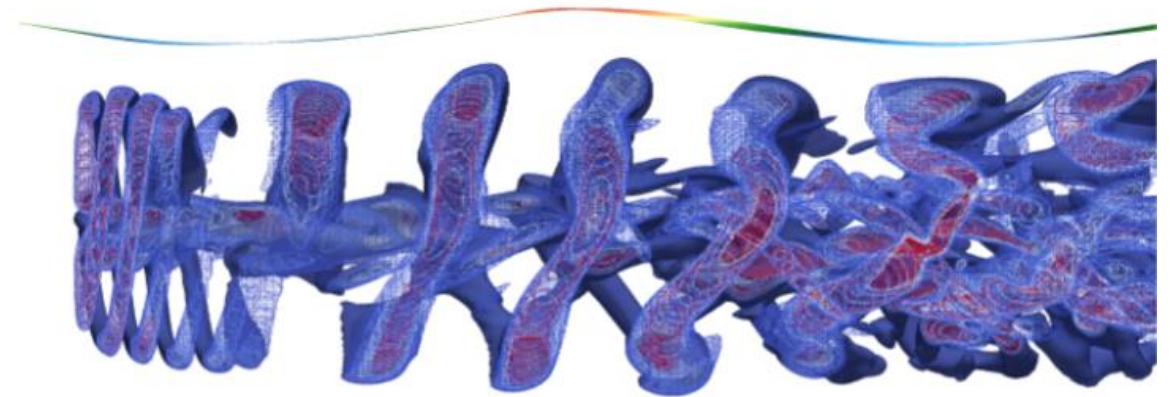
$f = 0.60$  Hz



$f = 0.50$  Hz



$f = 0.65$  Hz





# Plan de l'exposé

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- Introduction - Les premières thèses
- Vers des configurations de plus en plus réaliste
- **Conclusions et perspectives**

- Projet de GIS sur le logiciel DOROTHY (CNRS, ULHN, Ifremer)

Ifremer



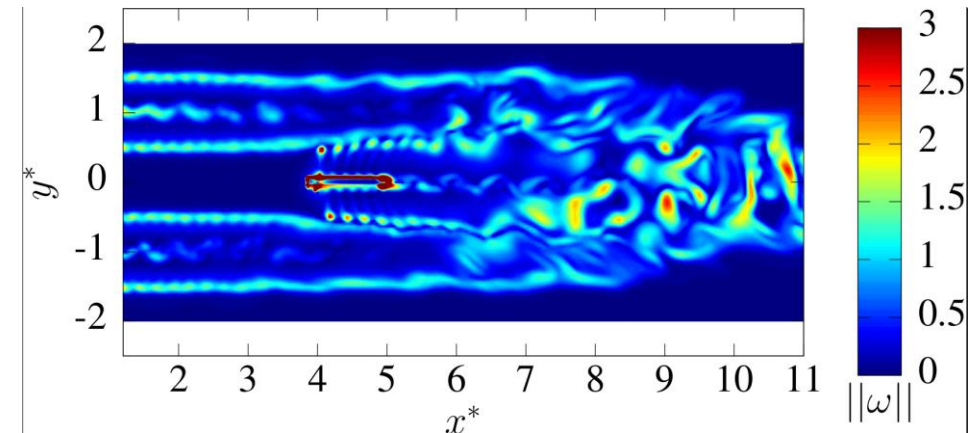
- Projet région Dorothy pour les futurs développements et la prise en compte de l'axe vertical



- Poursuite des travaux de benchmark avec le Oxford Bench #2



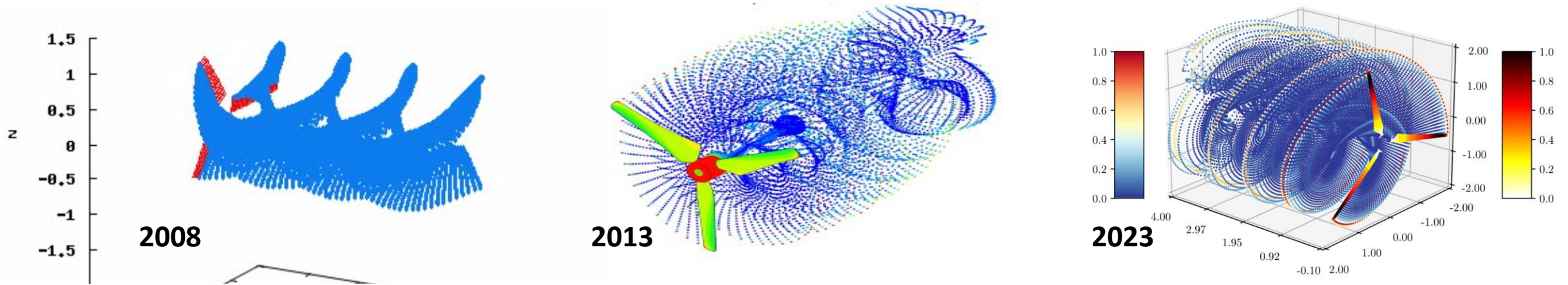
- Optimisation des performances dans le cadre du projet Labex EMC3 WILIAM





Inauguration du  
supercalculateur « Austral »

# Conclusions et perspectives



- Un grand merci au CRIANN :
  - Pour toute leur aide sur les développements
  - Pour leur expertise sur les optimisations
  - Pour leur disponibilité
- C'est un excellent service pour la recherche.



# Conclusions et perspectives

1. M. Slama, C. Choma Bex, G. Pinon, M. Togneri, and I. Evans. Lagrangian vortex computations of a four tidal turbine array : an example based on the NEPTHYD layout in the alderney race. *Energies*, 14(13), 2021.
2. M. Slama, G. Pinon, C. El Hadjo, M. Togneri, B. Gaurier, G. Germain, J.-V Facq, J. Nuno, P. Mansilla, E. Nicolas, J. Marcille, and A. Pacheco. Turbine design dependency to turbulence : an experimental study of three scaled tidal turbines. *Ocean Engineering*, 234 :109035, 2021
3. C. Choma Bex, C. Carlier, A. Fur, G. Pinon, G. Germain, and E. Rivoalen. A stochastic method to account for the ambient turbulence in lagrangian vortex computations. *Applied Mathematical Modelling*, 88 :38 – 54, 2020 - IF : 2.350, citation : 0.
4. M. Togneri, G. Pinon, C. Carlier, C. Choma Bex, and I. Masters. Comparison of synthetic turbulence approaches for blade element momentum theory prediction of tidal turbine performance and loads. *Renewable Energy*, 145 :408 – 418, 2020 - IF : 4.357, citation : 3.
5. C. Choma Bex, G. Pinon, M. Slama, B. Gaston, G. Germain, and E. Rivoalen. Lagrangian vortex computations of turbine wakes: recent improvements using poletto's synthetic eddy method (SEM) to account for ambient turbulence. *Journal of Physics : Conference Series*, 1618 :062028, sep 2020 - référencé par Scopus, citation : 0.
6. B. Gaurier, C. Carlier, G. Germain, G. Pinon, and E. Rivoalen. Three tidal turbines in interaction : An experimental study of turbulence intensity effects on wakes and turbine performance. *Renewable Energy*, 148 :1150 – 1164, 2020 - IF : 4.357, citation : 5.
7. M. Togneri, G. Pinon, C. Carlier, C. Choma Bex, and I. Masters. Comparison of synthetic turbulence approaches for blade element momentum theory prediction of tidal turbine performance and loads. *Renewable Energy*, 145 :408 – 418, 2020 - IF : 4.357, citation : 3.
8. P. Mycek, G. Pinon, C. Lothodé, A. Dezotti, and C. Carlier. Iterative solver approach for turbine interactions: application to wind or marine current turbine farms. *Applied Mathematical Modelling*, 41 :331 – 349, 2017 - IF : 2.350, citation : 5.
9. G. Pinon, M. Fernández Hursto, and E. Lukebao. Semi-analytical estimate of energy production from a tidal turbine farm with the account of ambient turbulence. *International Journal of Marine Energy*, 19 :70 – 82, 2017 - IF : –, citation : 1.

# Conclusions et perspectives

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1. G. Pinon, C. Carlier, A. Fur, B. Gaurier, G. Germain, and E. Rivoalen. Account of ambient turbulence for turbine wakes using a synthetic-eddy-method. *Journal of Physics : Conference Series*, 854(1) :012016, 2017 - référencé par Scopus, citation : 0.
2. P. Mycek, G. Pinon, G. Germain, and E. Rivoalen. Formulation and analysis of a diffusion-velocity particle model for transport-dispersion equations. *Computational and Applied Mathematics*, 35(2) :447–473, 2016 - IF : 0.961, citation : 8.
3. P. Mycek, B. Gaurier, G. Germain, G. Pinon, and E. Rivoalen. Experimental study of the turbulence intensity effects on marine current turbines behaviour. part I : One single turbine. *Renewable Energy*, 66(0) :729 – 746, 2014 - IF : 4.357, citation : 159.
4. P. Mycek, B. Gaurier, G. Germain, G. Pinon, and E. Rivoalen. Experimental study of the turbulence intensity effects on marine current turbines behaviour. part II : Two interacting turbines. *Renewable Energy*, 68(0) :876 – 892, 2014 - IF : 4.357, citation : 88.
5. P. Mycek, G. Pinon, G. Germain, and E. Rivoalen. A self-regularising DVM–PSE method for the modelling of diffusion in particle methods. *Comptes Rendus Mécanique*, 341(9–10) :709 – 714, 2013 - IF : 1.029, citation : 3.
6. P. Mycek, B. Gaurier, G. Germain, G. Pinon, and E. Rivoalen. Numerical and experimental study of the interaction between two marine current turbines. *International Journal of Marine Energy*, 1(0):70 – 83, 2013 - référencé par Scopus, citation: 46.
7. G. Pinon, P. Mycek, G. Germain, and E. Rivoalen. Numerical simulation of the wake of marine current turbines with a particle method. *Renewable Energy*, 46(0):111 – 126, 2012 - IF: 4.357, citation: 39
8. Maganga, G. Germain, J. King, G. Pinon, and E. Rivoalen. Experimental characterisation of flow effects on marine current turbine behaviour and on its wake properties. *IET Renewable Power Generation*, 4(6) :498–509, 2010 - IF : 1.562, citation : 98.