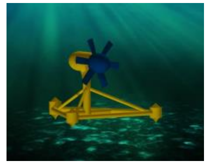



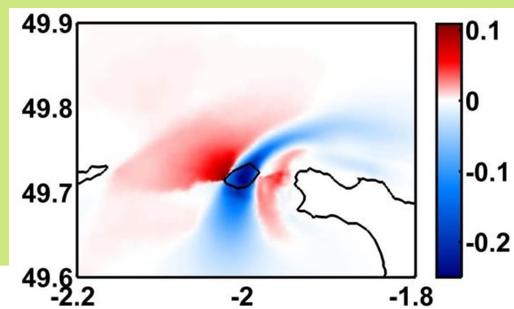


Modelling the effect of an array of tidal turbines with depth-averaged Actuator Disks

Jérôme Thiébot[1], Sylvain Guillou[1] , Van Thinh NGuyen[1,2]

1.LUSAC (Université de Caen)
60 rue Max Pol Fouchet - CS 20082
50130 Cherbourg-Octeville
jerome.thiebot@unicaen.fr
http://www.unicaen.fr/lusac/

2. Hanoï University of Mining and Geology



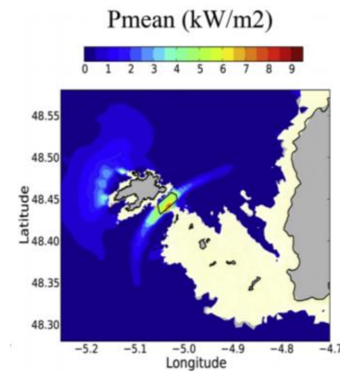
université de Caen
Basse-Normandie

Introduction

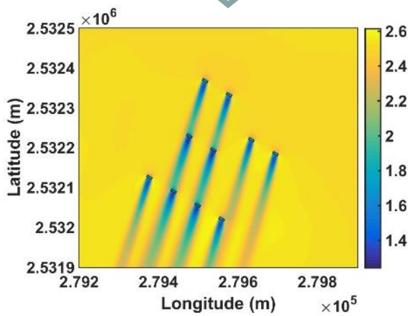
Modelling the effect of tidal turbines on the hydrodynamics is required for:

Assessing the energy production potential

Ressource assessment **considering the effect of the turbines** (on the current and the turbulence)



Guillou and Thiébot (2016, Energy)



Simulation 3D d'hydroliennes dans le Raz blanchard (Thiébot)

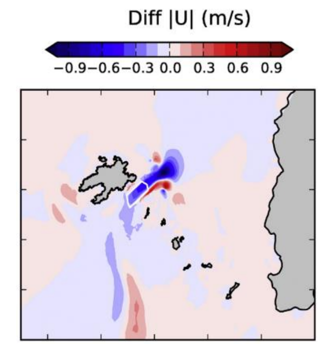
Optimizing the arrangement of turbines placed in array

Aligned layout / Staggered layout / other ?

Optimal turbine density ?

Assessing the effect of large arrays on the hydrodynamics and the sediment transport

Environmental impact (far-field effects)

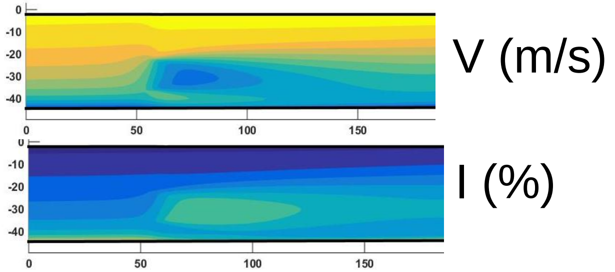


Guillou and Thiébot (2016, Energy)

A highly multiscale problem !

At the turbine scale (o(s) – o(m))

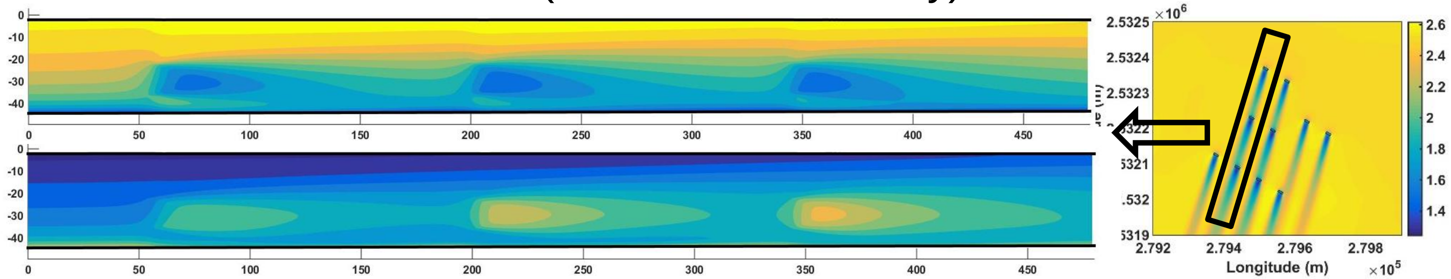
- Blocage effects → Increased velocity around the turbine & Reduced velocity besides the turbine
- Turbulence generation in the wake of the turbine
- Flow recovery (highly dependent on the turbulence)



Simulation 3D d'hydroliennes dans le Raz Blanchard (Thiébot)

At the scale of the tidal farm (o(s) – o(m))

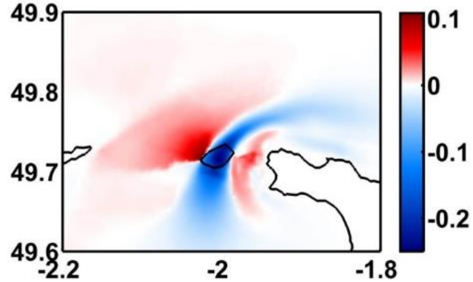
- Wake interactions (turbulence & velocity)



Simulation 3D d'hydroliennes dans le Raz blanchard (Thiébot)

At the regional scale (o(days) – o(km))

- Tide / Meteorological effects / Waves
- Blocage effects → Reduced velocity in the farm & Increased velocity on each side of the farm
- Far-field effect of the array of turbines

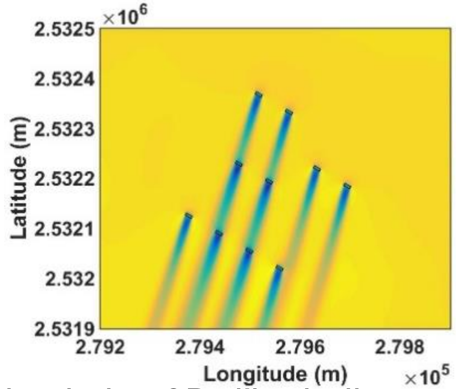


Thiébot et al. (2015, Ren En)

Turbine representation in RANS models

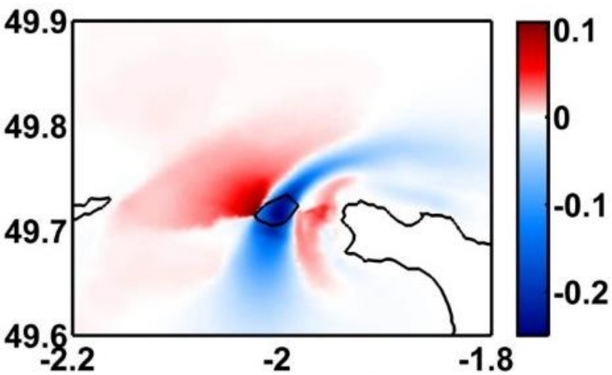
Two popular methods for representing the turbine in regional RANS models (e.g. Telemac, MARS, ROMS, Delft…) :

- The Actuator Disk (AD)
  - 3D
  - Each horizontal-axis turbine is represented individually



Simulation 3D d'hydroliennes dans le Raz Blanchard avec des AD

- The « bed friction » or « enhanced drag »
  - Mostly 2D
  - The tidal farm is represented as a whole



Thiébot et al. (2015, Ren En)

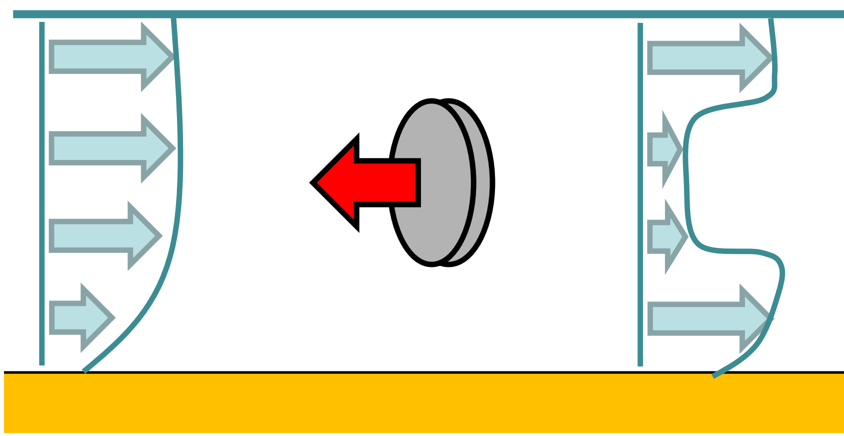
the Actuator Disk concept

Modelling a turbine with an AD

- 3D approach
- RANS + sink term $\boxed{\boldsymbol{f}}$

$$\nabla.\boldsymbol{u} = 0$$

$$\frac{\partial \boldsymbol{u}}{\partial t} + u\nabla\boldsymbol{u} = -\frac{1}{\rho}\nabla p + g + \nabla.(\upsilon\nabla\boldsymbol{u}) + \boxed{\boldsymbol{f}}$$



$$\boxed{f = -\frac{1}{2}\frac{\rho K}{T_{Disk}}u_d{}^2}$$

Local velocity

or

$$\boxed{f = -\frac{1}{2}\frac{\rho C_T}{T_{Disk}}u_\infty{}^2}$$

Upstream velocity

- Turbulence model parameterisation (e.g. Nguyen et al., 2016 Ren En)
  → sink / source term in the disk to represent the turbulence production

université de Caen Basse-Normandie

The Bed friction method

Modelling an arrays with the « bed friction » approach

- Mostly 2D applications
  - RANS + sink term

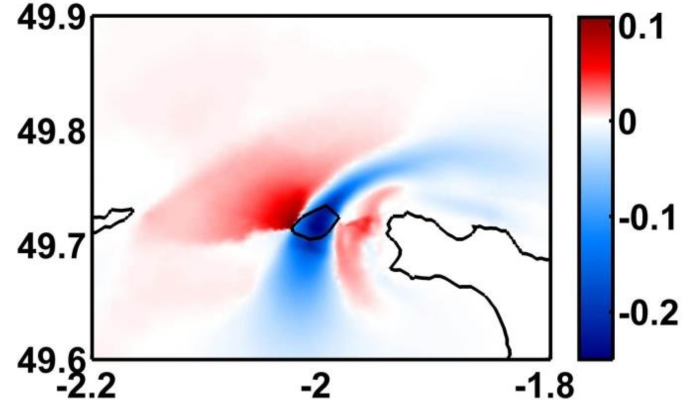
$$\frac{\partial H}{\partial t} + U\frac{\partial H}{\partial x} + V\frac{\partial H}{\partial y} + H\left(\frac{\partial U}{\partial x} + \frac{\partial V}{\partial y}\right) = 0$$

2D

$$\frac{\partial U}{\partial t} + U\frac{\partial U}{\partial x} + V\frac{\partial U}{\partial y} = -g\frac{\partial Z_s}{\partial x} + \frac{1}{H}\left(\frac{\partial}{\partial x}\left(H\upsilon\frac{\partial U}{\partial x}\right) + \frac{\partial}{\partial y}\left(H\upsilon\frac{\partial U}{\partial y}\right)\right) + \boxed{F_x}$$

$$\frac{\partial V}{\partial t} + U\frac{\partial V}{\partial x} + V\frac{\partial V}{\partial y} = -g\frac{\partial Z_s}{\partial y} + \frac{1}{H}\left(\frac{\partial}{\partial x}\left(H\upsilon\frac{\partial V}{\partial x}\right) + \frac{\partial}{\partial y}\left(H\upsilon\frac{\partial V}{\partial y}\right)\right) + \boxed{F_y}$$

$$\boxed{\vec{F}} = -\frac{1}{2}n\rho(C_T A_{Bal} + C_D A_{Proj})\vec{U}\|\vec{U}\|$$



Thiébot et al. (RenEn 2015)

Modelling an array of turbines

	Actuator Disks	Bed friction
☺	- 3D hydrodynamics (blocage effects) - Realistic velocity prediction in the far wake in the far wake (x>5D) - Realistic turbulence prediction in the far wake (x>5D) - Flow interactions between turbines - Validation with flume experiments	- Realistic tidal flows - Possibility to model large array of turbines - Low computational expense (it is possible to simulate several weeks)
☹	**- Computational expense (mesh size o(m))** →Schematic flow configurations →Schematic coastal geometries	- Simple turbine representation (the force is evenly distributed over the tidal farm) **→ the flow interactions between turbines are neglected**

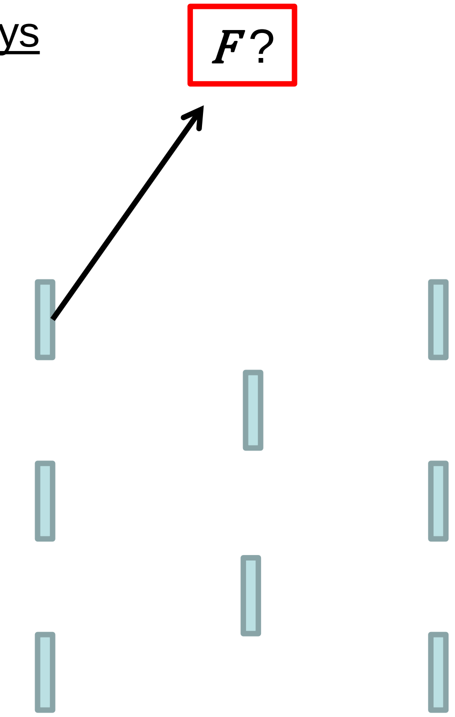
université de Caen Basse-Normandie

Objectives

We propose a new approach for modelling arrays of turbines.

The requirements are :

- <u>Modelling realistic tidal flows (long simulations) and large arrays</u>
  - → Regional tidal model based on the SWE (2D)
- <u>Modelling the flow interactions between the turbines</u>
  - → Modelling the each turbine individually
  - → Each turbine is a rectangle of sink momentum



How can we calculate the sink momentum ?

→ **We propose to use <u>depth-averaged AD</u>**

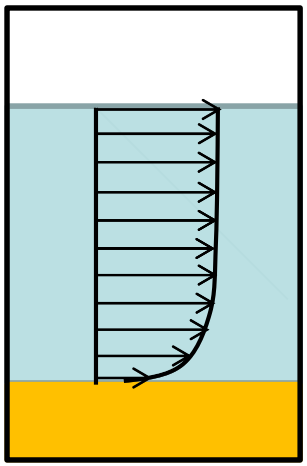
Plan of the talk

1. Mathematical background
2. Model validation
3. Application to the Alderney Race

   Comparison Bed friction vs. Depth-averaged AD

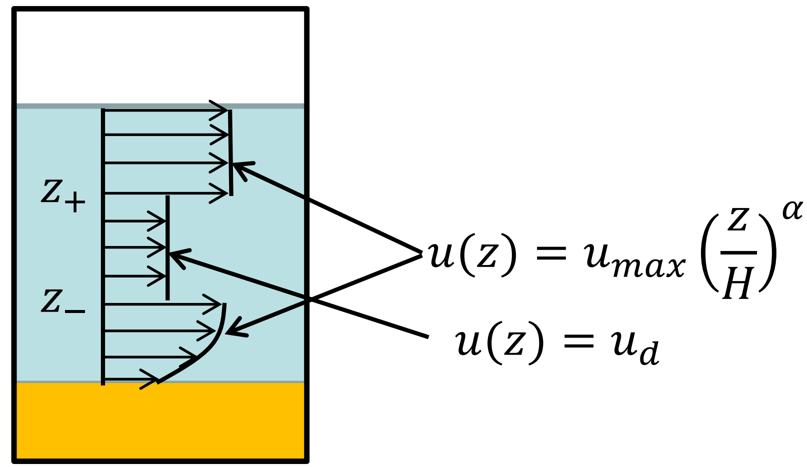
Mathematical background

Hypothesis n°1
<u>In the free stream</u>



$$u(z) = u_{max}\left(\frac{z}{H}\right)^{\alpha}$$

Hypothesis n°2
<u>In the area occupied by the turbine</u>



No vertical blockage effect

3D volumetric force : $f = -\frac{1}{2}\frac{\rho K}{T_{Disk}}{u_d}^2$

Depth-averaged force: $F = \frac{1}{H}\int_0^H -\frac{1}{2}\frac{\rho K}{T_{Disk}}u^2 dz = -\frac{1}{2}\frac{\rho K}{T_{Disk}}\frac{\Delta z}{H}{u_d}^2$

université de Caen Basse-Normandie

Mathematical background

$$F = -\frac{1}{2}\frac{\rho K}{T_{Disk}}\frac{\Delta z}{H}{u_d}^2 \qquad (1)$$

$$U_d = \frac{1}{H}\int_0^H u dz = \frac{1}{H}\left(u_d \Delta z + u_{max} H\left(1 - (z_+/H)^{\alpha+1} + \frac{(z_-/H)^{\alpha+1}}{\alpha+1}\right)\right) \qquad (2)$$

$$u_\infty(z = H/2) = u_{max}(1/2)^\alpha$$

Turbine at mid-depth

$$u_\infty(z = H/2) = (1 + 0.25K)u_d$$

Taylor (1963)
Hypothesis n°3

(1) & (2) $\Rightarrow$

$F(u_d)$ $u_d(U_d)$

$$F(U_d) = -\frac{\rho K {U_d}^2}{2T_{Disk}} \frac{\frac{\Delta z}{H}}{\left(\frac{\Delta z}{H} + \frac{(1 + 0.25K)}{(1/2)^\alpha}\left(1 - \left(\frac{z_+}{H}\right)^{\alpha+1} + \frac{\left(\frac{z_-}{H}\right)^{\alpha+1}}{\alpha+1}\right)\right)^2}$$

$$\Delta z = z_+ - z_-$$

Model validation

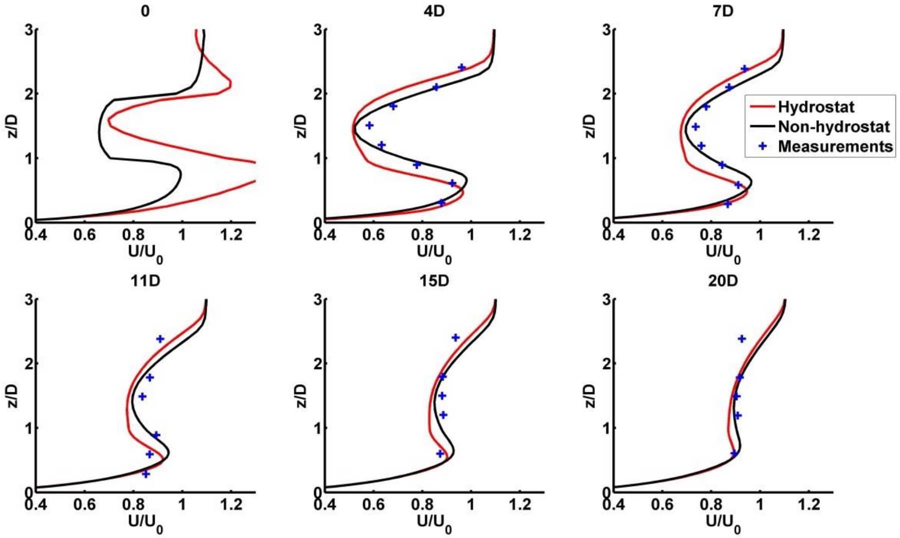
Comparison with the results of reference 3D models

Step 1 : validation of the reference 3D models

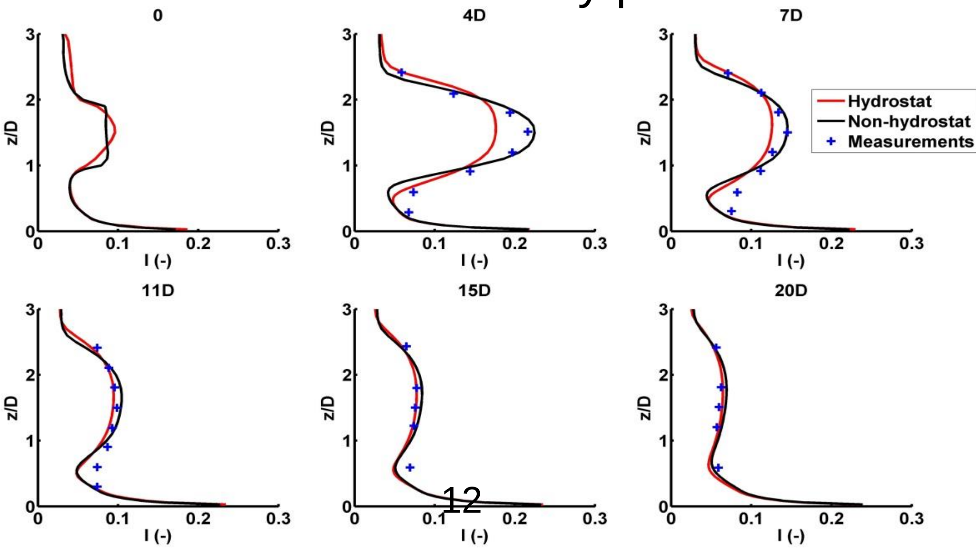
- Telemac3D hydrostatic & AD vs experimental data
- Telemac3D & AD vs experimental data

Myers and Bahaj (2010, Oc. Eng.)

Velocity deficit profiles



Turbulent intensity profiles

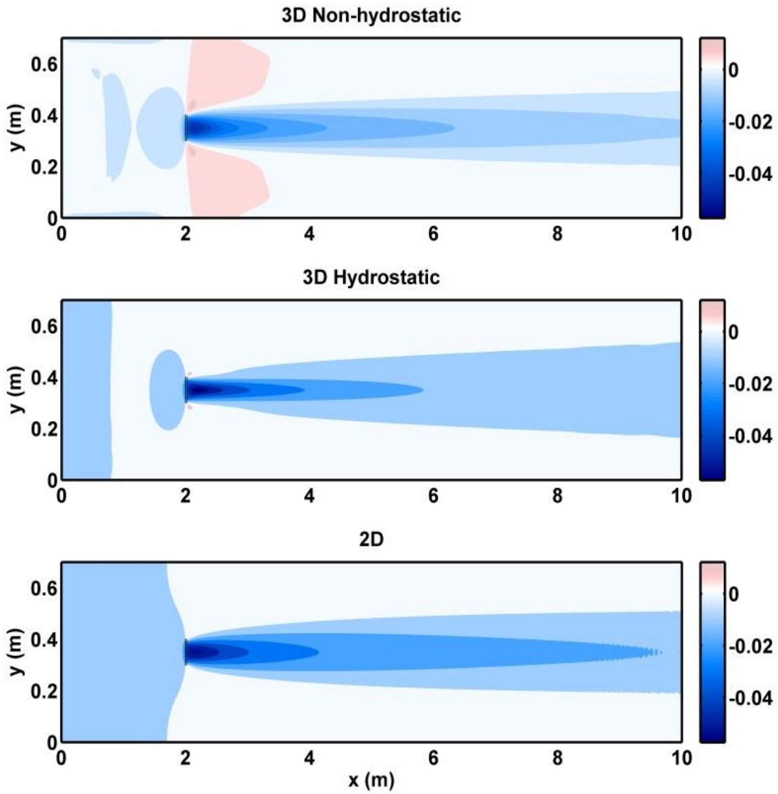


LUSAC

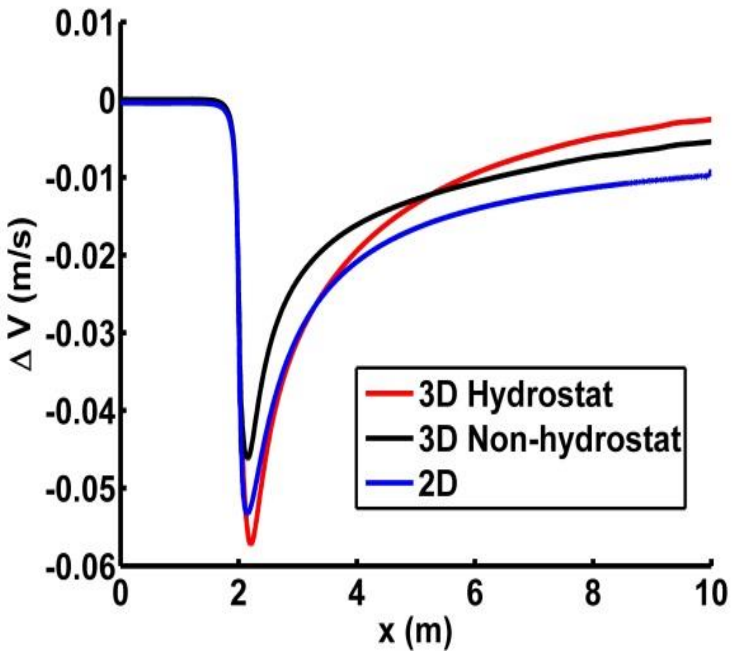
Model validation

Step 2 : depth-averaged AD vs. reference 3D models

The reference 3D model results have been depth-averaged



Horizontal distribution of the velocity deficit



Velocity deficit along the x-axis

UNICAEN
université de Caen Basse-Normandie

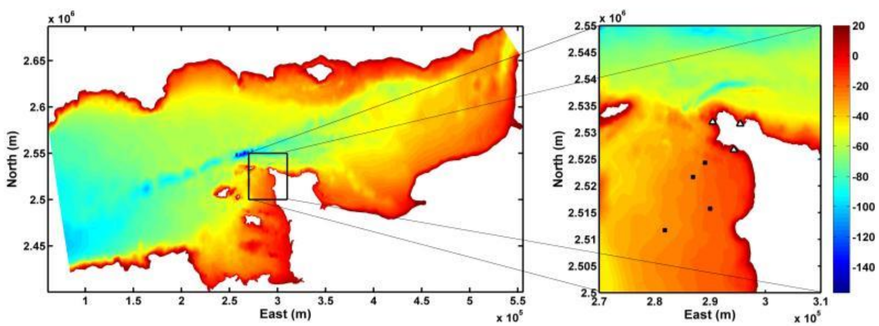
LUSAC

Application at regional scale

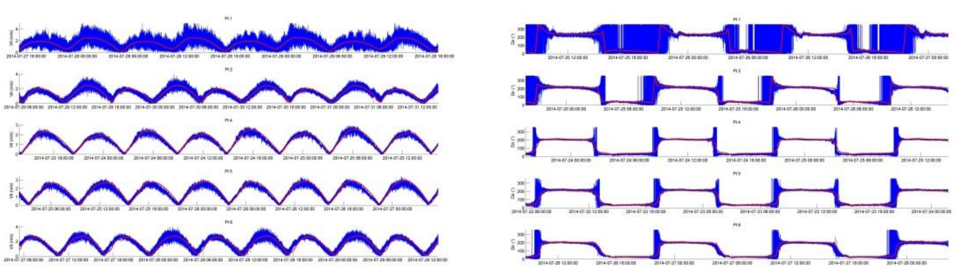
Integration of depth-averaged AD in a regional model

Regional model Telemac2D : SWE

Configuration of Thiébot et al. (2015, Ren. En.)



Telemac2D calculation domain



Model validation : Current velocity / direction
Model results vs. ADCP measurements

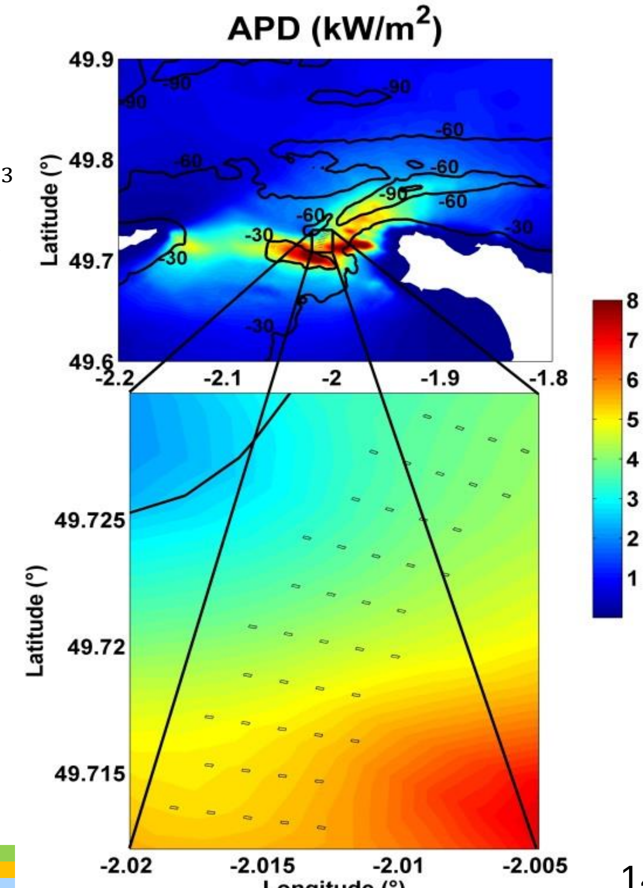
$$APD = \frac{1}{2}\rho U^3$$

Extraction scenario

45 turbines ; Staggered layout

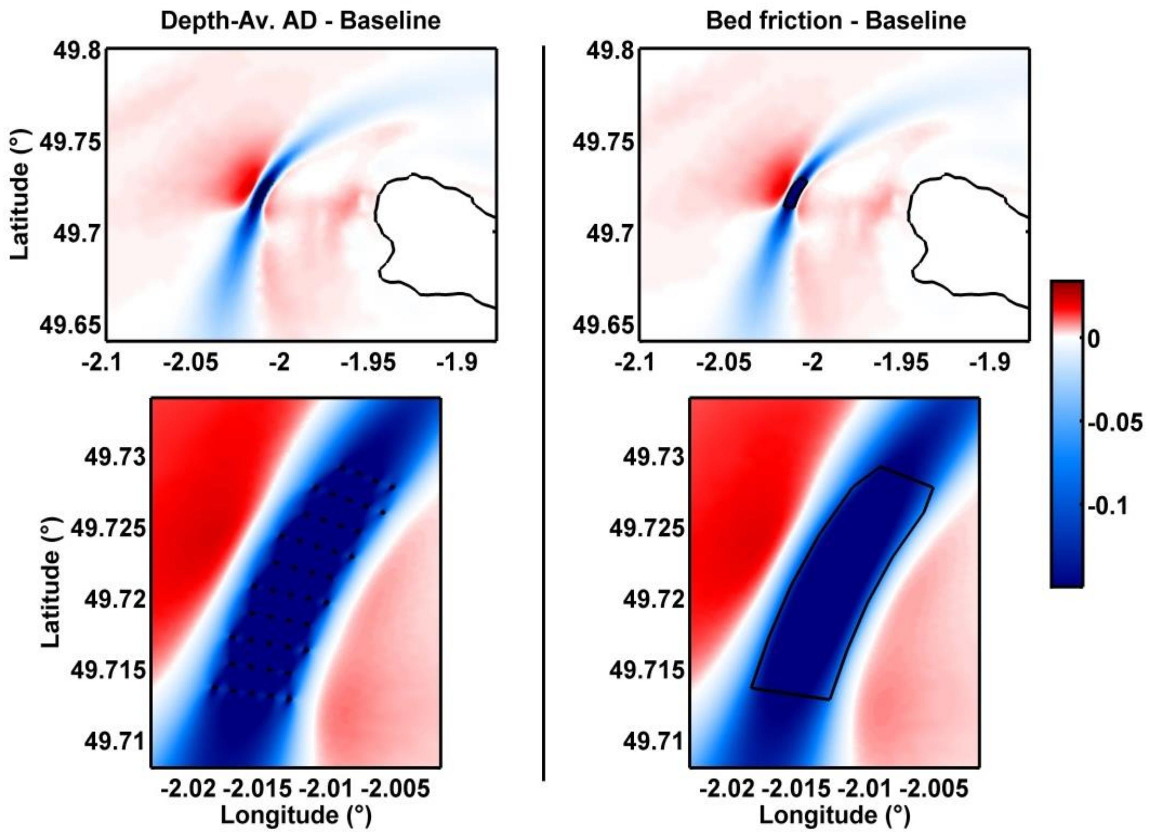
D = 20m & C_T=0.8

Lat/Long spacing : 5D/10D



LUSAC

Bed friction vs. Depth-avaraged AD



Horizontal distribution of the velocity deficit. Results are averaged over a tide (Thiébot et al., 2016, Oc Eng)

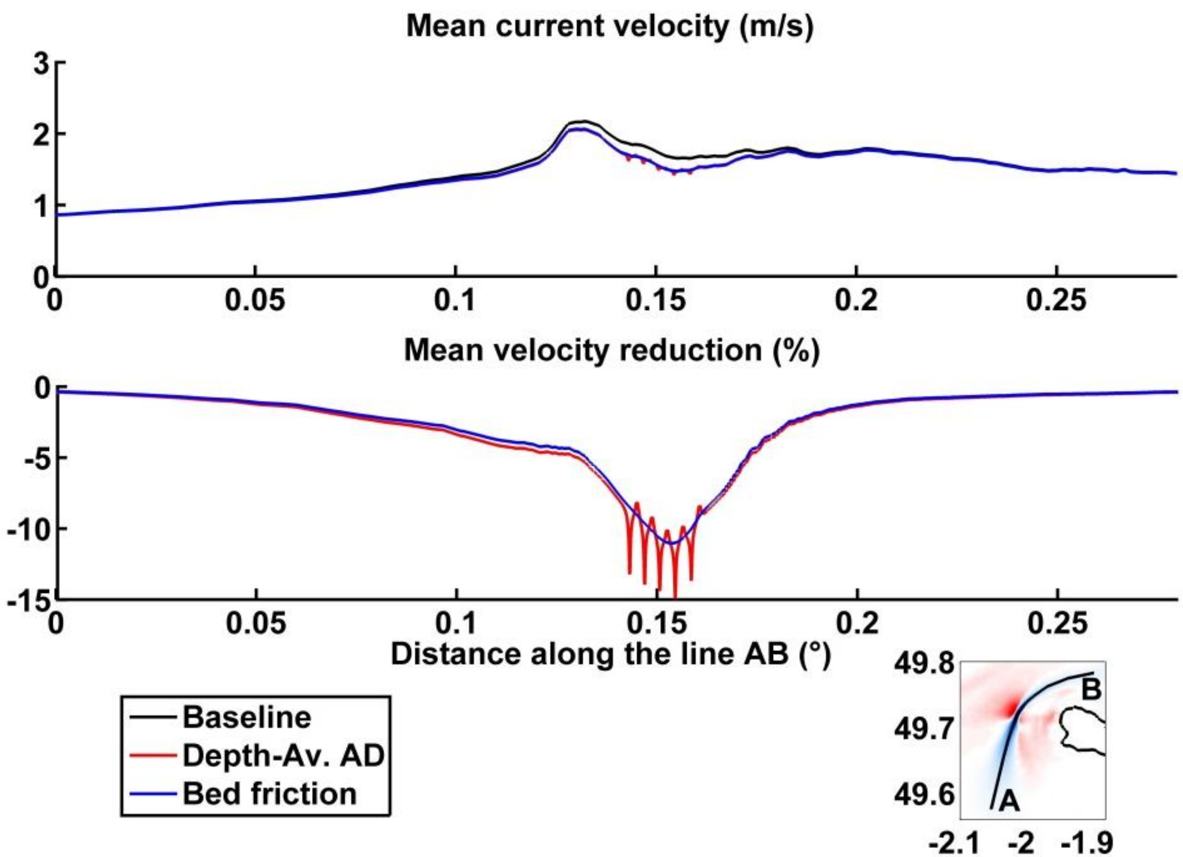
The depth-averaged AD and the bed friction approach give similar results

→ A 10% reduction of the velocity in the tidal farm & a slight acceleration on each side of the farm.

→ The flow interactions between turbines play a negligible role on the far-field effect

UNICAEN
université de Caen Basse-Normandie

Bed friction vs. Depth-avaraged AD

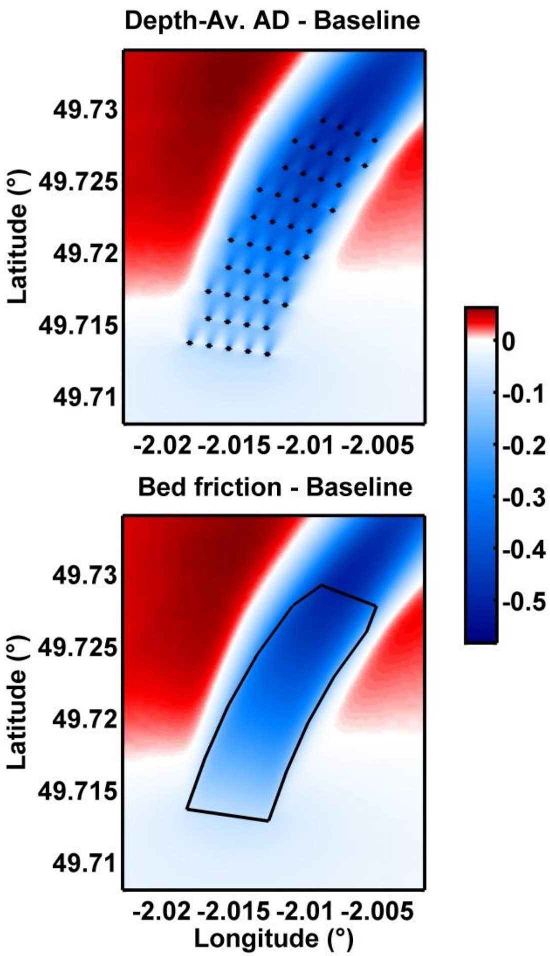


Velocity deficit along the line of maximal perturbation. Results are averaged over a tide (Thiébot et al., 2016, Oc Eng) .

The depth-averaged AD and the bed friction approach give similar results

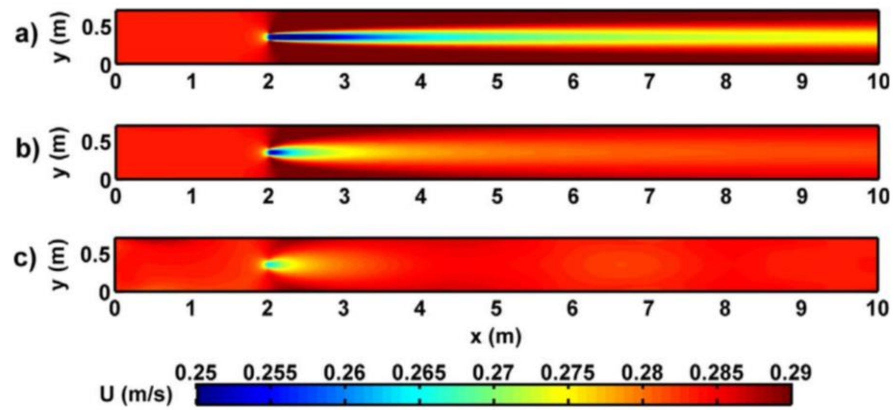
→ The depth-averaged AD predicts a slightly greater flow reduction

Bed friction vs. Depth-avaraged AD



- The wakes widen very rapidly
- A great flow recovery

→ Turbulence effect



I = 5%

I = 10%

I = 20%

- The « print » of a line of machine is rapidly erased.
- There is no clear interaction between machines.

→ In this case, the bed friction approach is appropriate

Velocity deficit along the line of maximal perturbation. Results correspond to the time when the tidal velocities are maximal (Thiébot et al., 2016, Oc Eng) .

université de Caen Basse-Normandie

Conclusion

- A new methodology for representing large arrays in bidimensionnal model.

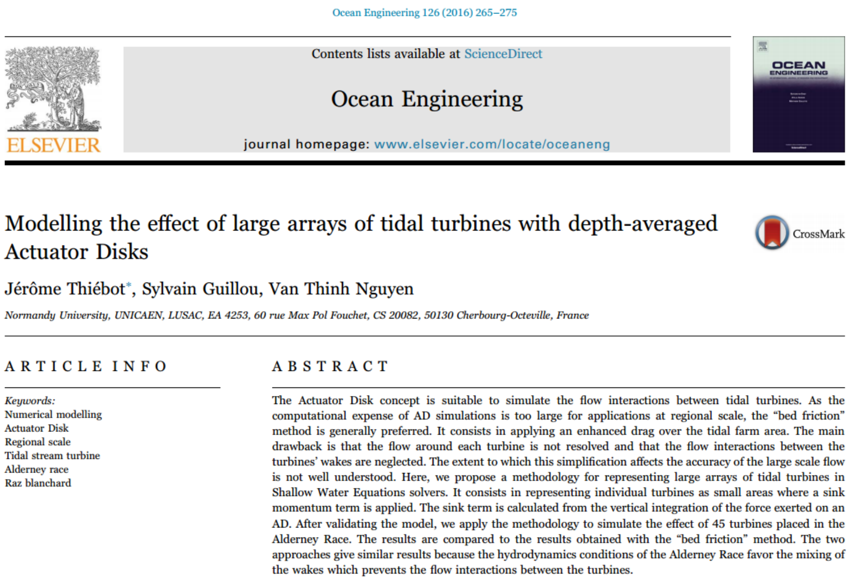
- It is hybrid method between AD and bed friction.

- Representing each turbine individually permits to account for the flow interactions between turbines.

- In the chosen configuration, the flow interactions between turbines are negligible.

université de Caen Basse-Normandie

Thank you. Do you have any question ?



Ocean Engineering 126 (2016) 265–275

Contents lists available at ScienceDirect

Ocean Engineering

journal homepage: www.elsevier.com/locate/oceaneng

Modelling the effect of large arrays of tidal turbines with depth-averaged Actuator Disks

Jérôme Thiébot*, Sylvain Guillou, Van Thinh Nguyen

Normandy University, UNICAEN, LUSAC, EA 4253, 60 rue Max Pol Fouchet, CS 20082, 50130 Cherbourg-Octeville, France

ARTICLE INFO

Keywords:
Numerical modelling
Actuator Disk
Regional scale
Tidal stream turbine
Alderney race
Raz blanchard

ABSTRACT

The Actuator Disk concept is suitable to simulate the flow interactions between tidal turbines. As the computational expense of AD simulations is too large for applications at regional scale, the "bed friction" method is generally preferred. It consists in applying an enhanced drag over the tidal farm area. The main drawback is that the flow around each turbine is not resolved and that the flow interactions between the turbines' wakes are neglected. The extent to which this simplification affects the accuracy of the large scale flow is not well understood. Here, we propose a methodology for representing large arrays of tidal turbines in Shallow Water Equations solvers. It consists in representing individual turbines as small areas where a sink momentum term is applied. The sink term is calculated from the vertical integration of the force exerted on an AD. After validating the model, we apply the methodology to simulate the effect of 45 turbines placed in the Alderney Race. The results are compared to the results obtained with the "bed friction" method. The two approaches give similar results because the hydrodynamics conditions of the Alderney Race favor the mixing of the wakes which prevents the flow interactions between the turbines.

- Thiébot J., Guillou S.S., Nguyen V.T. (2016). Ocean Engineering, 126, pp. 265-275. *Modelling the effect of large arrays of tidal turbines with depth-averaged Actuator Disks*
- Guillou N., Thiébot J. (2016) *The impact of seabed rock roughness on tidal stream power extraction*. Energy, 112, pp. 762-773.
- Nguyen V.T., Guillou S.S., Thiébot J., Santa Cruz A. (2016) *On the use of turbulent models for simulating the flow behind a tidal turbine represented by a parous media*. Renewable Energy, 97, pp. 625-635.
- Thiébot J., Bailly du Bois P., Guillou S. (2015) *Numerical modeling of the effect of tidal stream turbines on the hydrodynamics and the sediment transport - Application to the Alderney Race (Raz Blanchard), France*. Renewable Energy, 75, pp. 356-365.

université de Caen Basse-Normandie