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# On the modelling of WECs in wave models using far field coefficients

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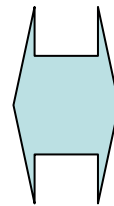
# Context

- > Environmental impact of wave energy converters and WEC arrays on the wave climate at regional scale
- > Numerical tools:

**Time domain models (SWAN, Artemis, Mild)**

- efficient to model wave propagation and transformation (variable bathymetry) over large domains ( $\sim 100 \text{ km}^2$ )
- WECs modeling: empirically calibrated sinks and sources coefficients. Approach not theoretically supported

**How to couple both approaches to make the best use of their strenghts and avoid their weaknesses?**

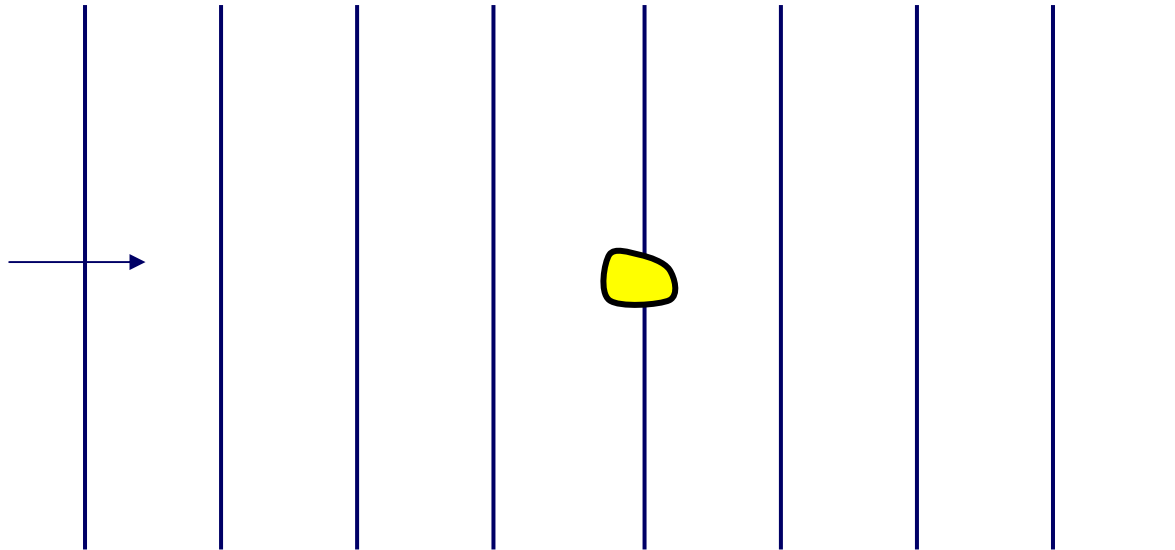


**on linear VAMIT, ..)**

- efficient to model physical processes involved in wave energy absorption ( $0.1 \text{ km}^2$ )
- Small domain of investigation due to computational resources

# Methodology

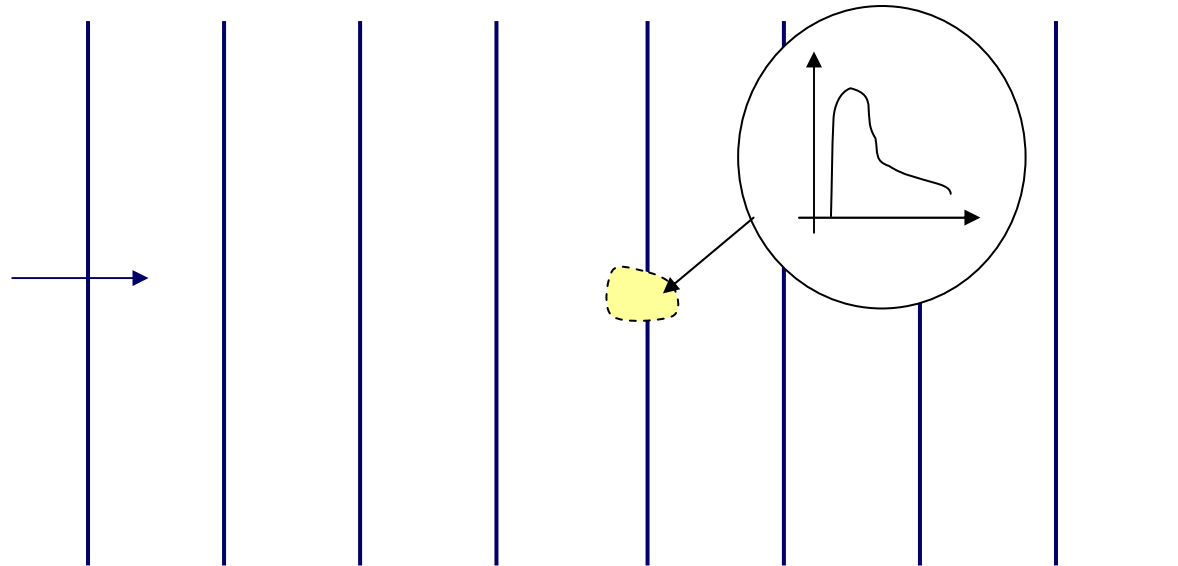
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**Coupling wave models and BEM:**

# Methodology

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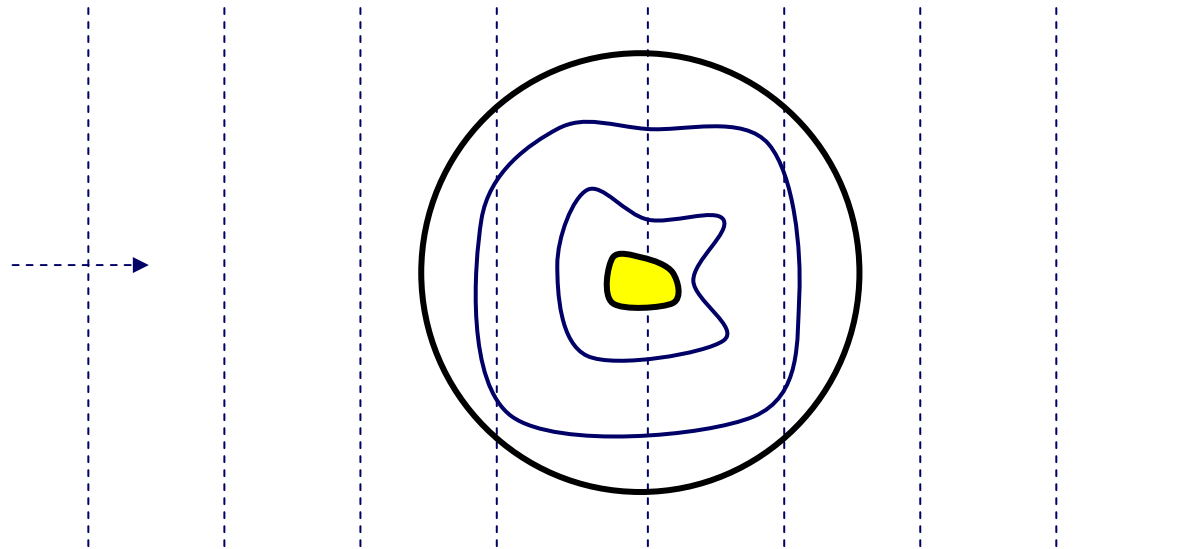


## Coupling wave models and BEM:

1. Use wave model to calculate unperturbed wave resource at WEC location

# Methodology

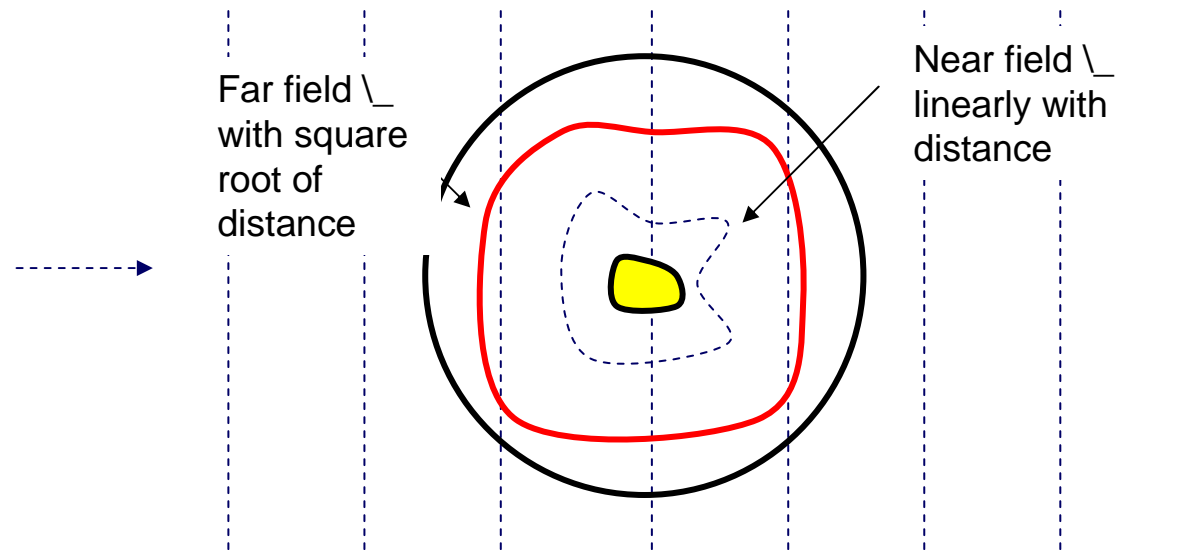
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## Coupling wave models and BEM:

1. Use wave model to calculate unperturbed wave resource at WEC location
2. Calculate WEC response and wave perturbation using BEM close to the WEC

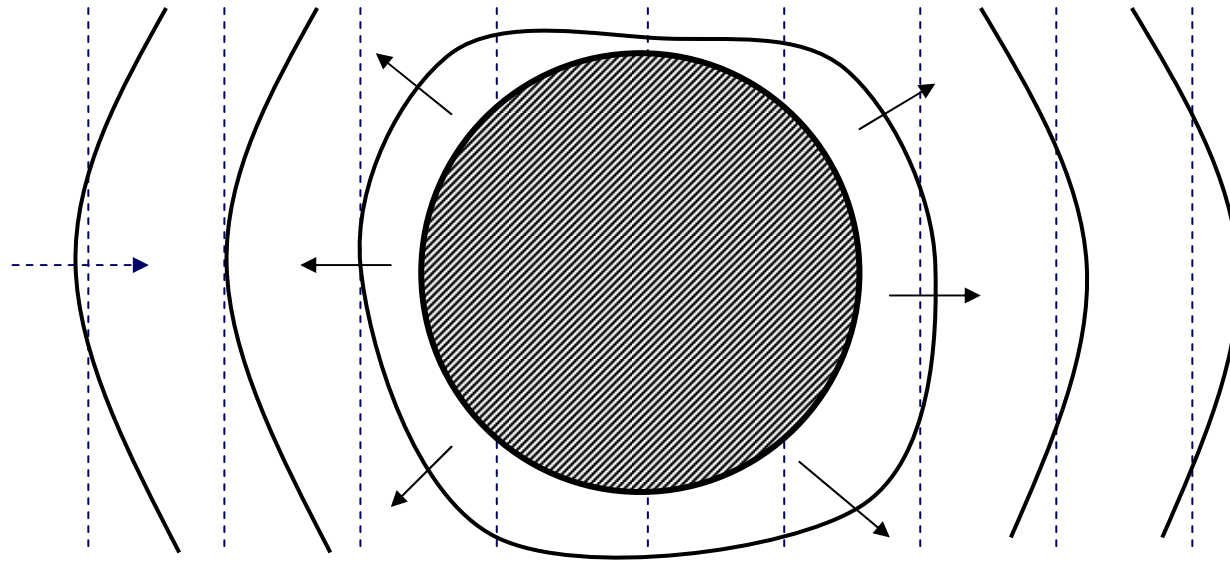
# Methodology



## Coupling wave models and BEM:

1. Use wave model to calculate unperturbed wave resource at WEC location
2. Calculate WEC response and wave perturbation using BEM
3. Separate near field and far field in wave perturbation. **Retain only far field.**

# Methodology



## Coupling wave models and BEM:

1. Use wave model to calculate unperturbed wave resource at WEC location
2. Calculate WEC response and wave perturbation using BEM **Critical step**
3. Separate near field and far field in wave perturbation. **Retain only far field.**
4. Re-introduce far field component of perturbation in wave models and propagate
  - > Using domain decomposition and line generation technique for phase resolving wave models
  - > Using sources and sinks calibrated against far field coefficients as a theoretically supported alternative to the empirical approach.

# Far field coefficients

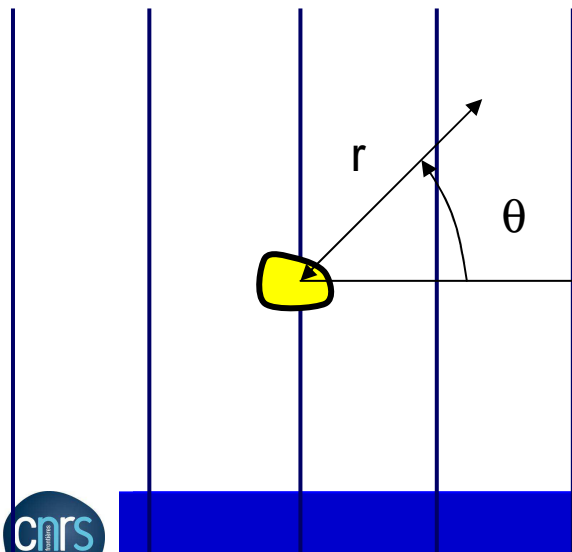
- > Far field approximation of velocity potential  $\Phi_p$  of perturbation:

$$\Phi_p(M) \equiv f_0(z) \sqrt{\frac{2}{\pi}} \frac{H(\theta)}{\sqrt{kr}} e^{i\left(kr - \frac{\pi}{4}\right)}$$

With:

- $(r, \theta, z)$  the cylindrical coordinates from WEC centre
- $H(\theta)$  the complex Kochin function

- > Kochin function  $H$ :



$$H(\theta) = \left\{ \begin{array}{l} -\frac{i}{2} \frac{k^2 - \sigma^2}{h(k^2 - \sigma^2) + \sigma} \times \text{From any BEM solver} \\ \iint_{S_B} \left( \Phi_P(M') \frac{\partial}{\partial n'} - \frac{\partial \Phi_P(M')}{\partial n'} \right) \times \left( \cosh k(z' + h) \cosh(kh) e^{-ikr' \cos(\theta - \theta')} \right) dS \end{array} \right.$$

# Example

- > Heaving WEC in 8s 1m regular wave

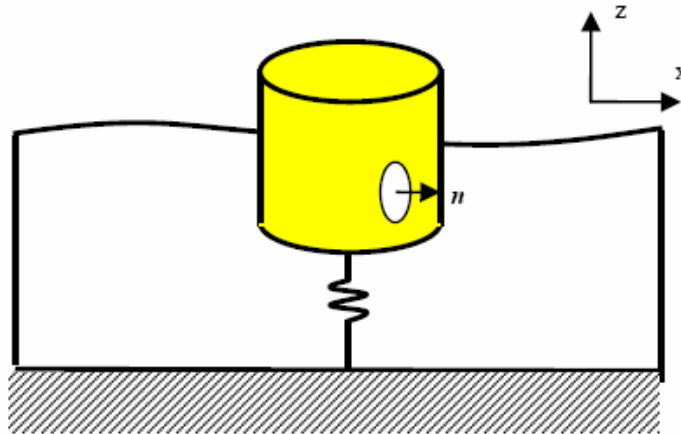


Fig. 1 A floating heaving wave energy converter in waves.

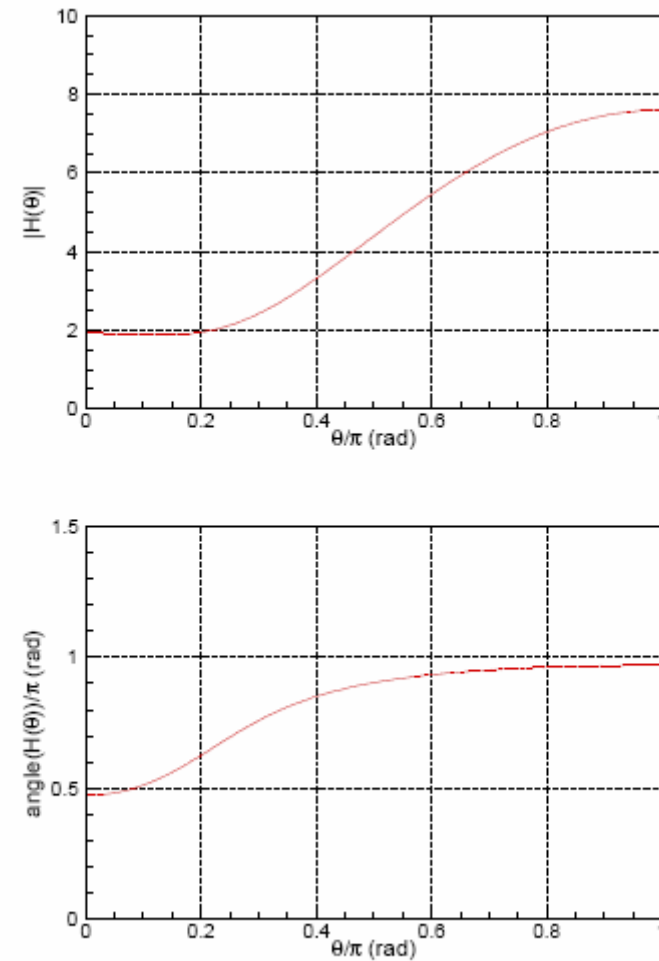


Fig. 5 Kochin function for a heaving WEC in a 8 seconds 1 meter regular wave.

# Comparison of far field approx. and direct BEM

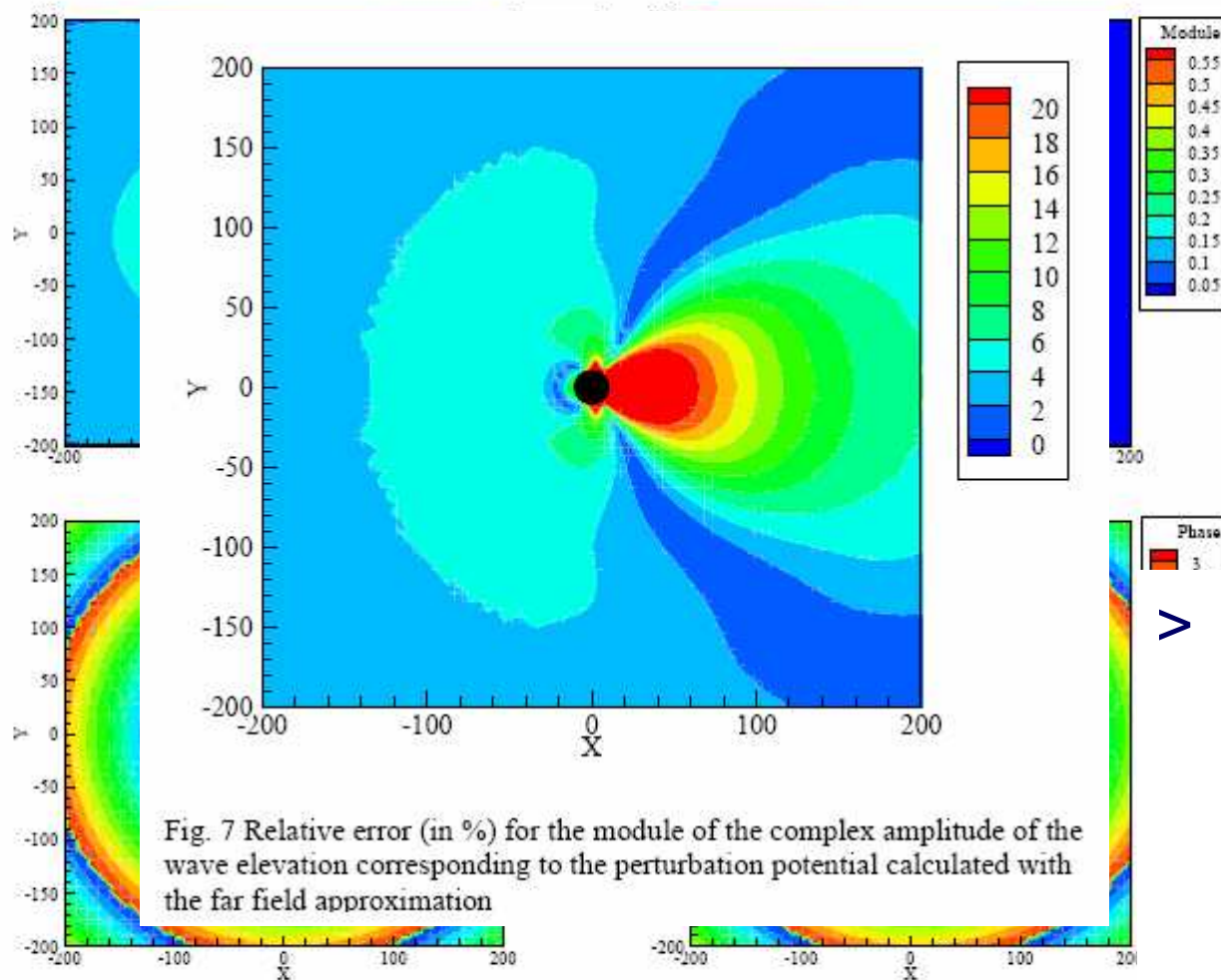


Fig. 6 Module and phase of the complex amplitude of the free surface elevation corresponding to the perturbation potential. Left figures are re obtained using the exact velocity potential. Right figures are obtained using the far field approximation. Case study is a 20m diameter heaving seconds 1 meter regular wave

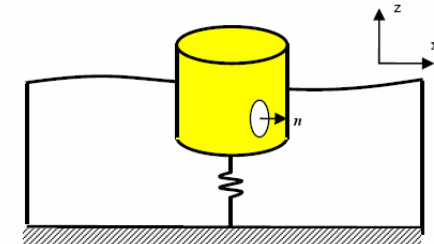
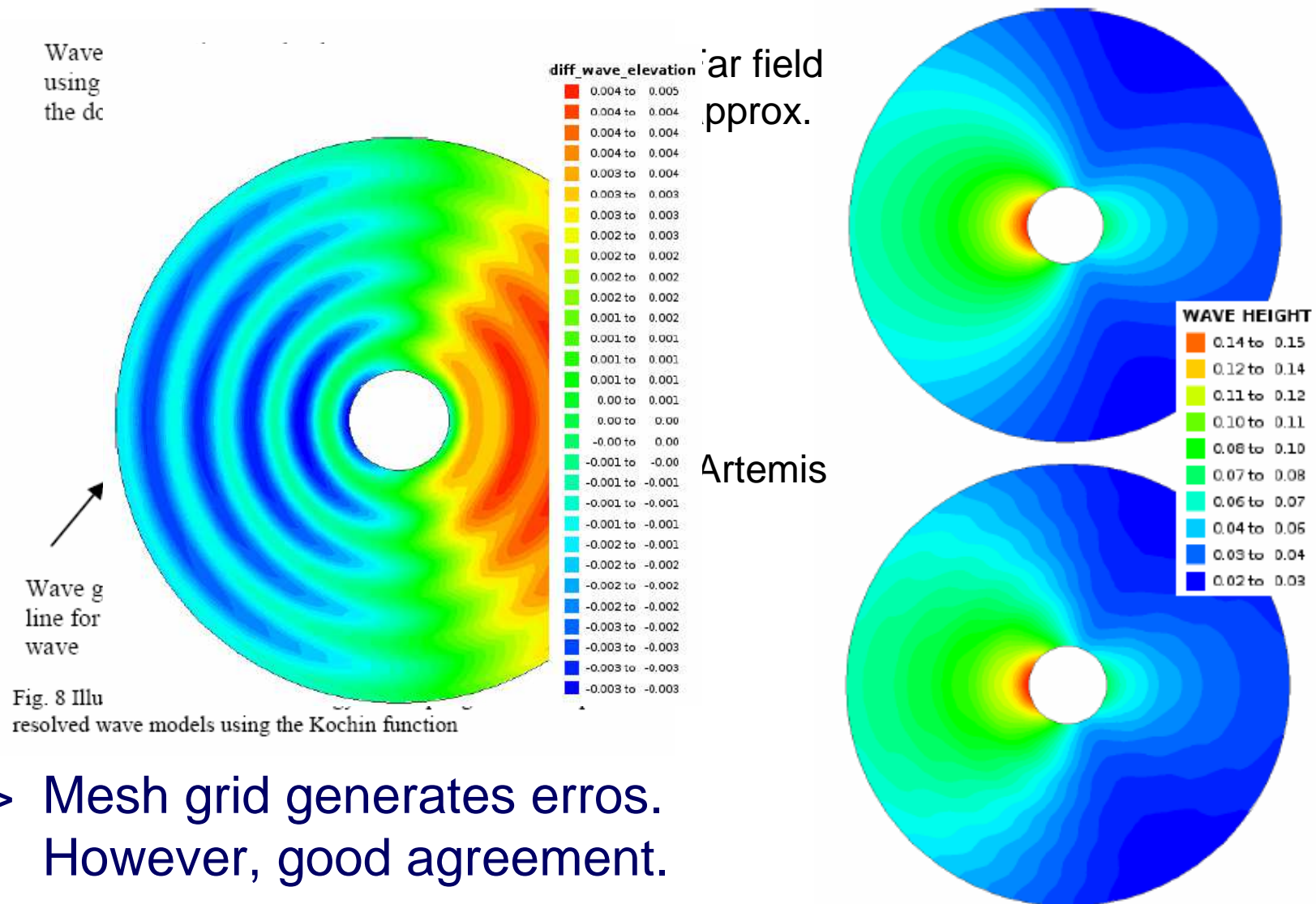


Fig. 1 A floating heaving wave energy converter in waves.

> Error smaller than 10% for distance larger than 1 wavelength

# Coupling BEM with phase resolving models



# Modified wave energy flux

- > Total energy potential:
- > Anywhere in the far field:

$$\Phi(M) = \Phi_i(M) + \Phi_p(M)$$

$$\Phi(M) \cong e^{kz} \left( -\frac{ig}{\omega} e^{ikx} + \sqrt{\frac{2}{\pi}} \frac{H(\theta)}{\sqrt{kr}} e^{i\left(kr - \frac{\pi}{4}\right)} \right)$$

$$\vec{J} = J_i \Re \left( \left( 1 + \sqrt{\frac{2}{\pi}} \frac{H^*(\theta)}{\sqrt{kr}} e^{-i\phi(\theta)} \right) \vec{x} + \left( \sqrt{\frac{2}{\pi}} \frac{H(\theta)}{\sqrt{kr}} e^{i\phi(\theta)} + \frac{2}{\pi} \frac{|H(\theta)|^2}{kr} \right) \vec{u}_r \right)$$

Unperturbed  
wave energy flux

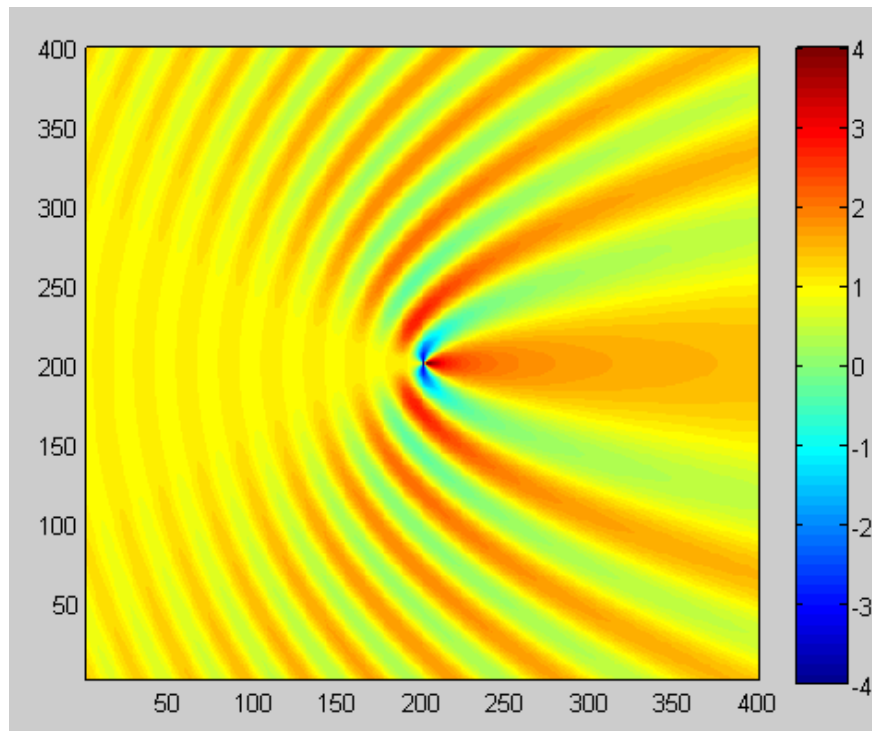
Amount of energy taken  
from the incident wave

Scattered energy  
(diffraction +  
radiation)

- > In the far far field ( $r \rightarrow \infty$ )

# Modified wave energy flux

Component in wave propagation direction



Lateral component

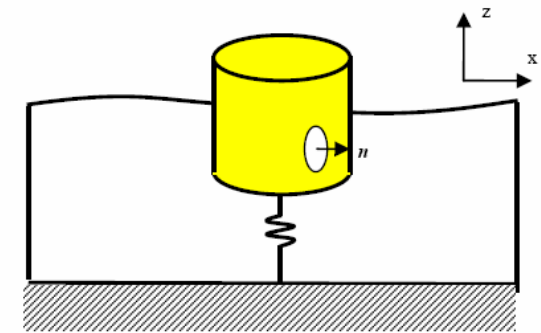
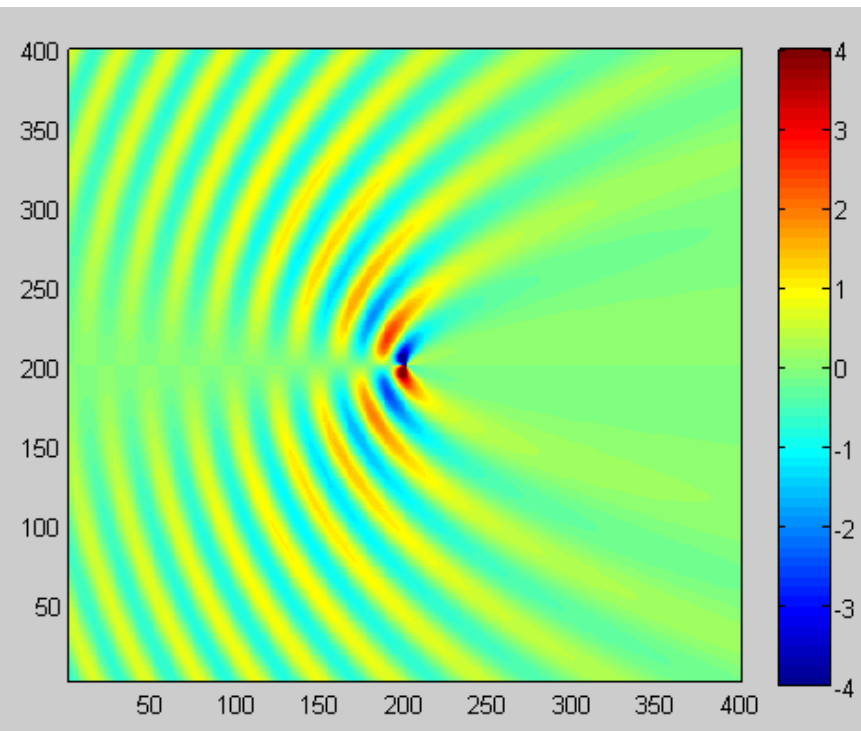


Fig. 1 A floating heaving wave energy converter in waves.

# Verifications

- > Deficit in wave energy = absorbed energy + diffracted/radiated

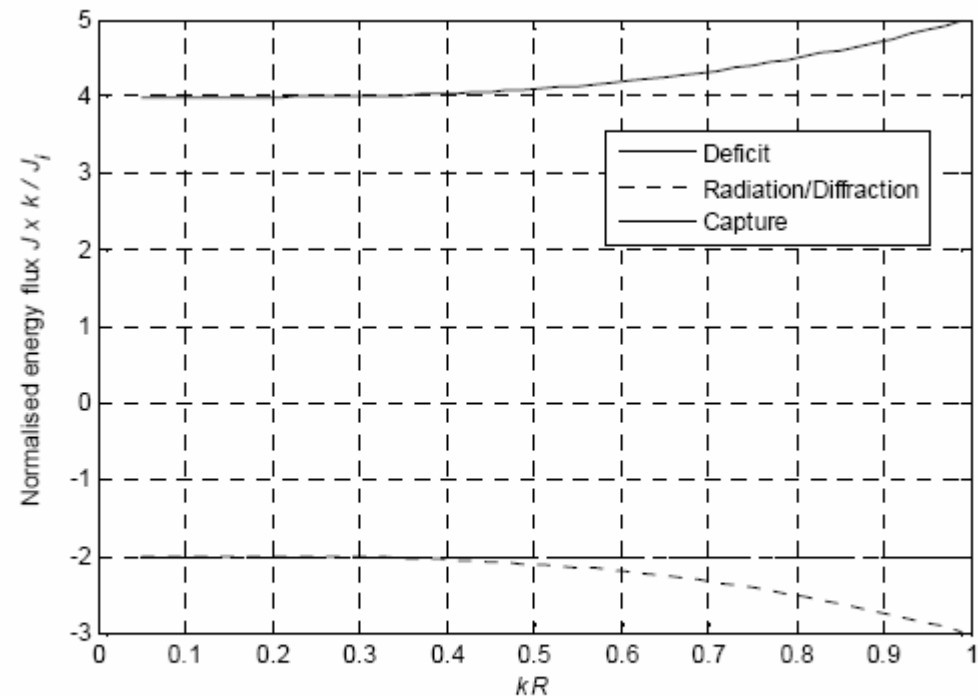


Fig. 13 Variation of the normalized energy flux with non-dimensional cylinder radius for a optimally damped resonant cylinder.

# Conclusion

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- > Far field coefficients enable to take into account WEC perturbation of wave field in wave propagation models
- > Work in progress...

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- > Financial support from French National Research Agency (ANR) is acknowledged
  - > Thank you for your attention

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