Procesos físicos en la interacción del flujo con SbN

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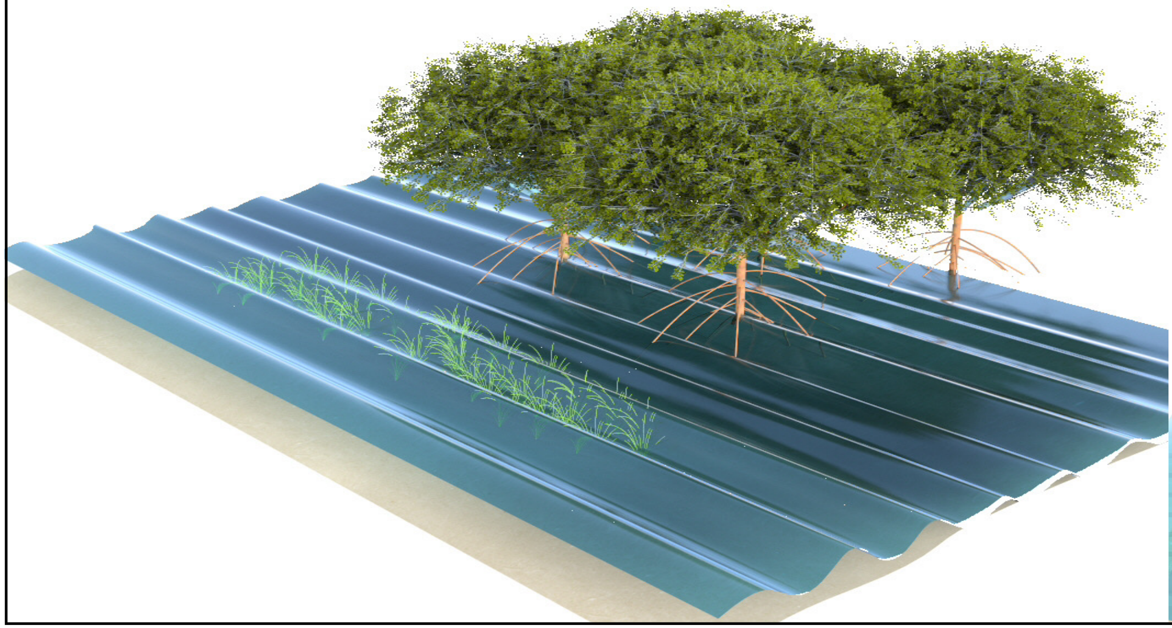
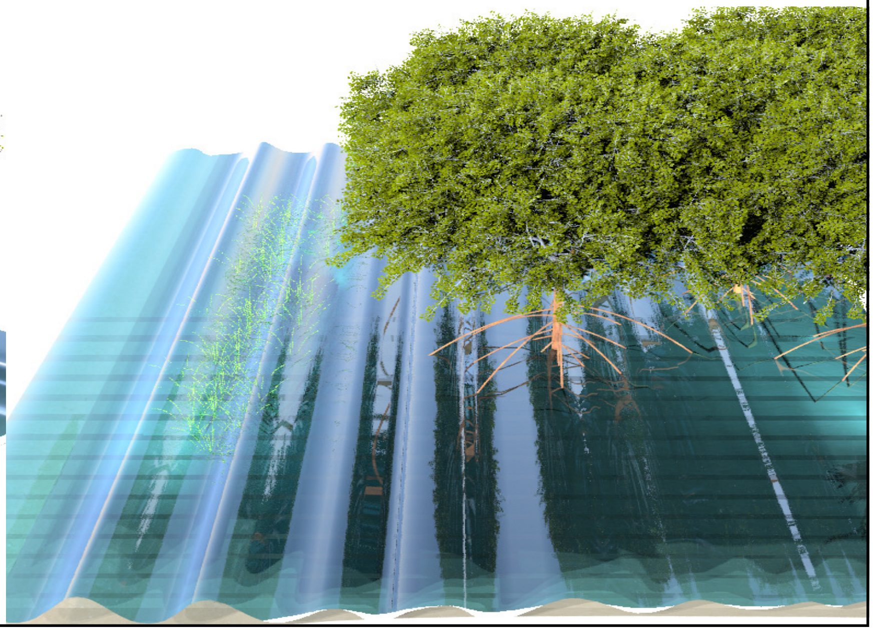
ble development

Protección costera

- Para incluir con **éxito** las **SbN** en las políticas de defensa costera y llevar a cabo acciones de restauración:
  - Mejor entendimiento de los procesos
  - Nuevas herramientas de cálculo y diseño
  - Estipulación del beneficio global
  - Recomendaciones de aplicación





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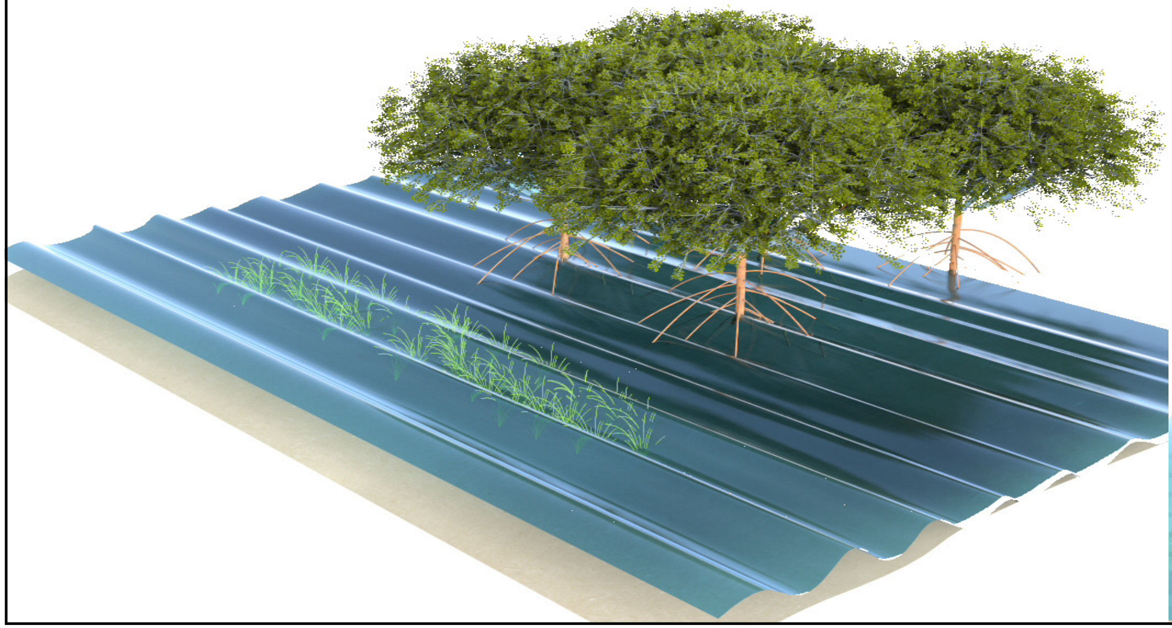
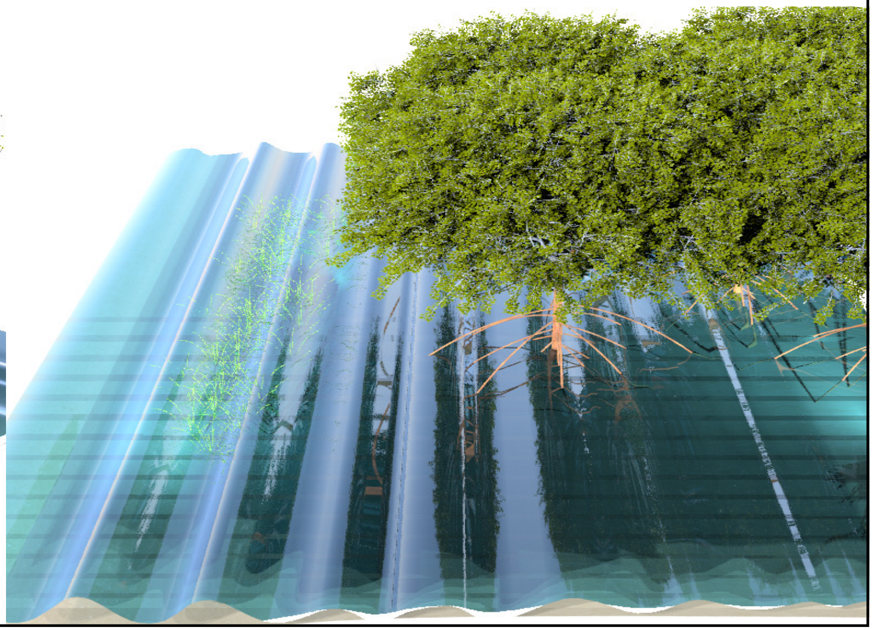
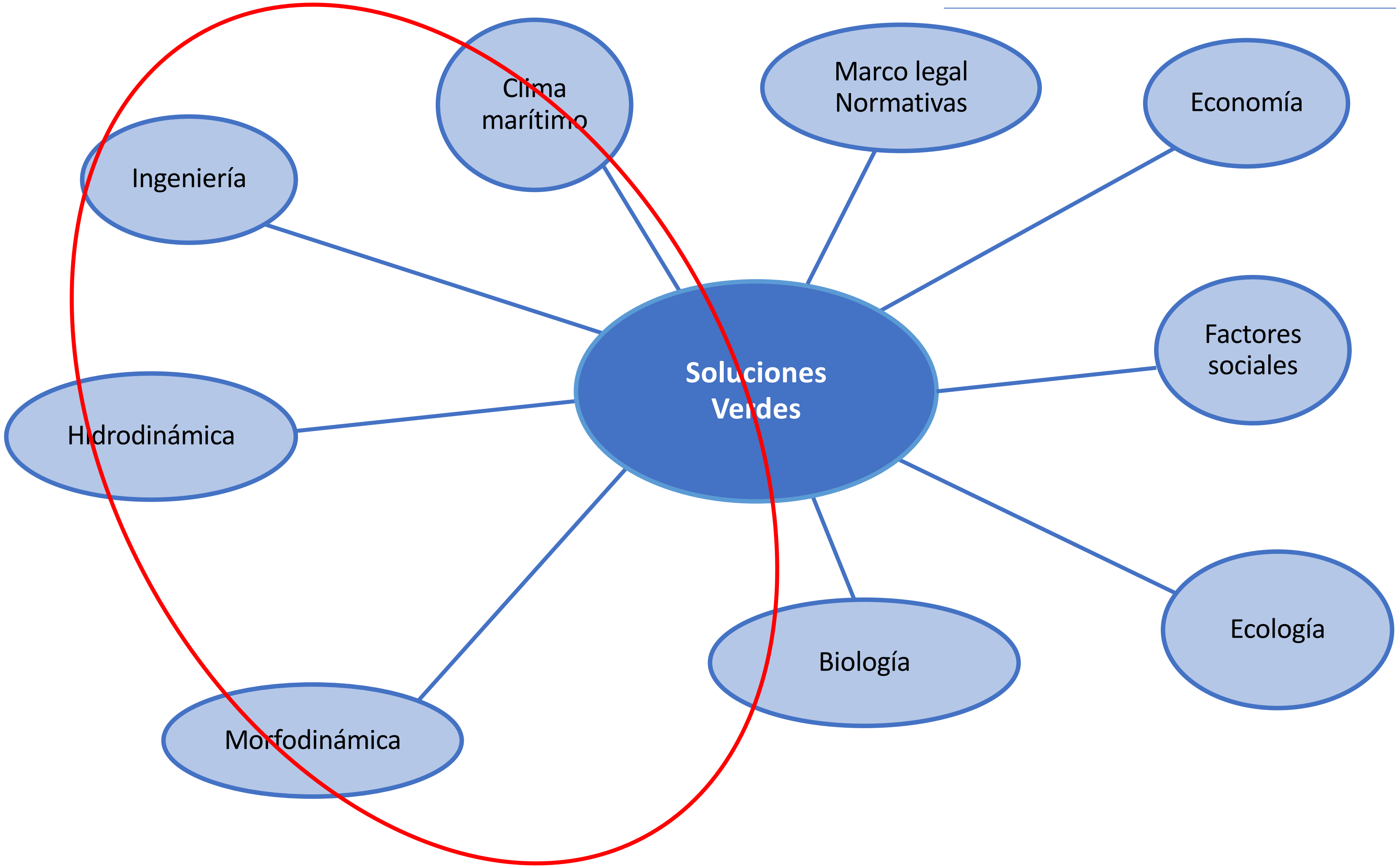




Complejidad del problema: Problema multidisciplinar



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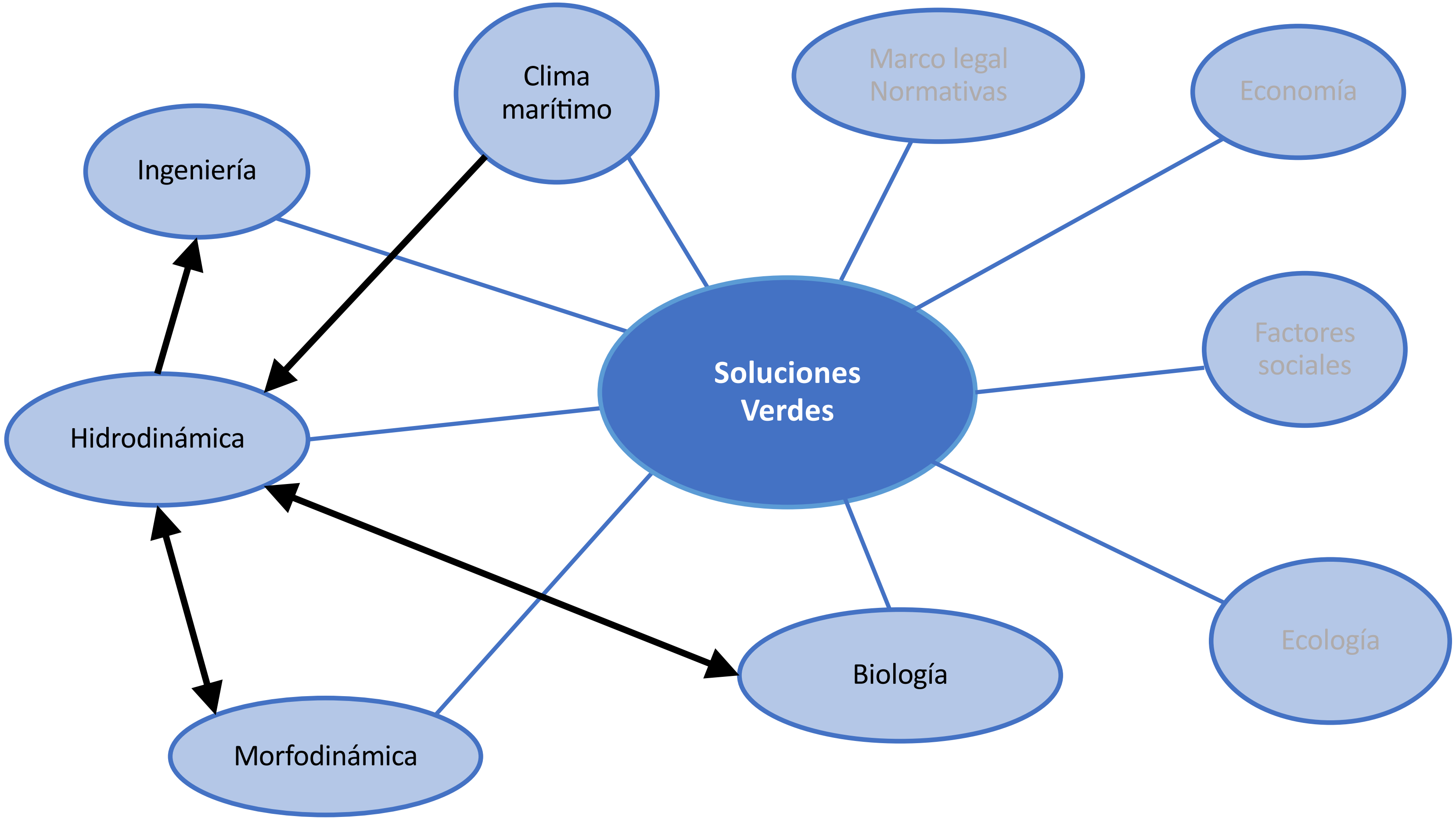

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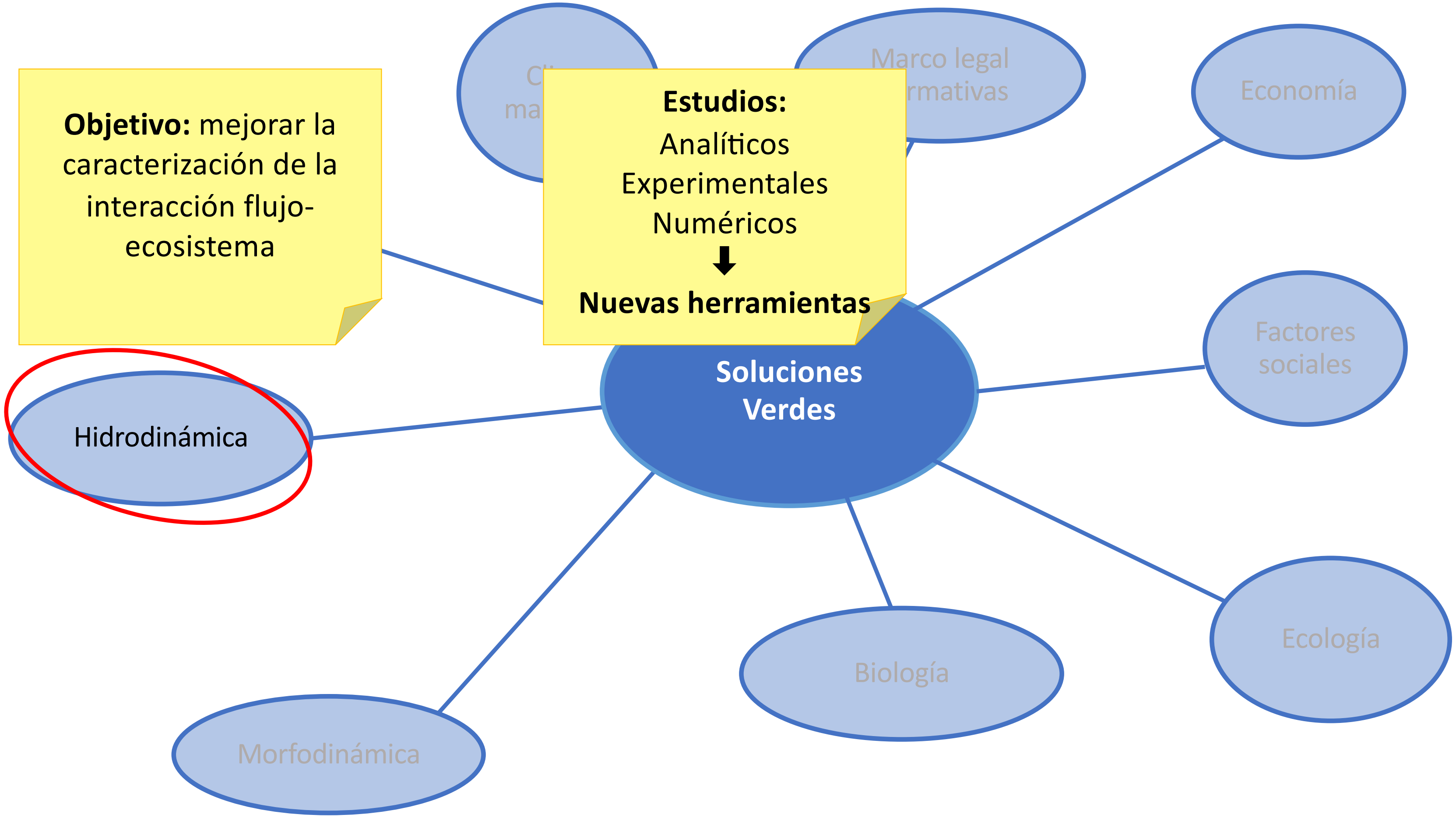

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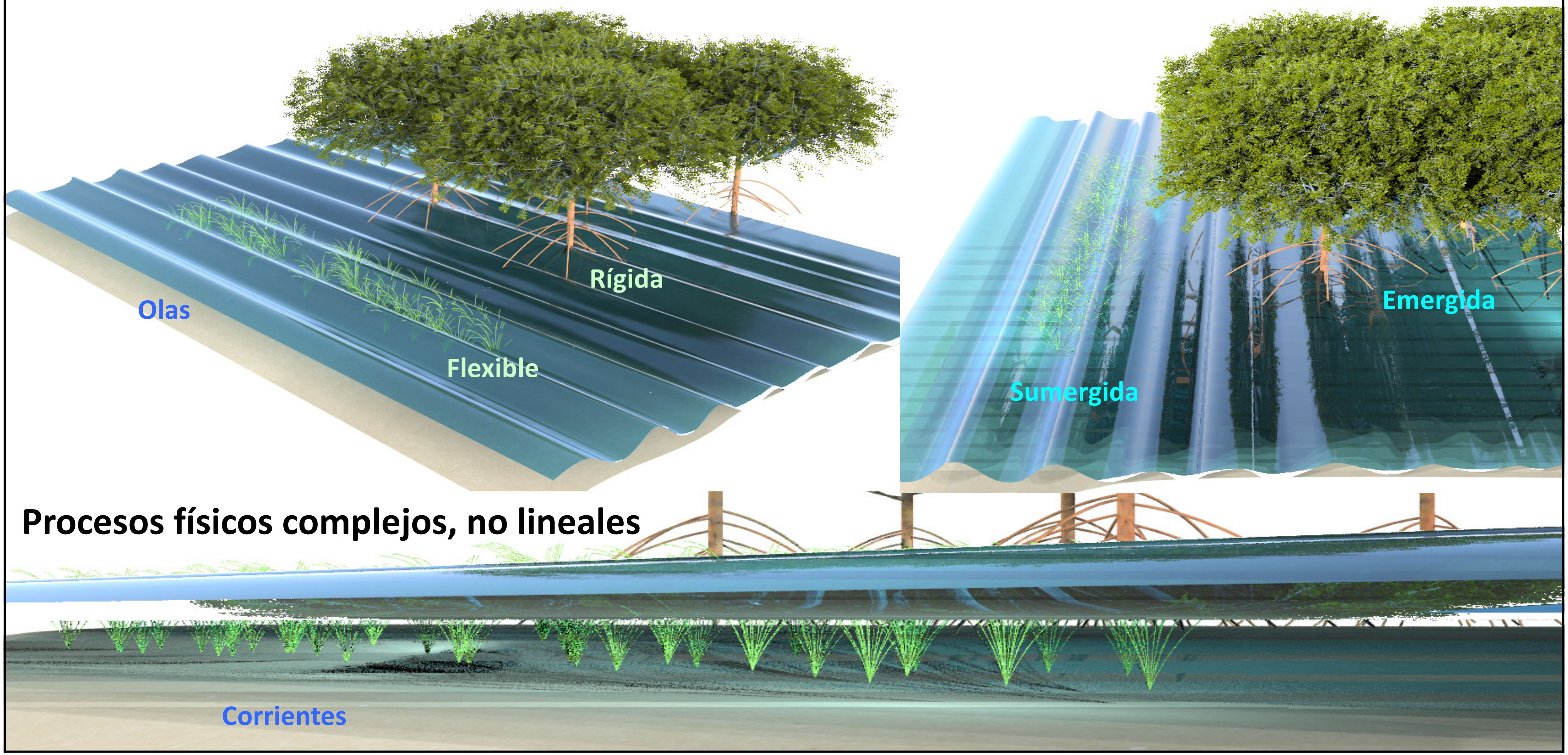
Complejidad del problema: Interacción flujo-ecosistema



1 **Fuerza de arrastre**

2 Transformación del oleaje

3 Oleaje y corriente

4 Tensiones tangenciales

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- Drag force – uniform flow & cylinder

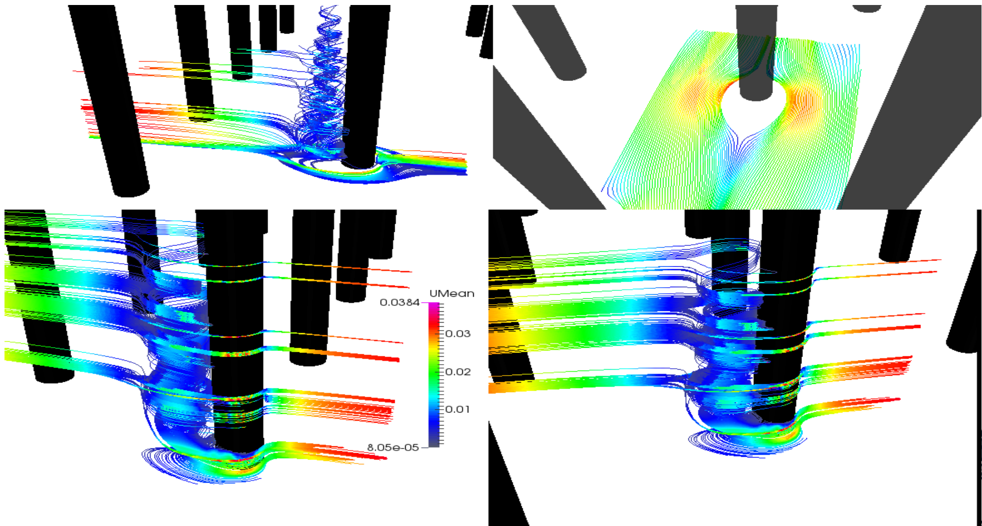
Flow-cylinder interaction depends on the Re:

- For Re<<1 inertia forces are negligible
- For Re>>1 viscous forces are negligible except close to the boundary: irrotational flow + boundary layer

$$F_D = \frac{1}{2}\rho C_D A_f U|U|$$

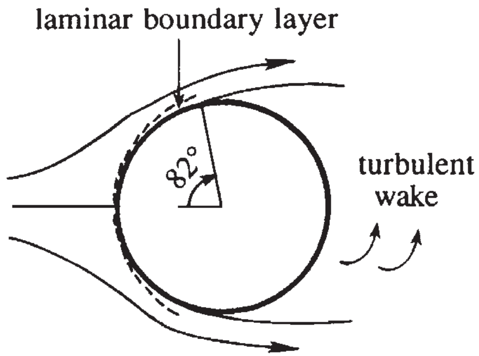
$$\mathrm{Re} = \frac{\text{inertial forces}}{\text{viscous forces}} = \frac{(\text{mass})(\text{acceleration})}{(\text{dynamic viscosity})\left(\frac{\text{velocity}}{\text{distance}}\right)(\text{area})}$$

$$= \frac{(\rho L^3)\left(\frac{v}{t}\right)}{\mu\left(\frac{v}{L}\right)L^2} = \frac{(\rho L^3)\left(\frac{1}{t}\right)}{\mu\left(\frac{1}{L}\right)L^2} = \frac{(\rho L^2)\left(\frac{1}{t}\right)}{\mu} = \frac{(\rho)\left(\frac{L}{t}\right)(L)}{\mu} = \frac{\rho v L}{\mu} = \frac{vL}{\nu}$$

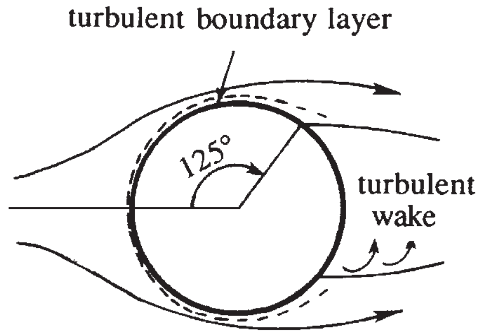


Re < 3 x 10⁵: the BL remains laminar, although the wake may be completely turbulent. The laminar BL separates at 82º. Pressure in the wake is nearly constant and lower than the upstream pressure. This asymmetry in pressure leads to a nearly constant drag force with $C_D \approx 1.2$

3 x 10⁵ < Re < 3 x 10⁶: laminar BL becomes turbulent and it separates at 125º. $C_D \approx 0.33$

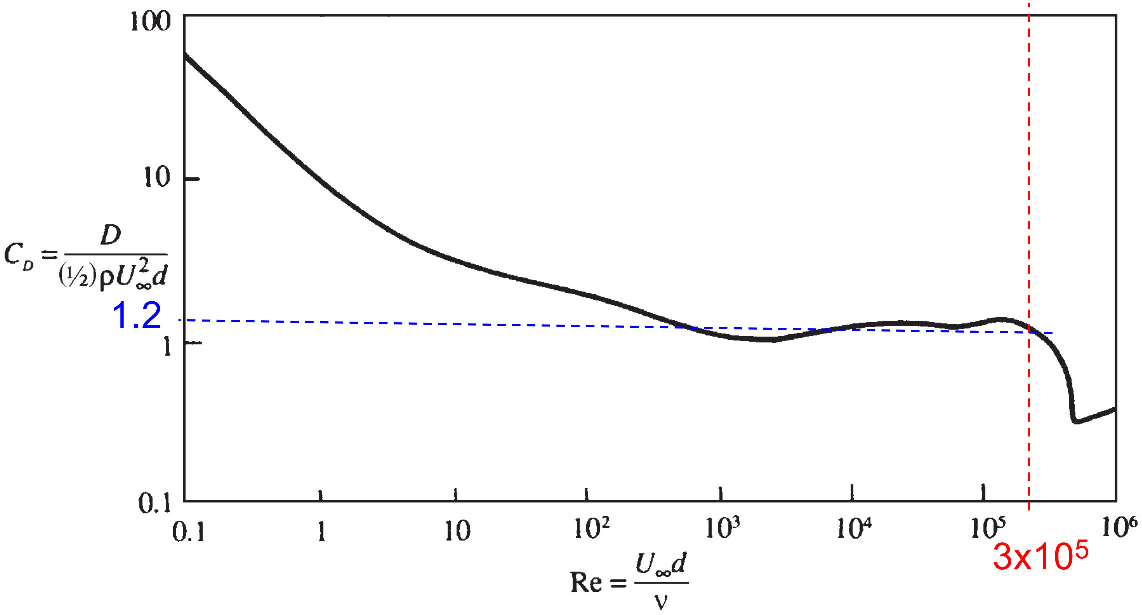


$Re < 3 \times 10^5$



$Re > 3 \times 10^5$

Pressures within the wake are higher when the BL is turbulent. This results in a sudden drop in the drag coefficient from 1.2 to 0.33 at the point of transition.

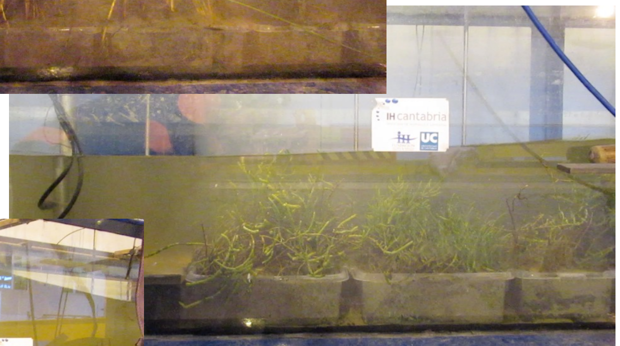


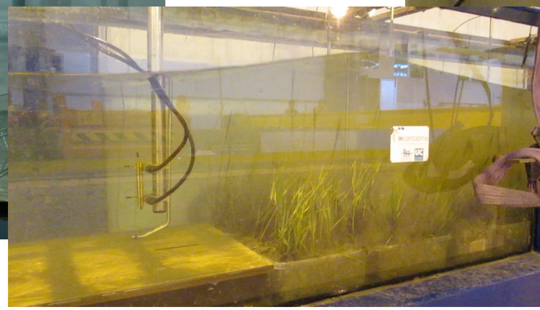
- Drag force – more complex (and realistic) cases

Flow-vegetation interaction:

- **Complex geometries**
- Submerged / Emergent
- Flexible / Rigid

$$F_D = \frac{1}{2}\rho C_D A_f N U|U|$$





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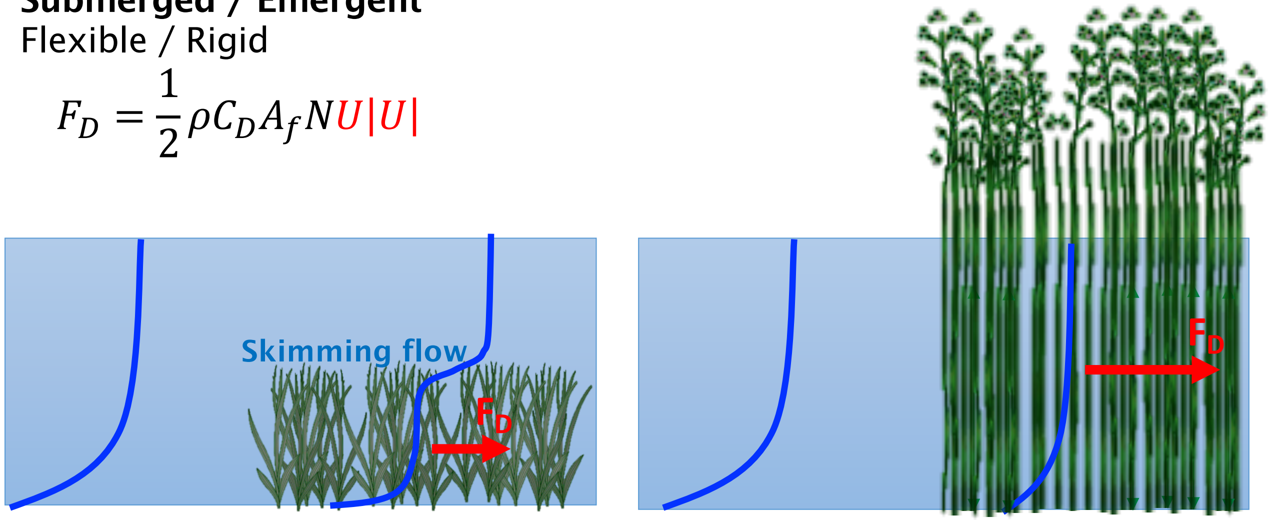

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- Drag force – more complex (and realistic) cases

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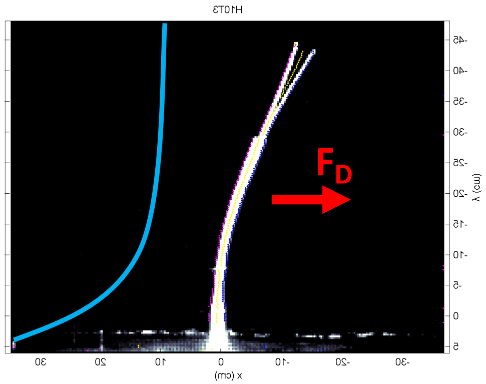
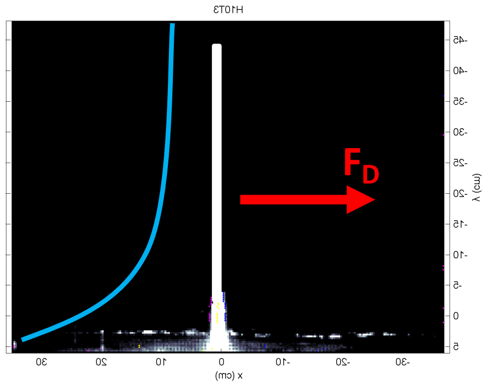
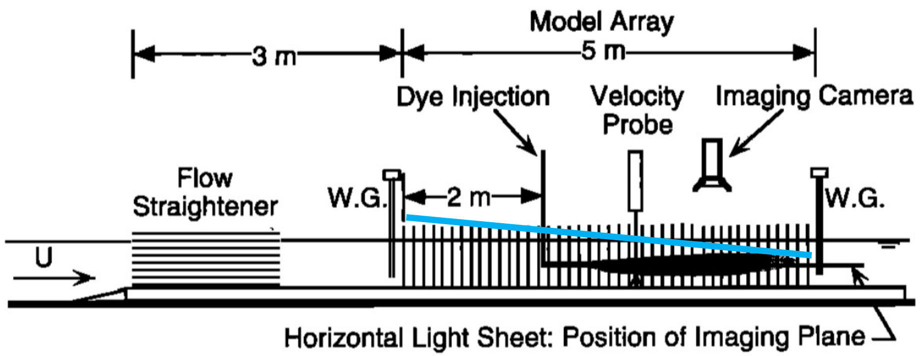




- Energy attenuation – Uniform flow

Force balance between free surface gradient and drag force:

$$gh\frac{\partial h}{\partial x} = F_D$$



Nepf, H. (1999). Drag, turbulence, and diffusion in flow through emergent vegetation. Water Resources Research 35.2

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- Energy attenuation – Waves

Dissipation is considered to be only due to drag force:

$$\frac{\partial E c_g}{\partial x} = -\varepsilon_D$$

$$\varepsilon_D = \overline{\int_{-h}^{-h+h_v} F_D U dz}$$

$$H = \frac{H_0}{1+\beta x}$$

Dalrymple, R.A., Kirby, J.T., Hwang, P.A., 1984. Wave diffraction due to areas of energy dis- sipation. J. Waterw. Port Coast. Ocean Eng. 110, 67–79.

$$H_{rms} = \frac{H_{rms,0}}{1+\beta' x}$$

Mendez, F.J., Losada, I.J., 2004. An empirical model to estimate the propagation of random breaking and non-breaking waves over vegetation fields. Coast. Eng. 52, 103–118.

$$H = \frac{H_0}{1+\beta_{wc} x}$$

$$H_{rms} = \frac{H_{rms,0}}{1+\beta'_{wc} x}$$

Losada, I. J., Maza, M., & Lara, J. L. (2016). A new formulation for vegetation-induced damping under combined waves and currents. Coastal Engineering, 107, 1–13.

Wave damping coefficient (beta) is a function of the drag force and the flow conditions

$$C_D = \frac{9\pi}{4aNH_0k}\frac{(\sinh 2kh + 2kh)\sinh kh}{\sinh^3 kl_D + 3\sinh kl_D}\beta$$

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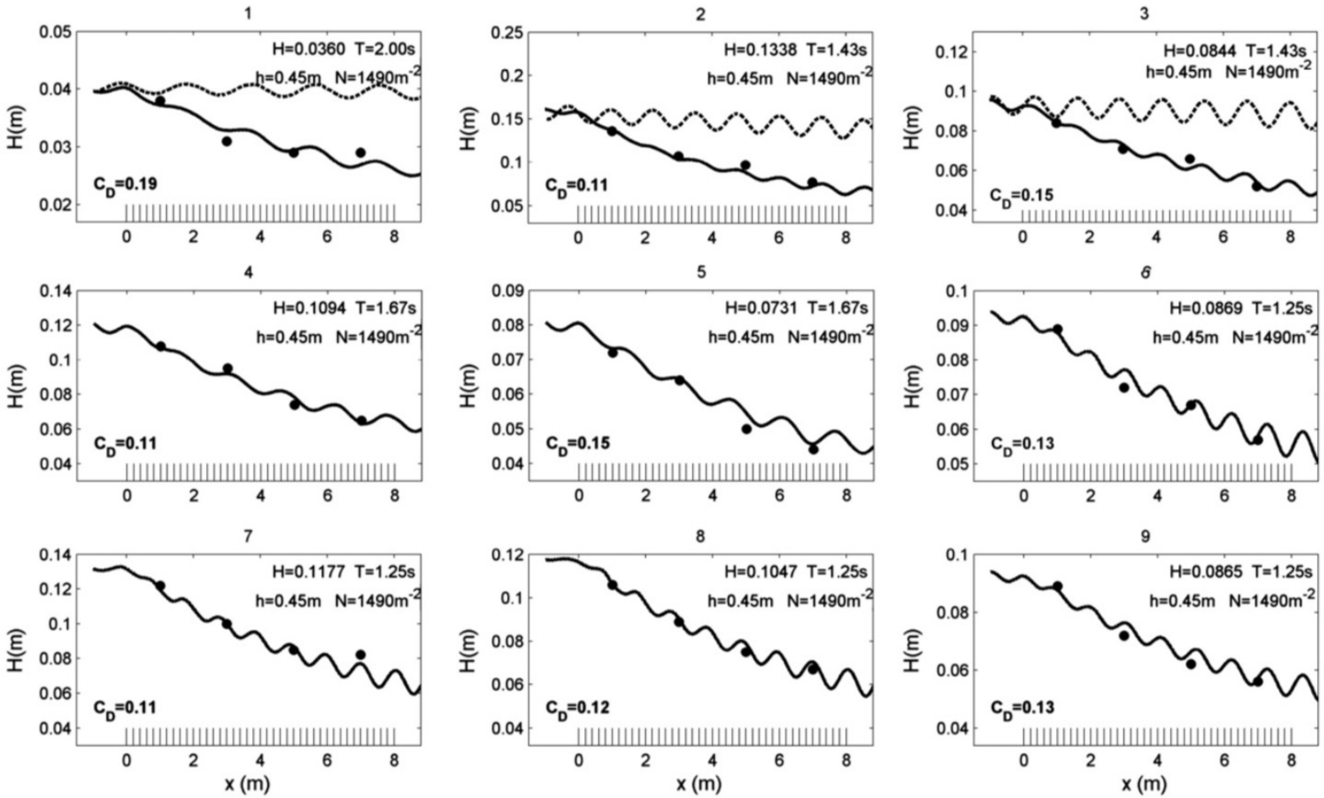
- Energy attenuation – Waves



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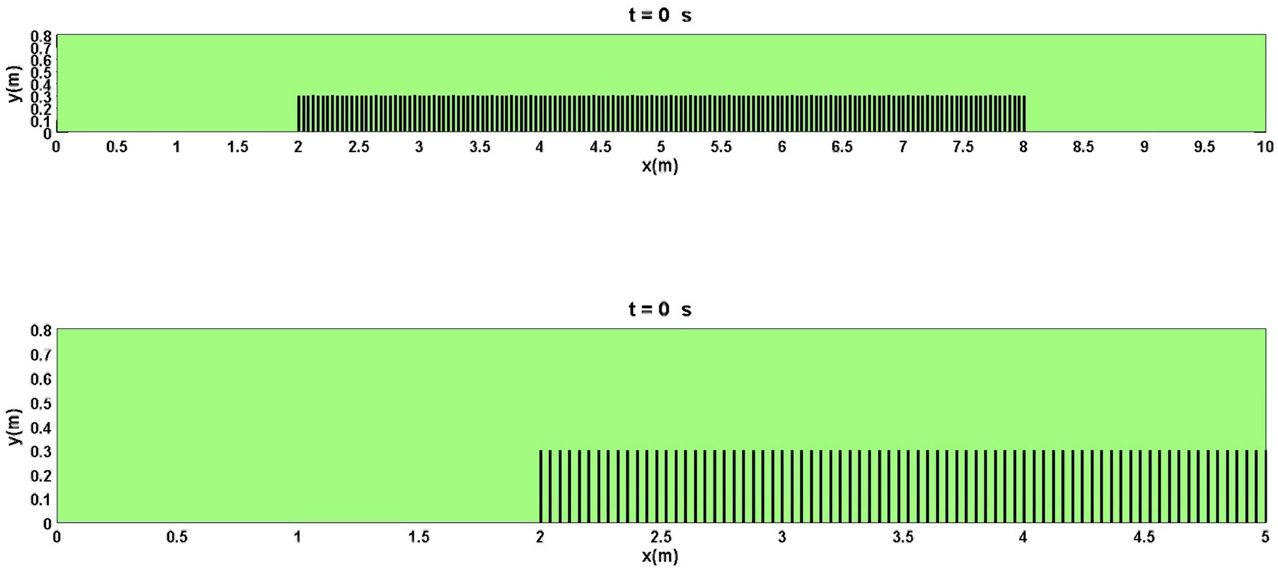
- Energy attenuation – Waves

Seaweed: H_s=0.1 m T_p=1.7 s
Coupled flow-seaweed dynamics

Work developed by:



- Drag force ➞ C_D?
- Energy attenuation ➞ C_D? β?

- Numerical modelling
- Physical modelling
- Field campaigns

1. Fuerza de arrastre
2. **Transformación del oleaje**
3. Oleaje y corriente
4. Tensiones tangenciales

Refraction

Transformation of wave characteristics (height, direction) due to changes in wave celerity generated by changes in water depth.

Wave height can also be estimated assuming energy flux conservation within wave rays.

Wave direction can be determined using the wave propagation equation.

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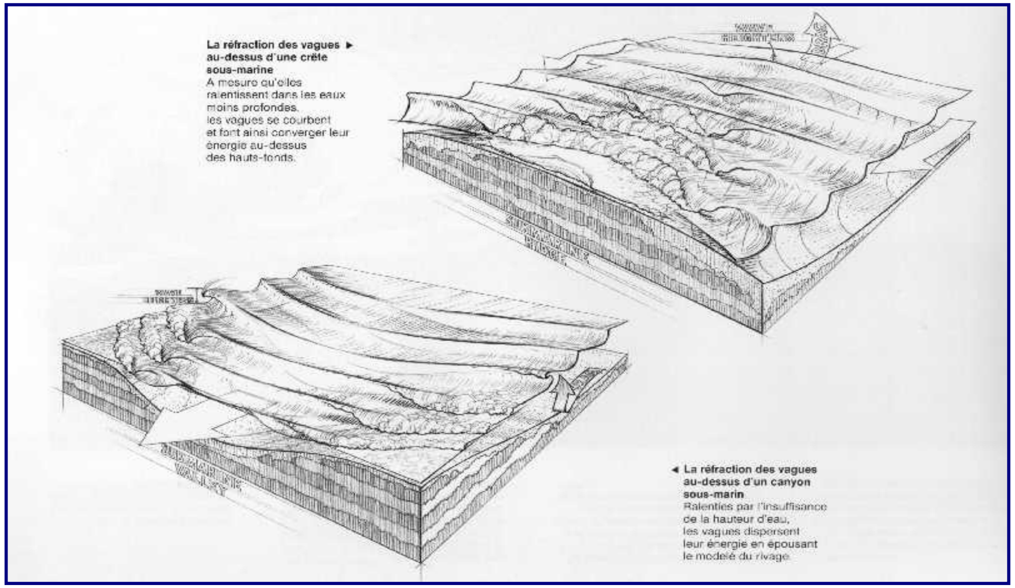
Refraction

In intermediate and shallow waters, wave length is related with water depth

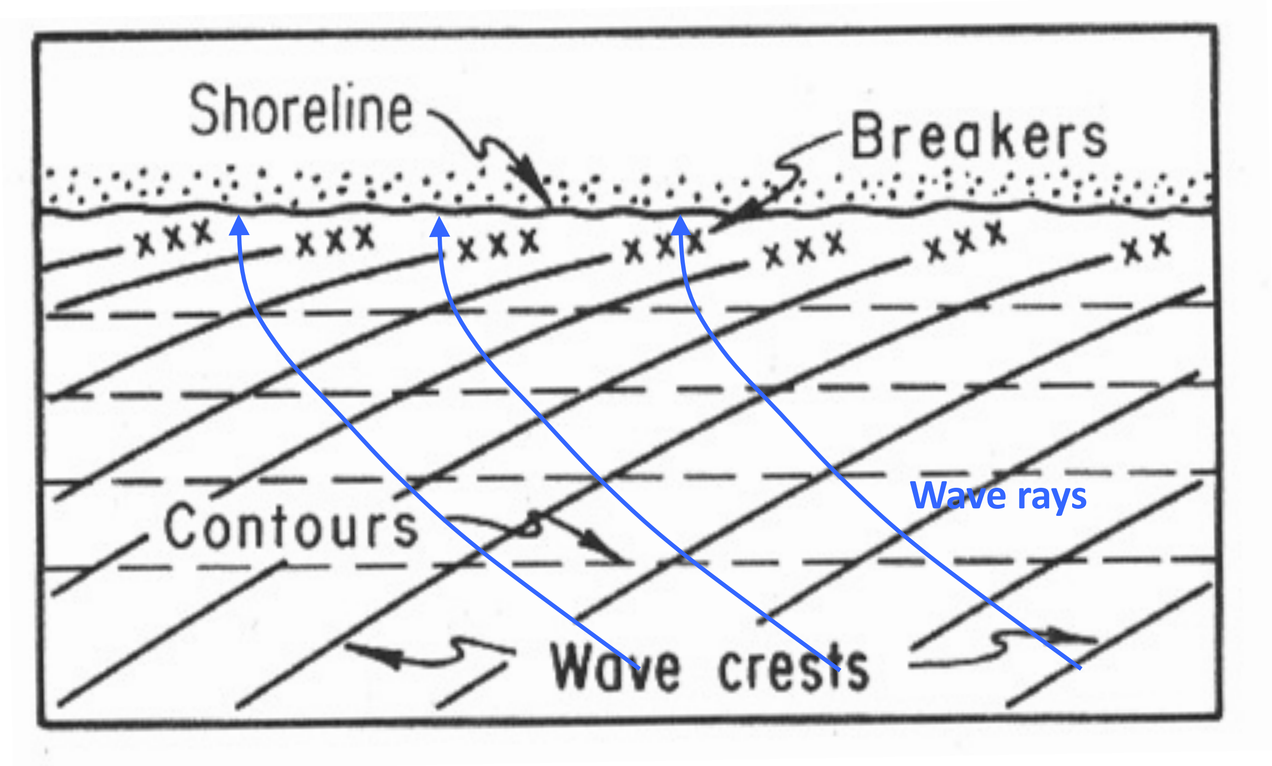
wave length decreases as water depth decreases



Consequently, wave celerity decreases as water depth decreases

These changes in wave celerity bend the wave crest

Refraction



Wave crests tend to be parallel to the shoreline

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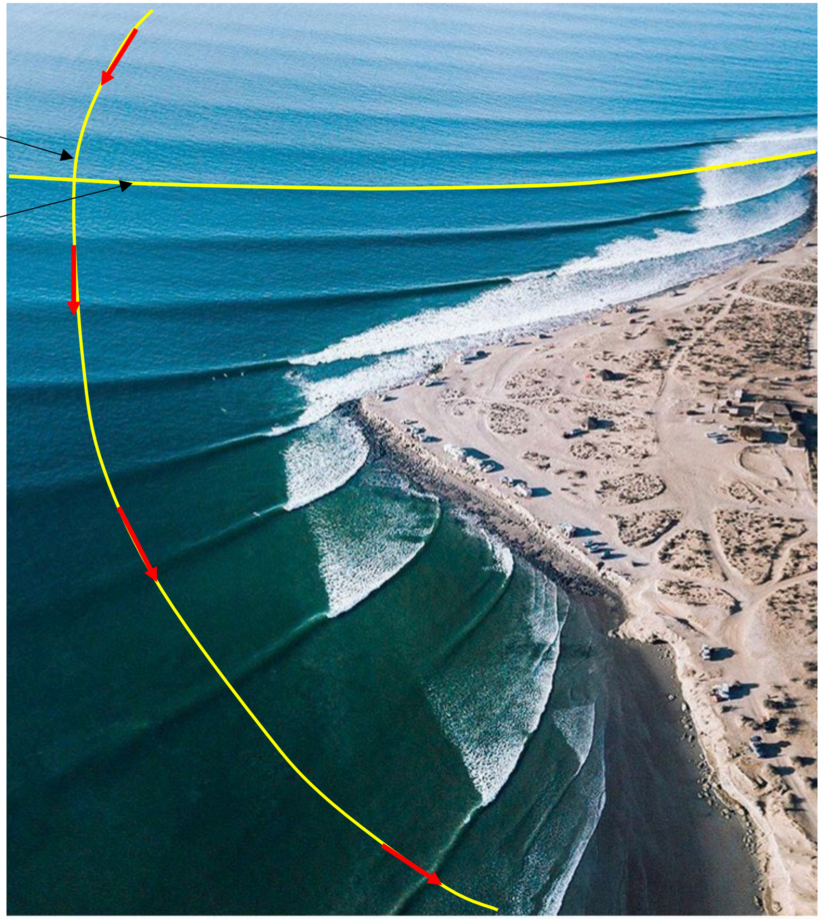
Refraction



Refraction of
a SWELL
due to the
bathymetry

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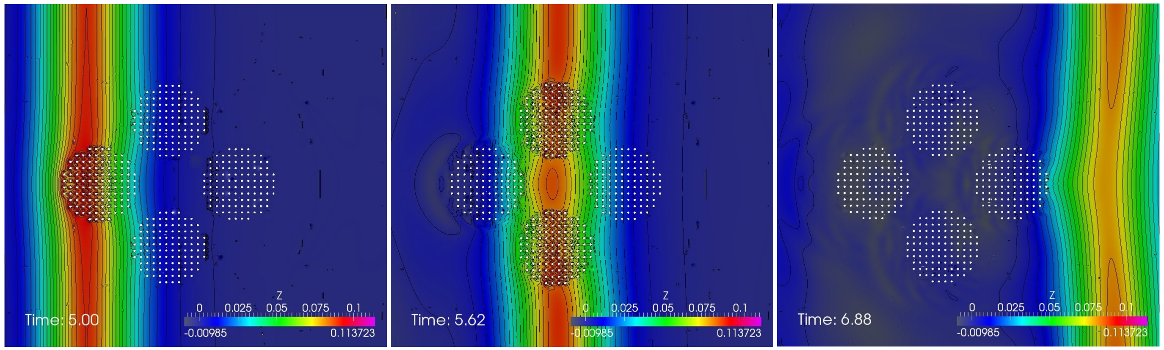
Refraction

- When we have a vegetation field in a particular area, it can lead to refraction phenomena because it decreases the effective depth in the area.
- The phenomenon of refraction is not significant for small ecosystems or those that do not have sufficient density to influence the flow.



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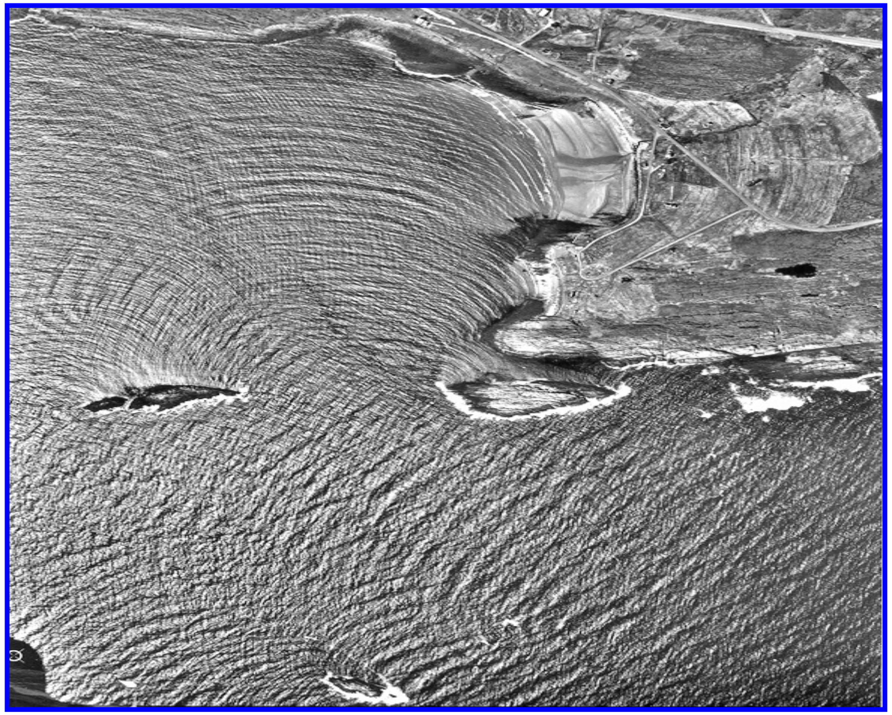
Diffraction

Energy transfer across wave rays due to gradients in wave height

It is clearly observed behind islands and breakwaters but is present all over the wave propagation.

If there is a gradient of wave height, diffraction tries to compensate the gradient.



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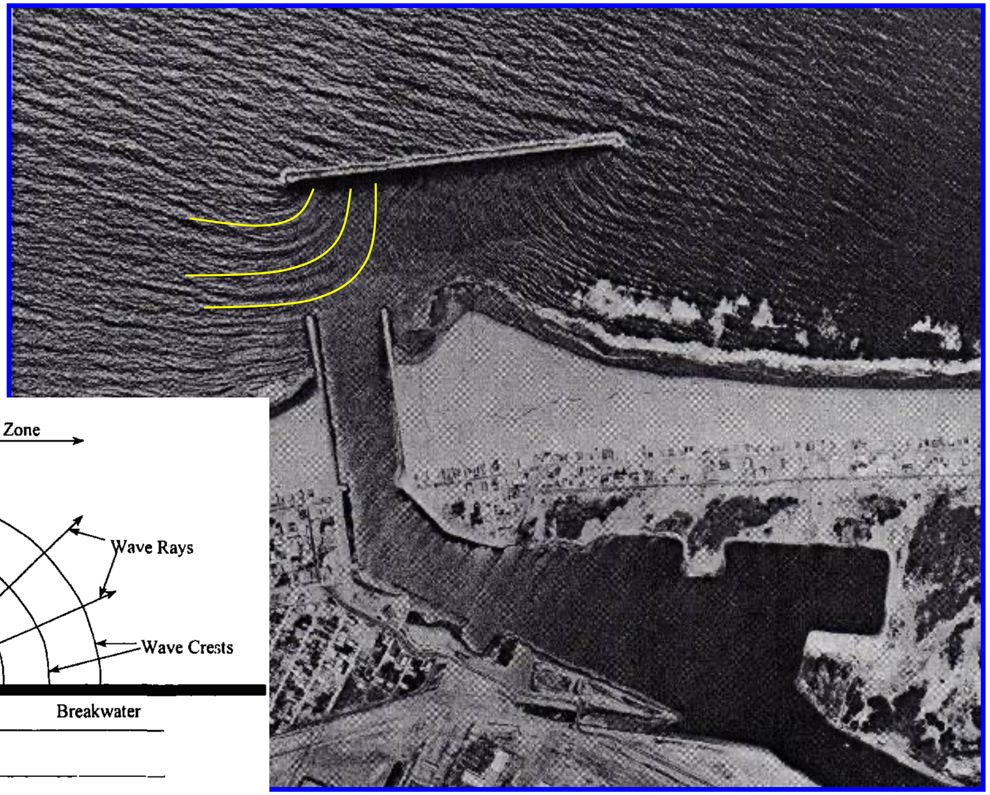
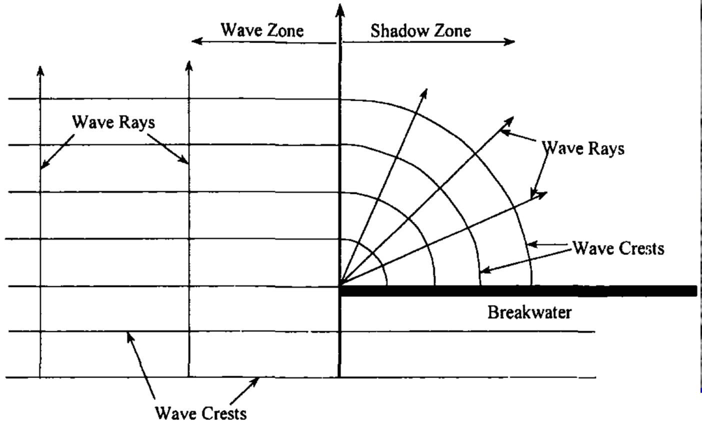
Diffraction

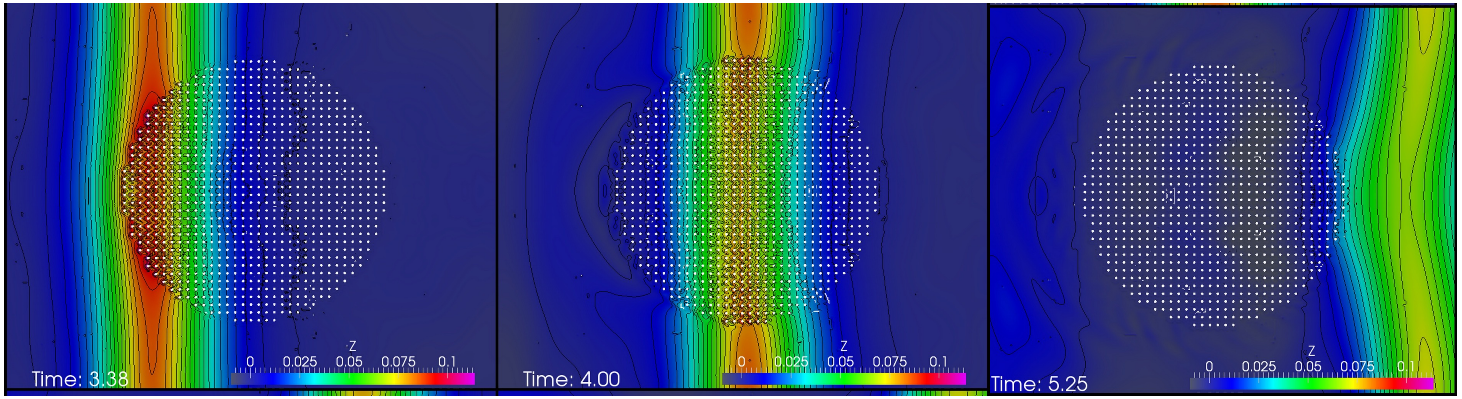
Diffraction generates a typical circular wave crest pattern behind breakwaters.





Diffraction

- When we have an emerged and sufficiently dense vegetation field, the energy behind the field is lower than in the surrounding areas. Therefore, behind the field there is a lateral energy transfer.



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Reflection

$$K_R = \frac{H_{m0R}}{H_{m0i}}$$

Structure	Reflection coefficient
Vertical Breakwater	0.7 – 1
Mound Breakwater (1:2 to 1:3)	0.3 - 0.6
Natural Beach	0.05 - 0.2

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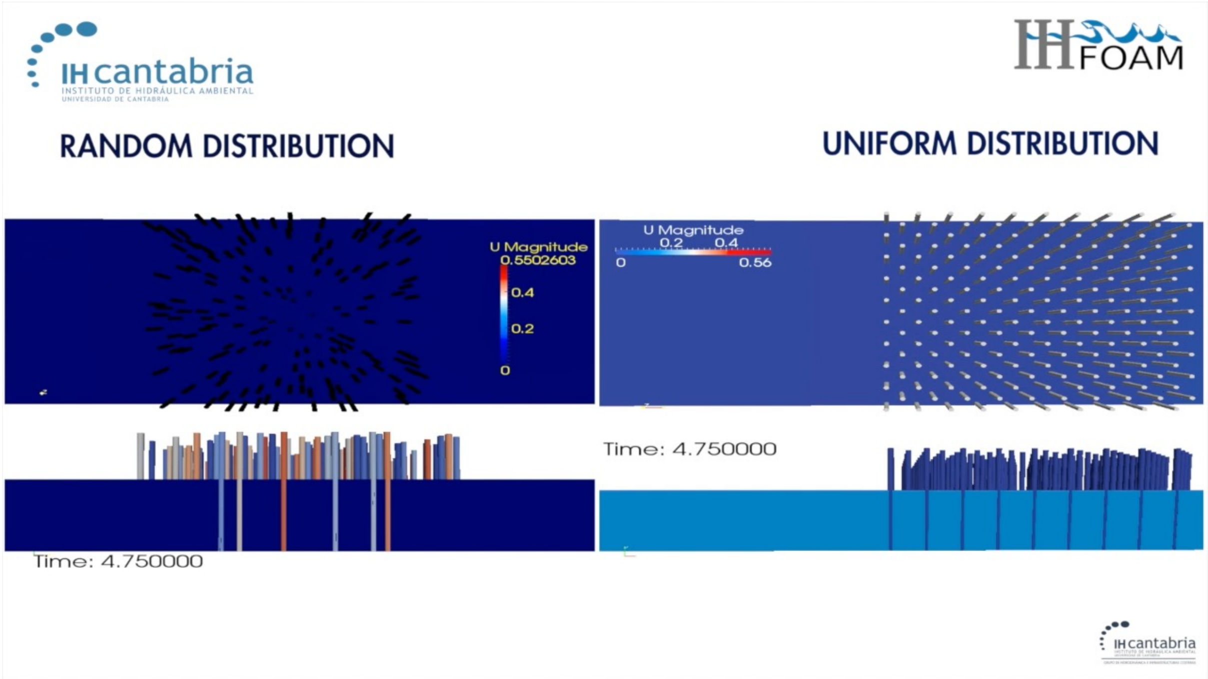
Reflection

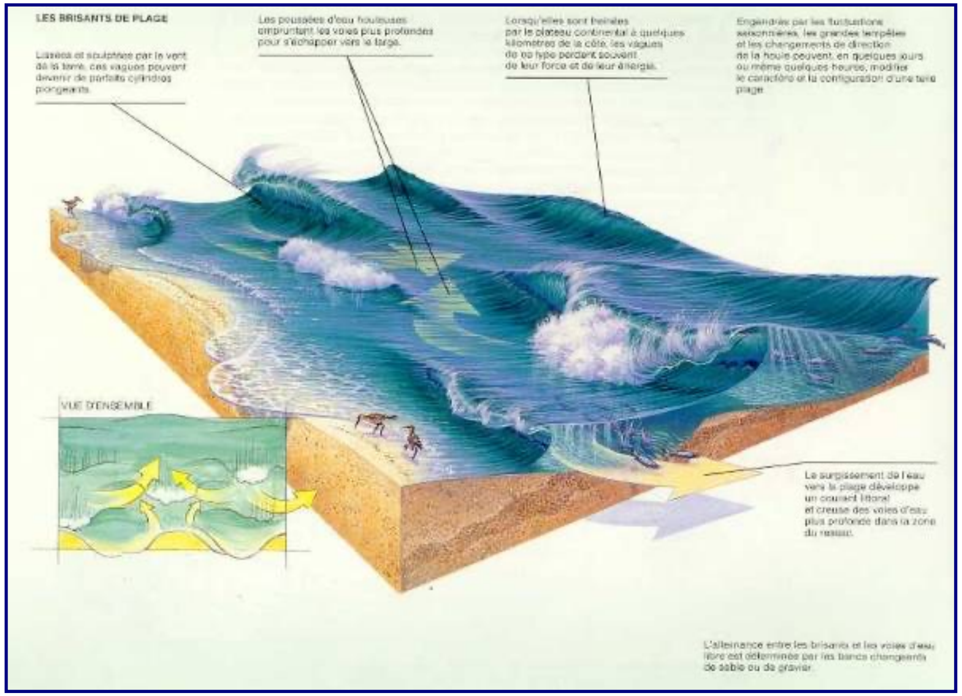
- When a wave interacts with an ecosystem part of the energy is reflected, especially for dense and emerged vegetation fields.



Breaking

Wave steepness exceed a physical limit an particles velocities are larger than wave celerity

Wave energy is dissipated by turbulence and wave height decreases suddenly



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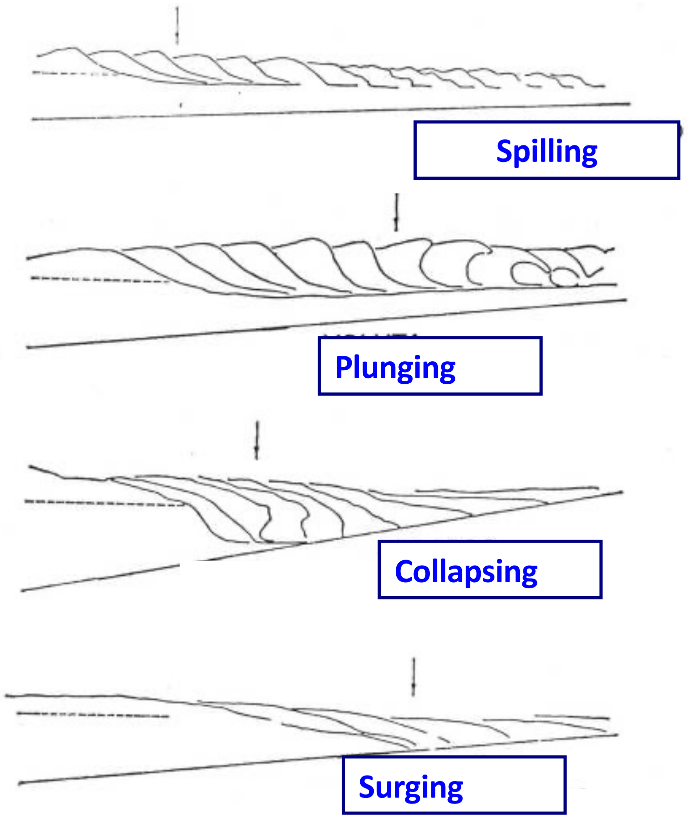
Breaking



There are 4 different types of breakers depending on the Iribarren´s number (also know as surf similarity parameter)

$$I_{ro} = \frac{\tan \alpha}{\sqrt{\frac{H}{L_o}}}$$

Breaker Types	Iribarren number, I_{r0}
Spilling	< 0.4
Plunging	0.4 – 2
Collapsing	2 – 3.1
Surging	> 3.1

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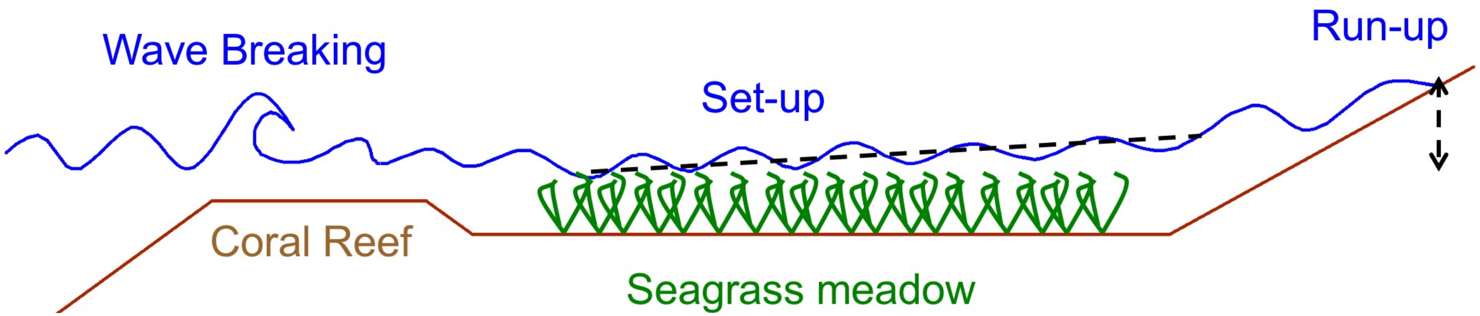
Breaking

- Depending on the depth and the characteristics of the ecosystem, breakage may occur. This is a crucial process in coral reefs.

Long wave

- Set-up: mean water level increase due to wave breaking
- Submerged breakwaters can increase this phenomenon, specially in the presence of infragravity waves
- The same effect has been reported in coral reefs



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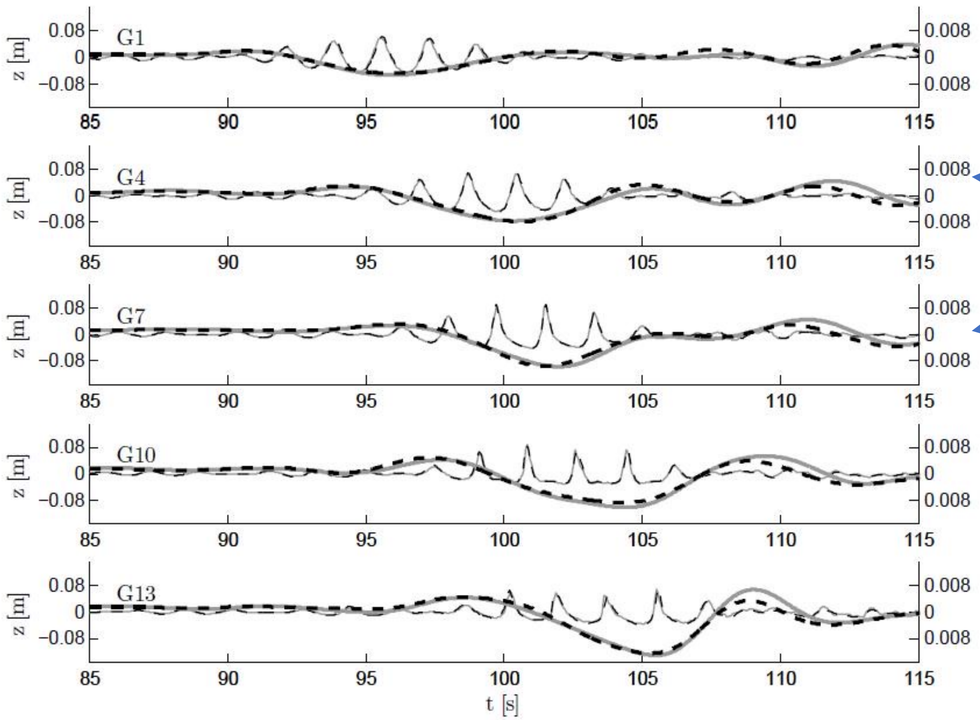
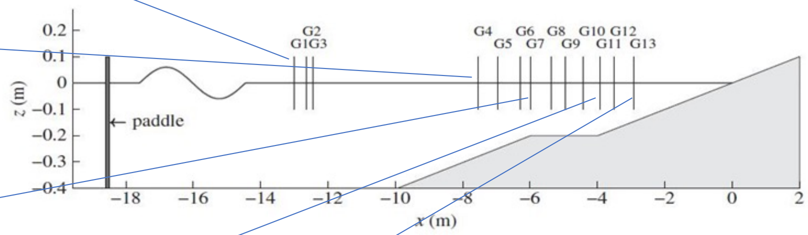
Long wave





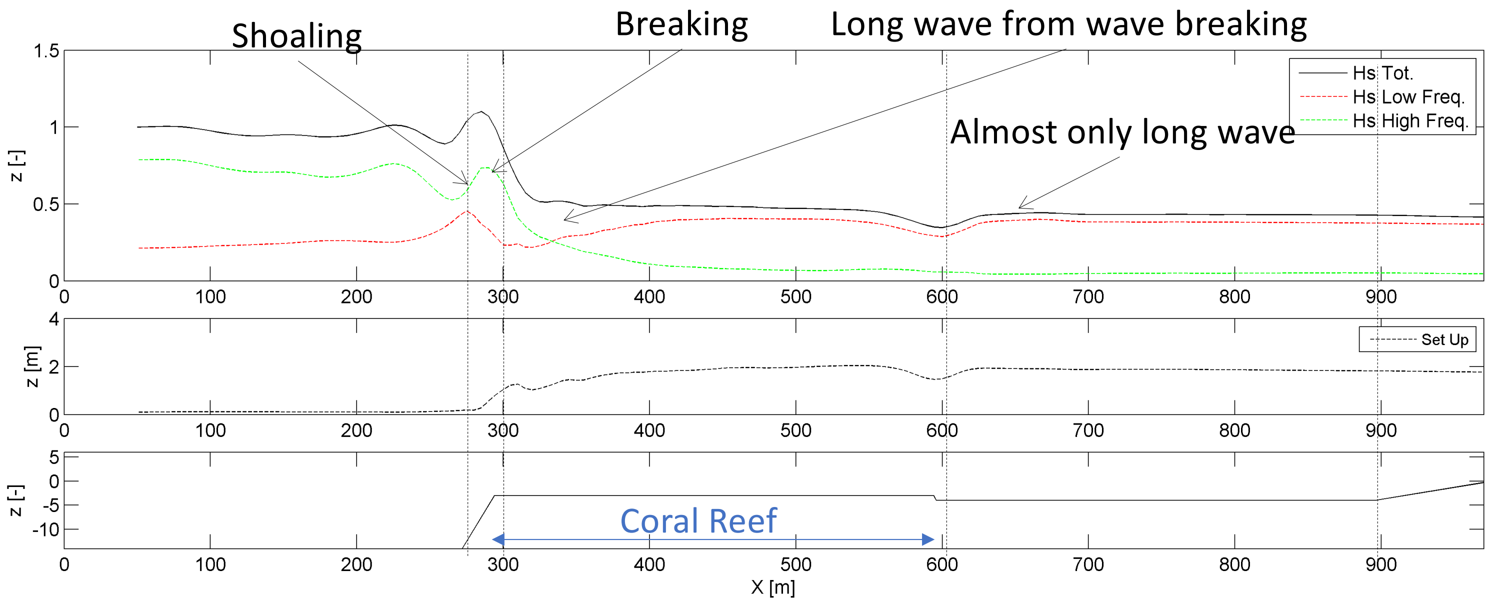
Constan water depth: long wave in phase with the wave group (bound wave)

Shoaling zone: long wave starts to be not at the same phase as the group. Additionally a wave set-up is produced in front of the group.

Surf zone: short waves are dissipated, but long wave doesn't and it can even increase its energy. This long wave is partially reflected back to the ocean when reaching the shoreline.

Long wave

- Example in a coral reef



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Long wave

- Coral reefs are very effective dissipating short waves

- However, in those cases where long waves are important their role should be carefully analyzed when quantifying wave run-up

1 Fuerza de arrastre

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3 **Oleaje y corriente**

4 Tensiones tangenciales

Waves and currents

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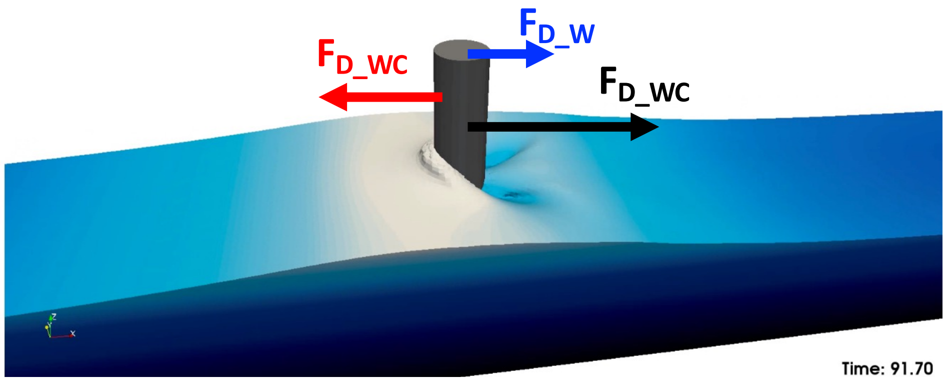
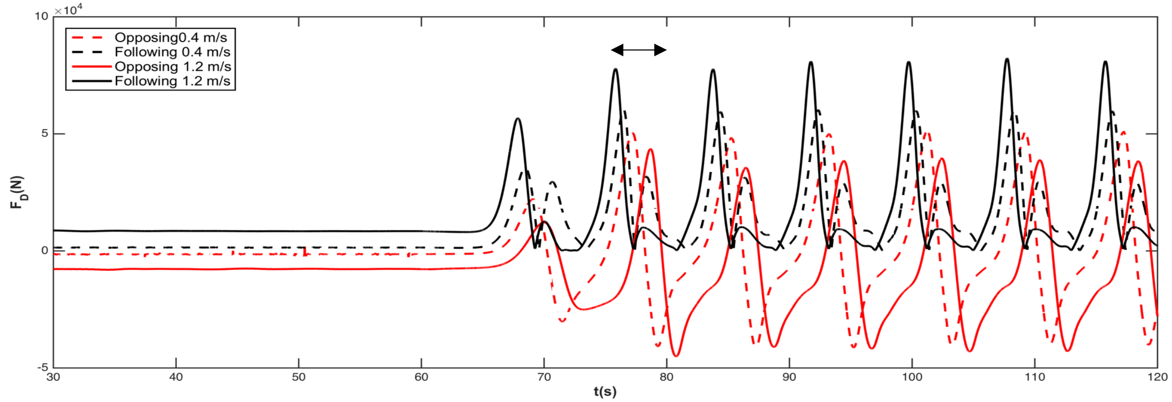
Waves and currents

- Drag force changes





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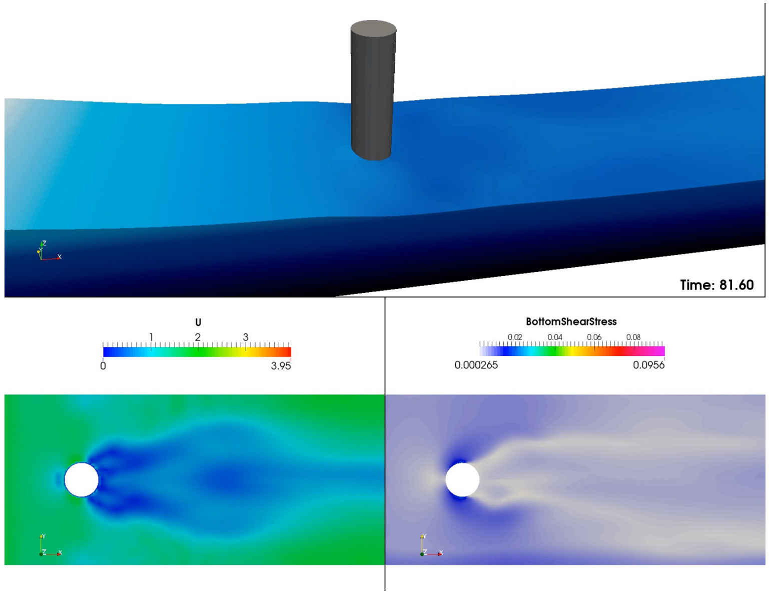
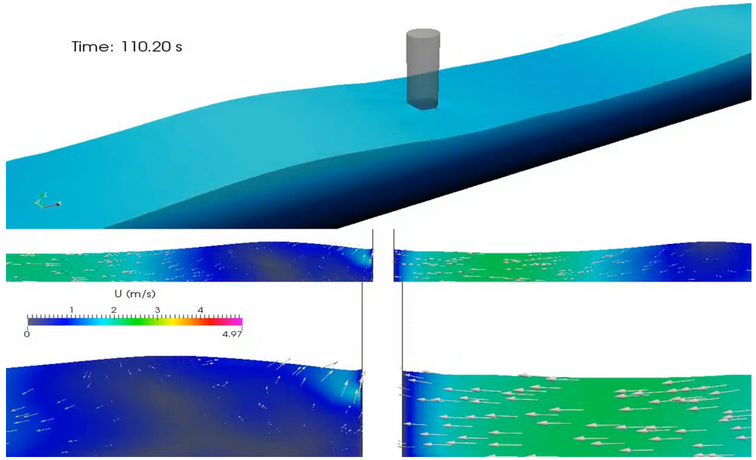
Waves and currents





Waves and currents

- Conservation of energy: $\frac{\partial E_{wc} c_{g_{wc}}}{\partial x} = -\varepsilon_{D_{wc}}$

$$H = \frac{H_0}{1 + \beta_{wc} x}$$

$$\beta_{wc} = \frac{A_0 H_0}{B}$$

$$A_0 = \frac{2}{3\pi} \rho C_{D_{wc}} a N \left(\frac{gk}{2(\sigma - U_0 k)} \right)^3 \frac{sinh^3 kl_D + 3 sinhkl_D}{3k cosh^3 kh}$$

$$B = \left[\frac{\rho g}{8} \left(1 + \frac{2kh}{sinh2kh} \right) \left(\frac{g}{k} tanhkh \right)^{\frac{1}{2}} + \frac{\rho g}{8} U_0 \left(3 + \frac{4kh}{sinh2kh} \right) + \frac{3\rho k}{8} U_0^2 \left(\frac{g}{k} cothkh \right)^{\frac{1}{2}} \right] \left[U_0 + \frac{1}{2} \left(1 + \frac{2kh}{sinh2kh} \right) \left(\frac{g}{k} tanhkh \right)^{\frac{1}{2}} \right]$$

$$C_{Dwc} = \frac{3\pi}{2aN \left(\frac{gk}{2(\sigma - U_0 k)} \right)^3 H_0} \frac{3k cosh^3 kh}{sinh^3 kl_D + 3 sinhkl_D} \left[\frac{g}{8} \left(1 + \frac{2kh}{sinh2kh} \right) \left(\frac{g}{k} tanhkh \right)^{\frac{1}{2}} + \frac{g}{8} U_0 \left(3 + \frac{4kh}{sinh2kh} \right) + \frac{3k}{8} U_0^2 \left(\frac{g}{k} cothkh \right)^{\frac{1}{2}} \right]$$

$$\left[U_0 + \frac{1}{2} \left(1 + \frac{2kh}{sinh2kh} \right) \left(\frac{g}{k} tanhkh \right)^{\frac{1}{2}} \right] \beta_{wc}$$

1 Fuerza de arrastre

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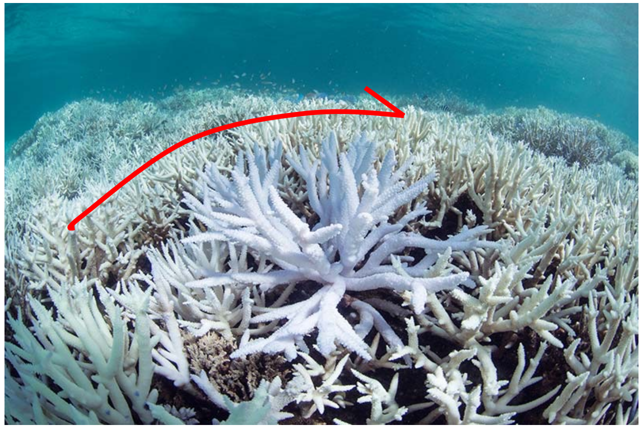
4 **Tensiones tangenciales**

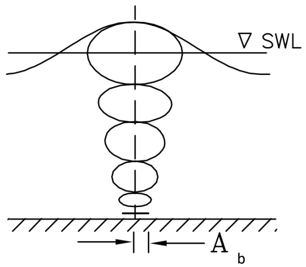
Shear stresses

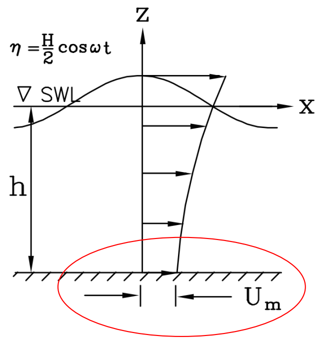
- Shear stresses are very important in vegetation fields and coral reefs: they will determine sediment transport and coral/plants loss by uprooting.



Waves and currents

- There are some analytical formulas for bottom shear stresses:





$$A_b = \frac{H}{2}\frac{\cosh\left(k\left(h-h\right)\right)}{\sinh\left(kh\right)} = \frac{H}{2}\frac{1}{\sinh\left(kh\right)}$$

$$u_b = \frac{H}{2}\sigma\frac{\cosh\left(k\left(h-h\right)\right)}{\sinh\left(kh\right)}\cos\left(k\frac{L}{4}-\sigma t\right) =$$

$$= \frac{H}{2}\sigma\frac{1}{\sinh\left(kh\right)}\sin\left(\sigma t\right) = U_m\sin\left(\sigma t\right) = A_b\sigma\sin\left(\sigma t\right)$$

Linear wave theory assumes no viscous fluid ➔water particle movement on the bottom ➔no true ➔boundary layer

Waves and currents

- For flat bottom and laminar boundary layer: second viscous Newton law:

$$\tau = \rho \nu \frac{\partial u}{\partial z}$$

- The maximum bottom shear stress results:

$$\tau_{b,\max} = \frac{\rho \nu U_{\mathrm{m}}}{\sqrt{\nu / \sigma}}$$

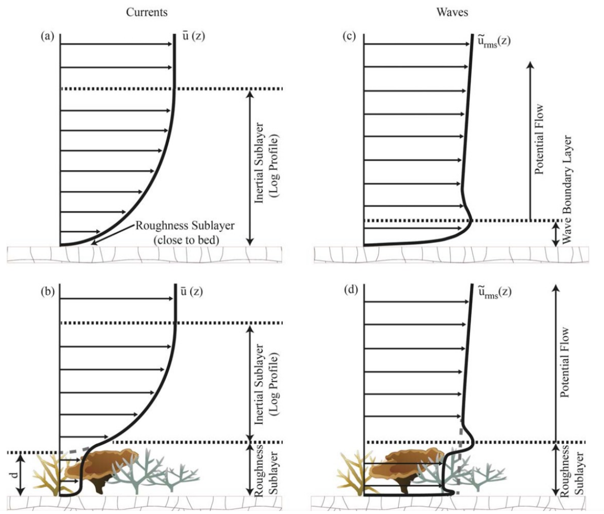
- This shear stress can be expressed as a function of a friction coefficient (Jonsson, 1966):

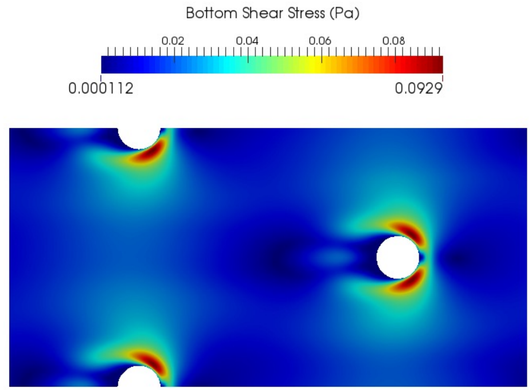
$$\tau_b = \frac{1}{2} \rho f_c U^2 \longrightarrow \tau_{b,\max} = \frac{1}{2} \rho f_w U_m^2$$

R & D + i for sustainable development

Waves and currents

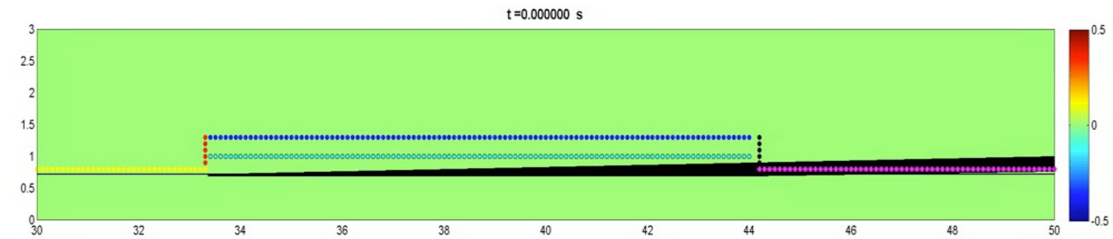
- Shear stress around ecosystem elements is high and can result in loss of ecosystem elements through a combination of sediment loss and force.

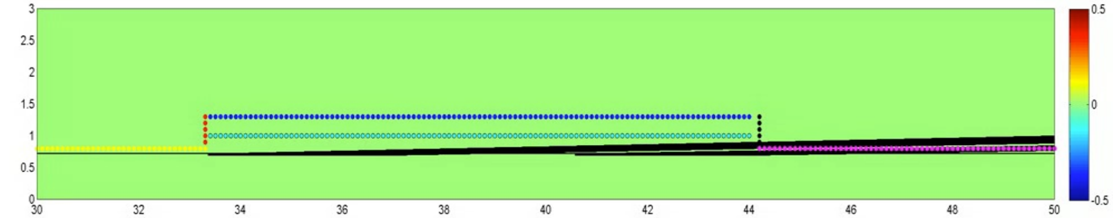




Waves and currents

- Additionally, shear stress on top of submerged canopies influences sediment, nutrients and oxigen transport.





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COHESION 30

¡GRACIAS POR SU ATENCIÓN!
¿PREGUNTAS?

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