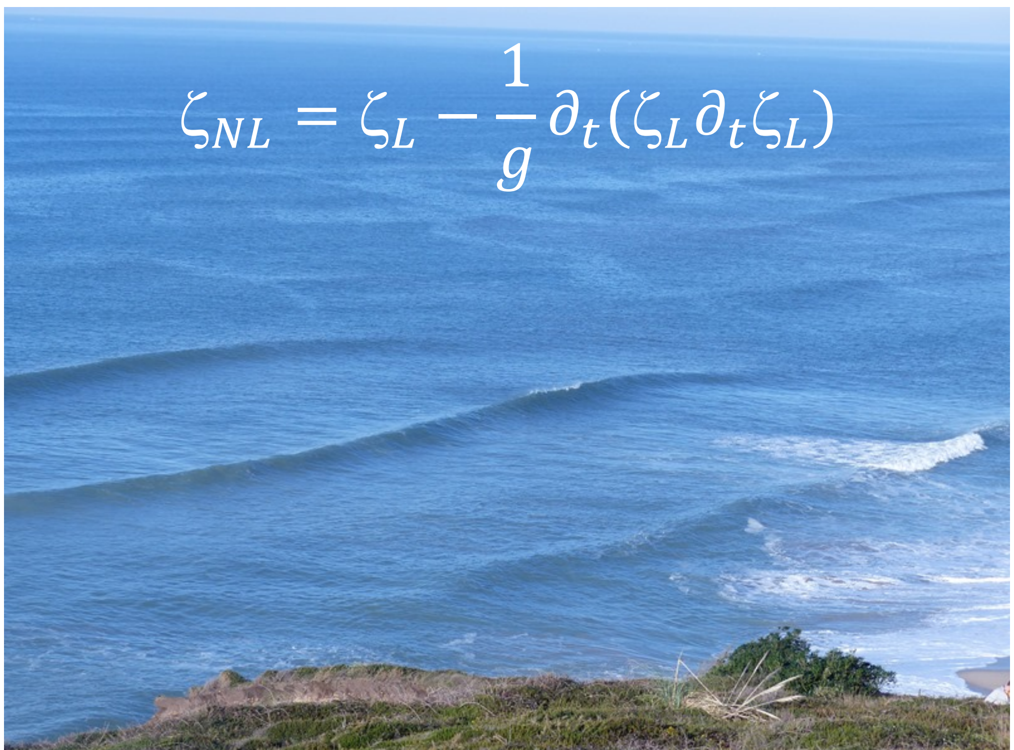
Reconstruction du champ de vagues à partir de la mesure de la pression près du fond

Philippe Bonneton (EPOC) et David Lannes (IMB)



Cadre général :

Les vagues jouent un rôle moteur dans la dynamique littorale

→ **caractérisation par mesure in situ**

Introduction

- circulation induite par les vagues

- transport sédimentaire et érosion

- impact sur les ouvrages côtiers
- franchissement et submersion

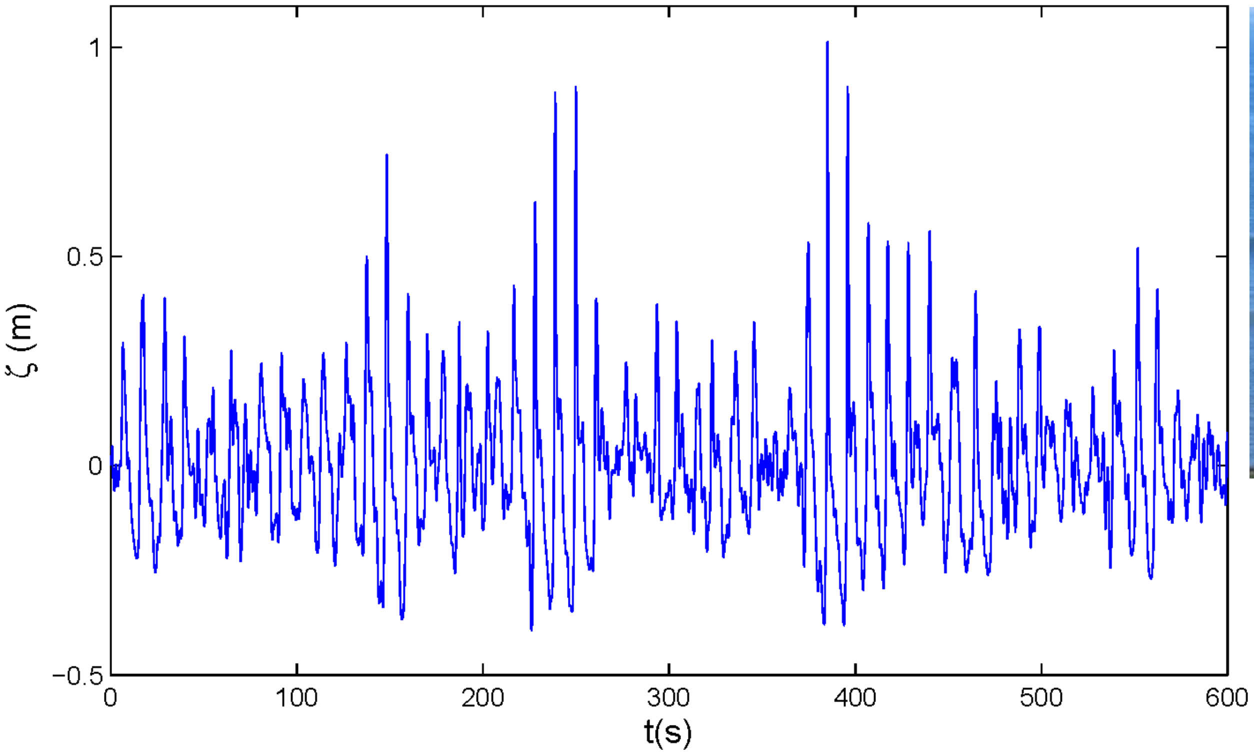
- sécurité de la navigation
  et des baignades
- opérations militaires

⇒ mesures précises des vagues

Depuis la seconde guerre mondiale (Sverdrup and Munk, 1947, Scripps)

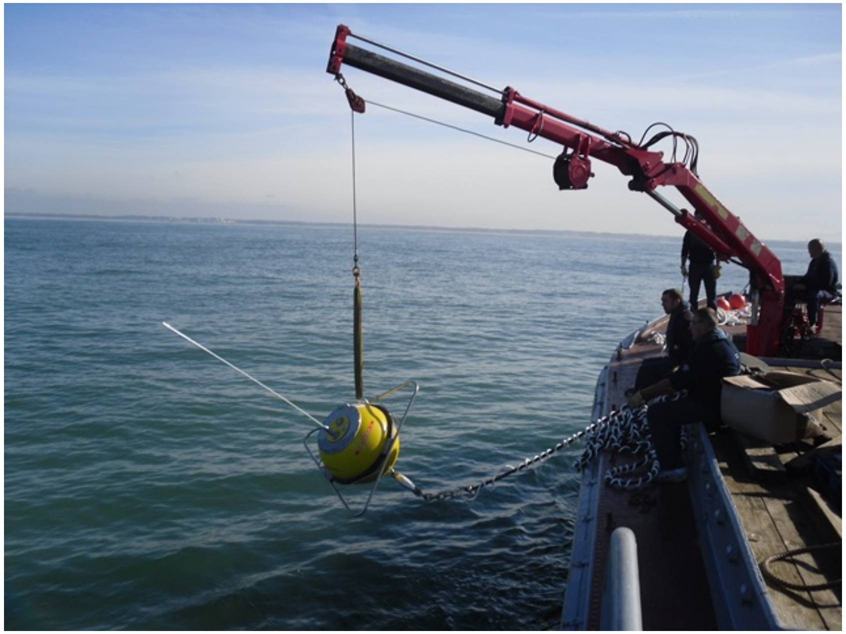
développement de nombreuses méthodes pour la mesure in situ

de la **surface libre des vagues ζ**



Houlographe – bouée côtière

ex.: bouées du Cap Ferret (EPOC) et d'Anglet (SIAME) – réseau CANDHIS



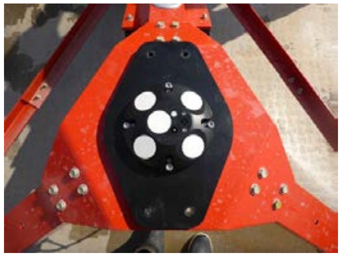
Bouée Datawell

mesures à partir d'accéléromètres

- avantages : assez robuste (tempêtes), transmission temps réel
- inconvénients : coûts (achat, déploiement, entretient), écrête les vagues

Méthodes récentes

Méthode acoustique



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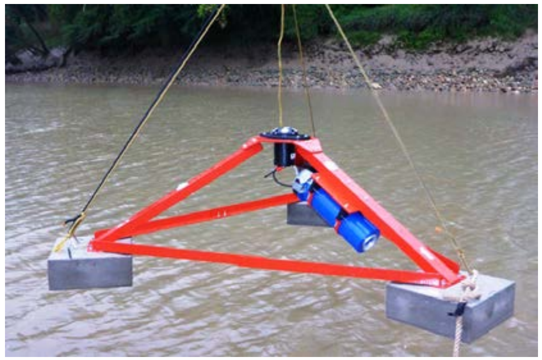
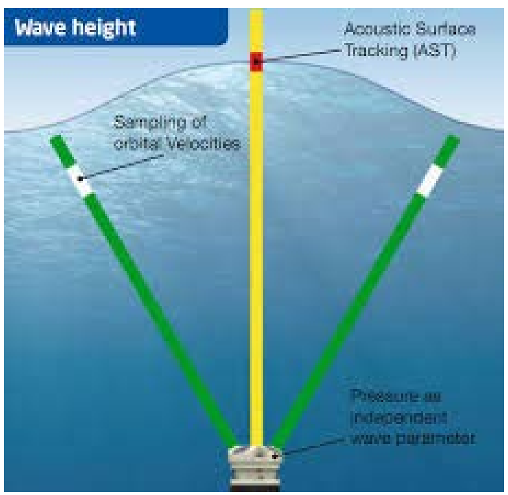
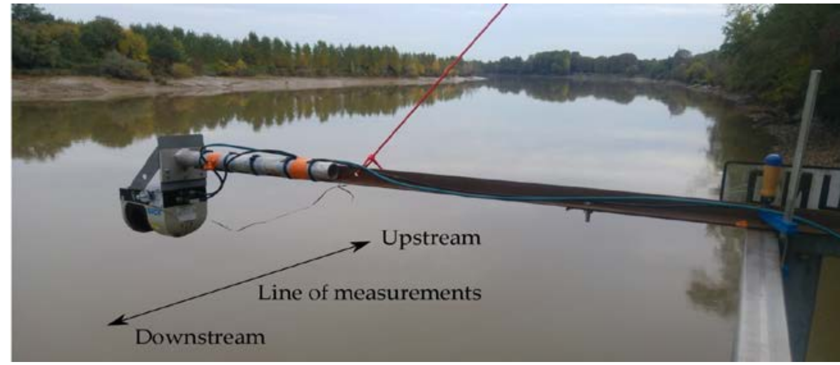
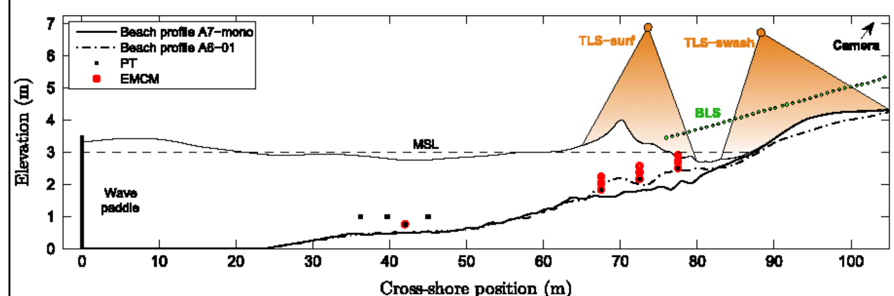




Lidar





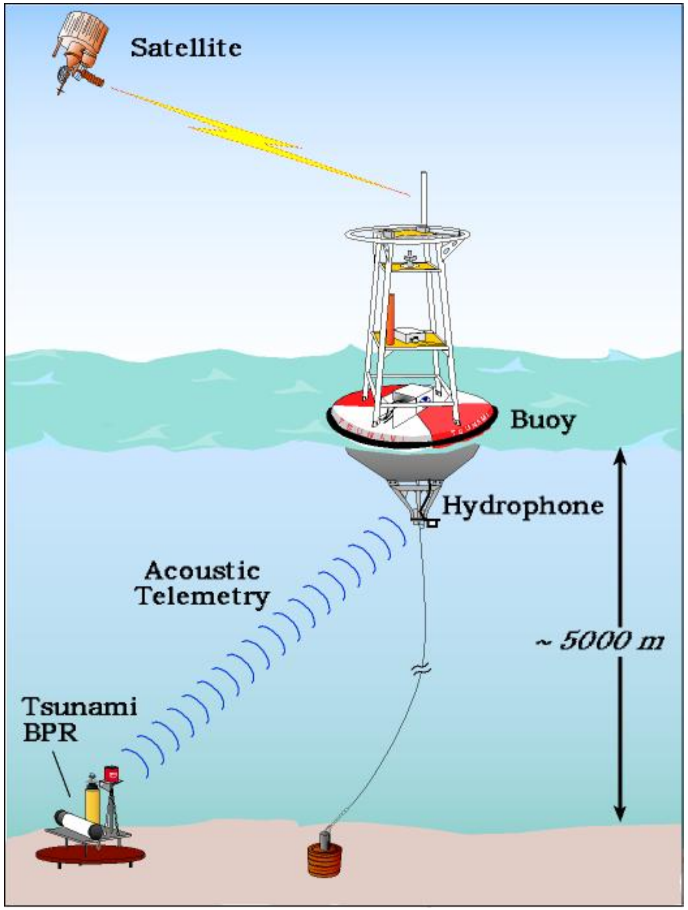
Martins et al. 2017

- ❑ avantages : précision de la mesure
- ❑ inconvénients : cher, fragile, déploiement difficile, faible autonomie

outils pour la recherche : difficile à utiliser pour des mesures à long terme

Capteur de pression

Ocean Sensor Systems
(capteur autonome)



Deep Ocean Assessment of *Tsunami* (*DART*)
(transmission des données)

Capteur de pression

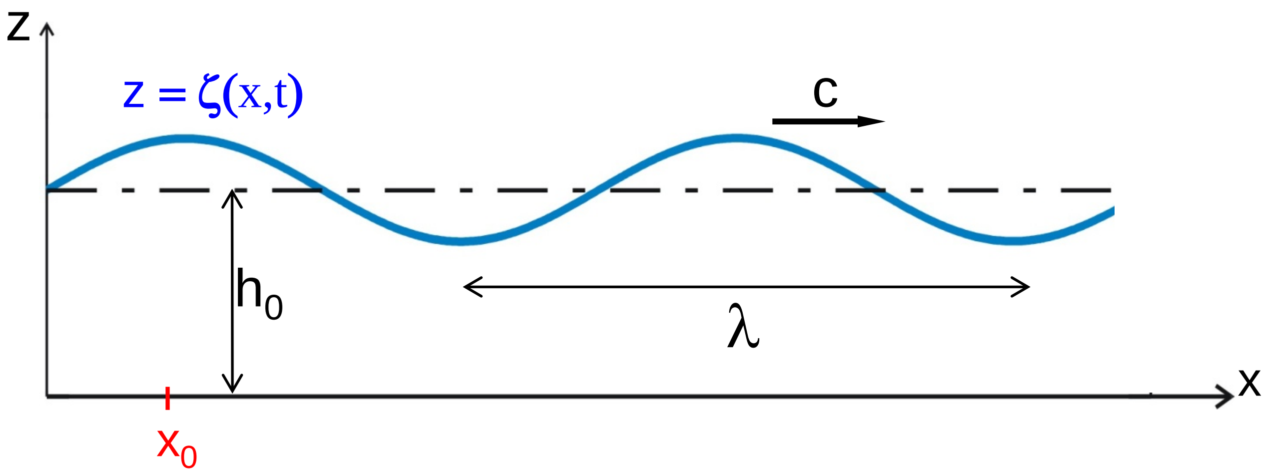
Ocean Sensor Systems
(capteur autonome)

Hurricane Gustav, *Kennedy et al. 2010*

- ❑ avantages : bon marché, robuste (tempête, chalutage, …)
  déploiement facile, grande autonomie

- ❑ inconvénients : mesure indirecte de ζ

→ reconstruction de la surface libre ζ à partir de la pression P_b

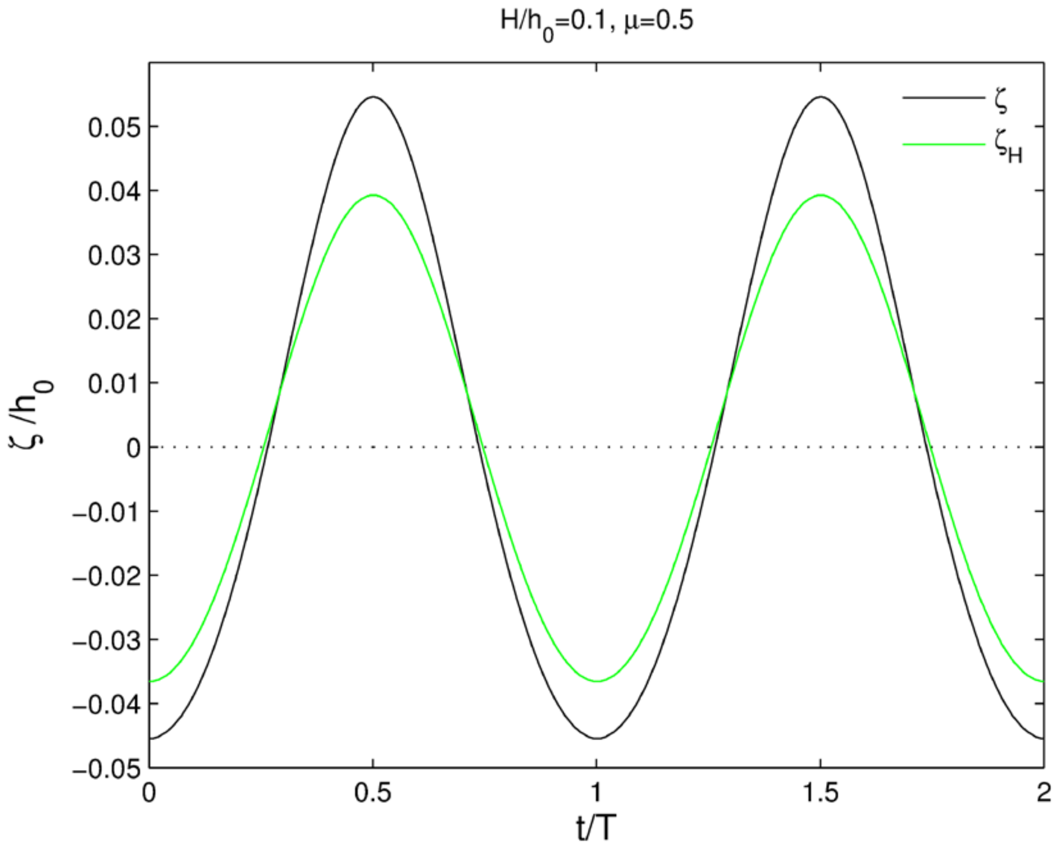


$P_b(x_0,t) \rightarrow \zeta\,(x_0,t)$

Ondes longues (tsunamis, marées, …) → hypothèse hydrostatique

$$\frac{\partial P}{\partial z} = -\rho_0 g \quad \Rightarrow \quad h_H(x_0,t) = \frac{P_b - P_a}{\rho_0 g} \quad \Rightarrow \quad \zeta_H = \frac{P_b - Pa}{\rho_0 g} - h_0$$

Houle et mer du vent



$\rightarrow$ reconstruction non-hydrostatique de ζ

reconstruction non-hydrostatique pour les vagues (houle et mer du vent)

Approche utilisée en océanographie côtière :

$\rightarrow$ théorie linéaire non-hydrostatique

Folsom (1947), Seiwell (1947), Hom-ma et al. (1966), Cavaleri et al. (1978),

Guza et Thornton (1980), … Karimpour et Chen (2017)

reproduit correctement les caractéristiques moyennes des vagues mais décrit mal la forme et l'élévation max des vagues non-linéaires

$\rightarrow$ jusqu'à 30% d'erreur sur la hauteur des vagues

Martins et al. 2017 et Bonneton et al. 2018

reconstruction non-hydrostatique pour les vagues (houle et mer du vent)

Approche utilisée en océanographie côtière :

$\rightarrow$ théorie linéaire non-hydrostatique

Folsom (1947), Seiwell (1947), Hom-ma et al. (1966), Cavaleri et al. (1978), Guza et Thornton (1980), … Karimpour et Chen (2017)

toujours utilisée pour l'opérationnel et la recherche

reproduit correctement les caractéristiques moyennes des vagues mais décrit mal la forme et l'élévation max des vagues non-linéaires

$\rightarrow$ reconstruction non-hydrostatique non-linéaire de ζ

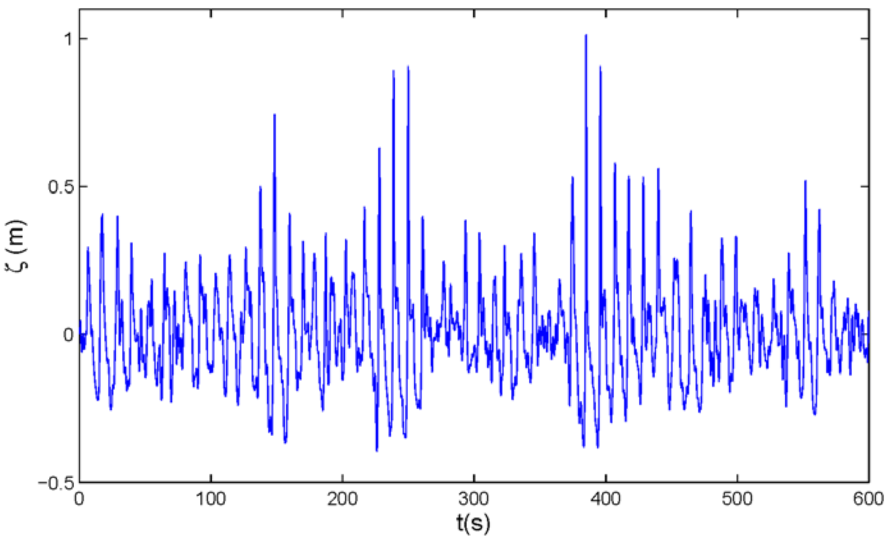
reconstruction non-hydrostatique non-linéaire de ζ

Plusieurs approches théoriques récentes

vagues unidirectionnelles de forme permanente : soliton ou houle périodique

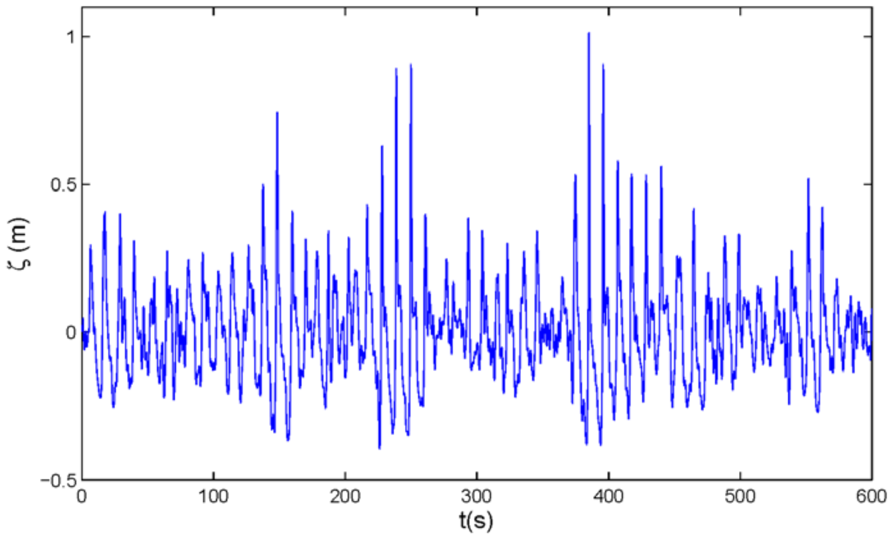
Deconink et al. (2012), Oliveras et al. (2012), Constantin (2012), Clamond (2013)

⇒ études à caractère fondamental pas applicables aux vagues réelles en milieu naturel



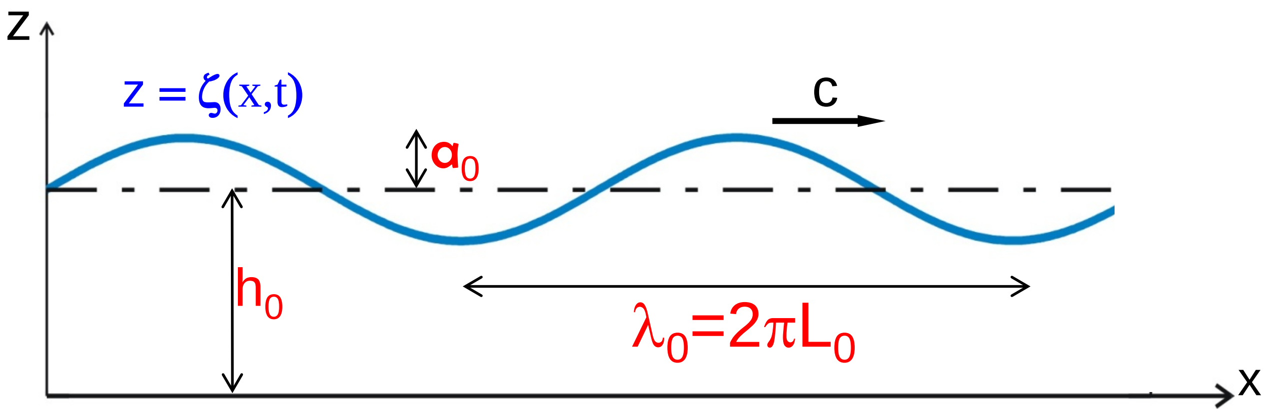
reconstruction non-hydrostatique non-linéaire de ζ

Développement d'un approche non-linéaire applicable aux vagues irrégulières observées en milieu océanique



Position du problème et équations

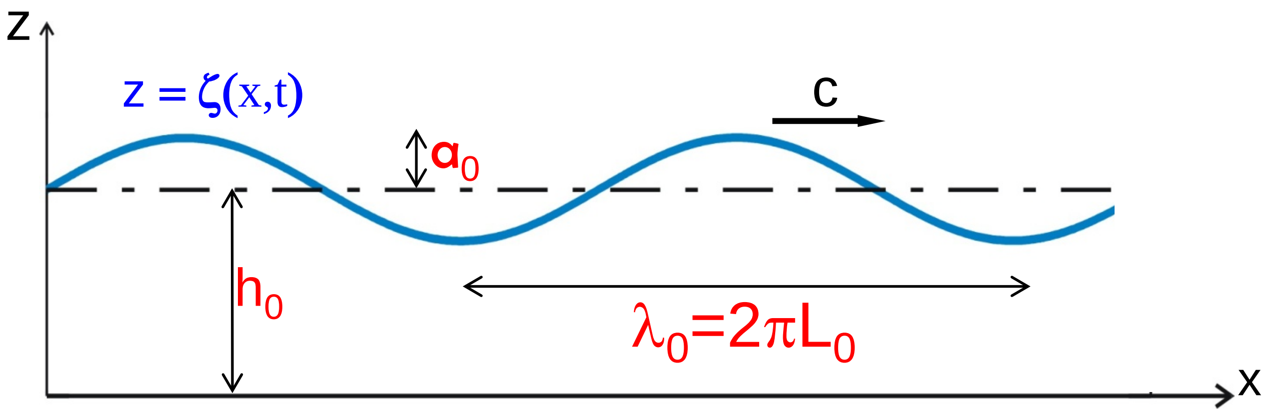
Position du problème et équations



$$\varepsilon = \frac{a_0}{h_0} \qquad \mu = \left(\frac{h_0}{L_0}\right)^2$$

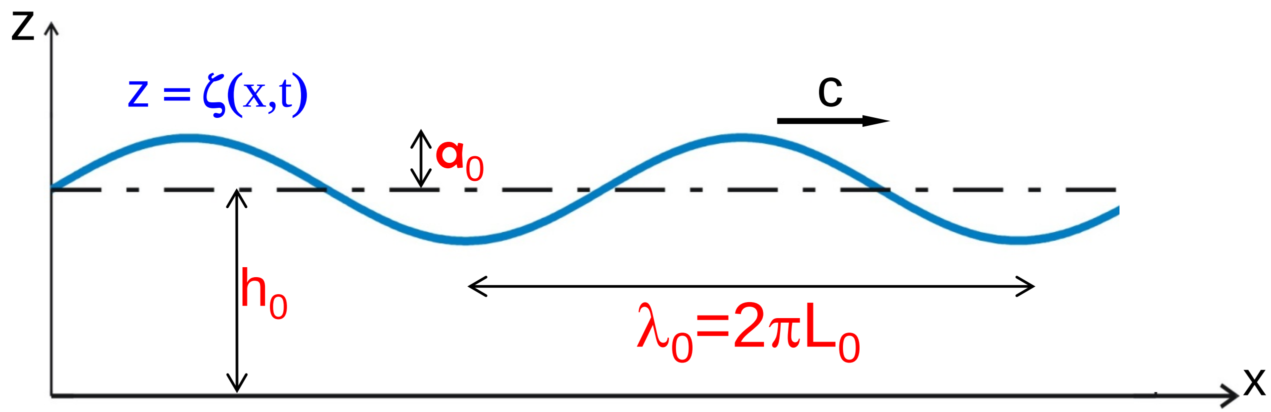
$$\sigma = \frac{a_0}{L_0} = \varepsilon\sqrt{\mu}$$

Position du problème et équations



$$\varepsilon = \frac{a_0}{h_0} \lesssim 1 \qquad \mu = \left(\frac{h_0}{L_0}\right)^2 \qquad \frac{\zeta_H}{a_0} \sim \frac{1}{\cosh(\sqrt{\mu}k)}$$

Position du problème et équations



$$\varepsilon = \frac{a_0}{h_0} \lesssim 1 \qquad\qquad \mu = \left(\frac{h_0}{L_0}\right)^2 \lesssim 1$$

$$\sigma = \frac{a_0}{L_0} = \varepsilon\sqrt{\mu} \ll 1$$

développements asymptotiques $\rightarrow$

$\zeta(x,t)$ fonction de $\zeta_H = \dfrac{P_b(x,t) - P_a}{\rho_0 g} - h_0$

$$
\begin{aligned}
\frac{\partial u}{\partial x}+\frac{\partial w}{\partial z} &= 0 \\
\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+w\frac{\partial u}{\partial z} &= -\frac{1}{\rho_0}\frac{\partial P}{\partial x} & & z\in[-h_0,\zeta(x,t)] \\
\frac{\partial w}{\partial t}+u\frac{\partial w}{\partial x}+w\frac{\partial w}{\partial z} &= -\frac{1}{\rho_0}\frac{\partial P}{\partial z}-g
\end{aligned}
$$

$$
\begin{aligned}
P &= P_a & & z=\zeta(x,t) \\
\frac{\partial \zeta}{\partial t}+u\frac{\partial \zeta}{\partial x} &= w & & z=\zeta(x,t) \\
w &= 0 & & z=-h_0
\end{aligned}
$$

$$
\begin{aligned}
\frac{\partial^2\Phi}{\partial x^2}+\frac{\partial^2\Phi}{\partial z^2} &= 0 && z\in[-h_0,\zeta(x,t)]\\
\frac{\partial\Phi}{\partial t}+\frac{1}{2}\left(\left(\frac{\partial\Phi}{\partial x}\right)^2+\left(\frac{\partial\Phi}{\partial z}\right)^2\right)+g\zeta &= 0 && z=\zeta(x,t)\\
\frac{\partial\zeta}{\partial t}+\frac{\partial\Phi}{\partial x}\frac{\partial\zeta}{\partial x} &= \frac{\partial\Phi}{\partial z} && z=\zeta(x,t)\\
\frac{\partial\Phi}{\partial z} &= 0 && z=-h_0
\end{aligned}
$$

$$
P(x,z,t)=P_a-\rho_0 gz-\rho_0\left(\frac{\partial\Phi}{\partial t}+\frac{1}{2}\left(\left(\frac{\partial\Phi}{\partial x}\right)^2+\left(\frac{\partial\Phi}{\partial z}\right)^2\right)\right)
$$

$$
\zeta_H=\frac{P_b-P_a}{\rho_0 g}-h_0=-\frac{1}{g}\left(\frac{\partial\Phi}{\partial t}+\frac{1}{2}\left(\frac{\partial\Phi}{\partial x}\right)^2\right)|_{z=-h_0}
$$

Adimensionnement des équations

$$x' = \frac{x}{L}, \quad z' = \frac{z}{h_0}, \quad t' = \frac{\sqrt{gh_0}}{L}t, \quad \zeta' = \frac{\zeta}{a}$$

$$\Phi' = \frac{h_0}{aL\sqrt{gh_0}}\Phi, \quad P' = \frac{P}{\rho g h_0},$$

Position du problème et équations

$$
\begin{aligned}
\mu \frac{\partial^2 \Phi}{\partial x^2} + \frac{\partial^2 \Phi}{\partial z^2} &= 0 & z \in [-1, \epsilon\zeta] \\
\frac{\partial \Phi}{\partial t} + \frac{1}{2}\left(\epsilon \left(\frac{\partial \Phi}{\partial x}\right)^2 + \frac{\epsilon}{\mu}\left(\frac{\partial \Phi}{\partial z}\right)^2\right) + \zeta &= 0 & z = \epsilon\zeta \\
\frac{\partial \zeta}{\partial t} + \epsilon \frac{\partial \Phi}{\partial x}\frac{\partial \zeta}{\partial x} &= \frac{1}{\mu}\frac{\partial \Phi}{\partial z} & z = \epsilon\zeta \\
\frac{\partial \Phi}{\partial z} &= 0 & z = -1
\end{aligned}
$$

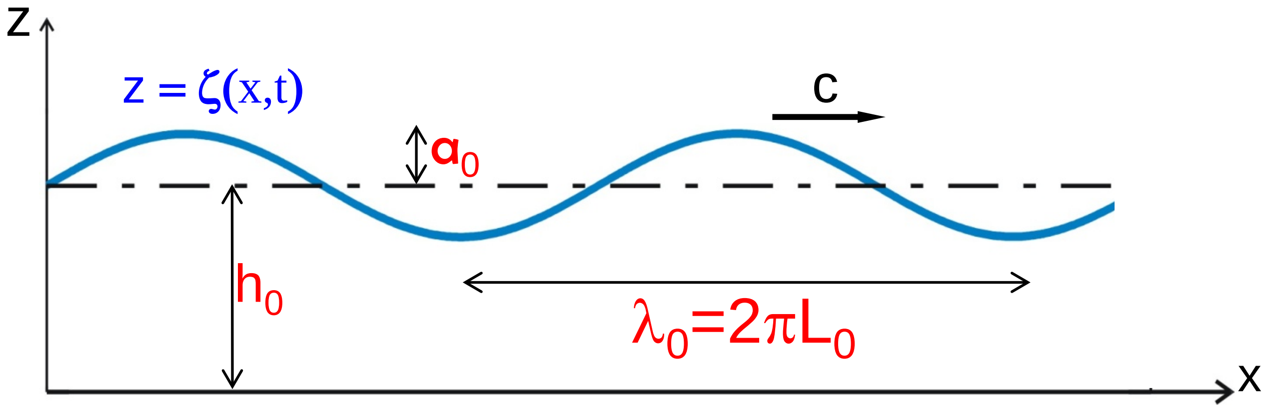
$$
\zeta_H = -\left(\frac{\partial \Phi}{\partial t} + \frac{1}{2}\varepsilon \left(\frac{\partial \Phi}{\partial x}\right)^2\right)\Big|_{z=-1}
$$

développements asymptotiques $\rightarrow$

$\zeta(x, t)$ fonction de $\zeta_H = \frac{P_b(x,t) - P_a}{\rho_0 g} - h_0$

Reconstruction entièrement dispersive

Bonneton, P., and Lannes, D. 2017. Recovering water wave elevation from pressure measurements. ***J. of Fluid Mech***., **833**, 399-429.



$$\sigma = \frac{a_0}{L_0} \ll 1$$

$$\phi = \phi_0 + \sigma\phi_1 + O(\sigma^2)$$

$$
\begin{aligned}
\mu \frac{\partial^2 \Phi}{\partial x^2} + \frac{\partial^2 \Phi}{\partial z^2} &= 0 & z \in [-1, 0] \\
\frac{\partial \Phi}{\partial t} + \zeta &= 0 & z = 0 \\
\frac{\partial \zeta}{\partial t} - \frac{1}{\mu} \frac{\partial \Phi}{\partial z} &= 0 & z = 0 \\
\frac{\partial \Phi}{\partial z} &= 0 & z = -1
\end{aligned}
$$

$$
\zeta_H = -\left(\frac{\partial \Phi}{\partial t} \right) |_{z=-1}
$$

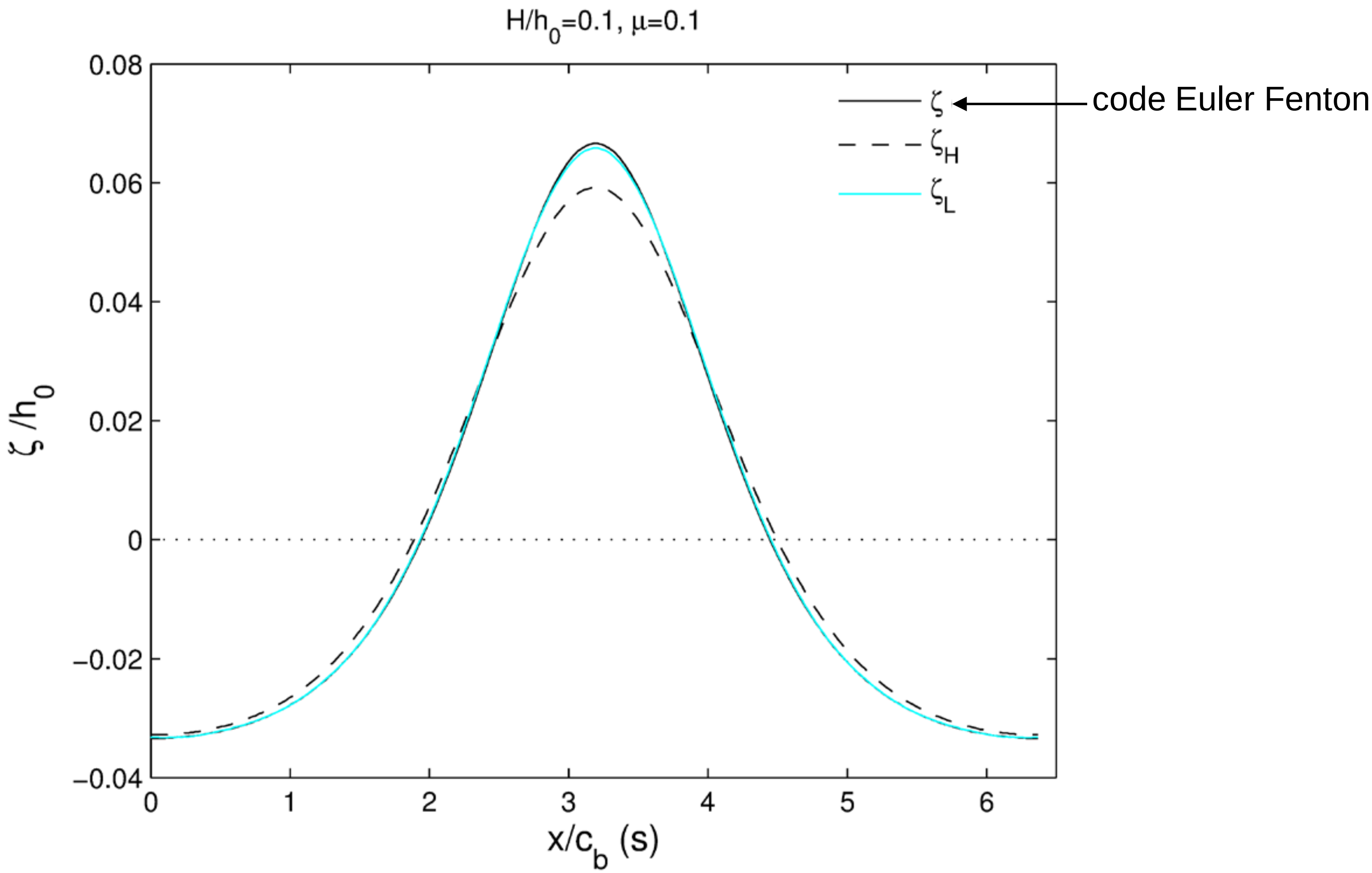
$$
\Phi(x, z, t) = \int_{\mathbb{R}} \widehat{\Phi}(k, z, t) e^{ikx} \, dk
$$

$$
\boxed{\widehat{\zeta}(k, t) = \cosh(\sqrt{\mu}|k|)\widehat{\zeta}_H}
$$

nécessite de connaître ζ_H(x,t)

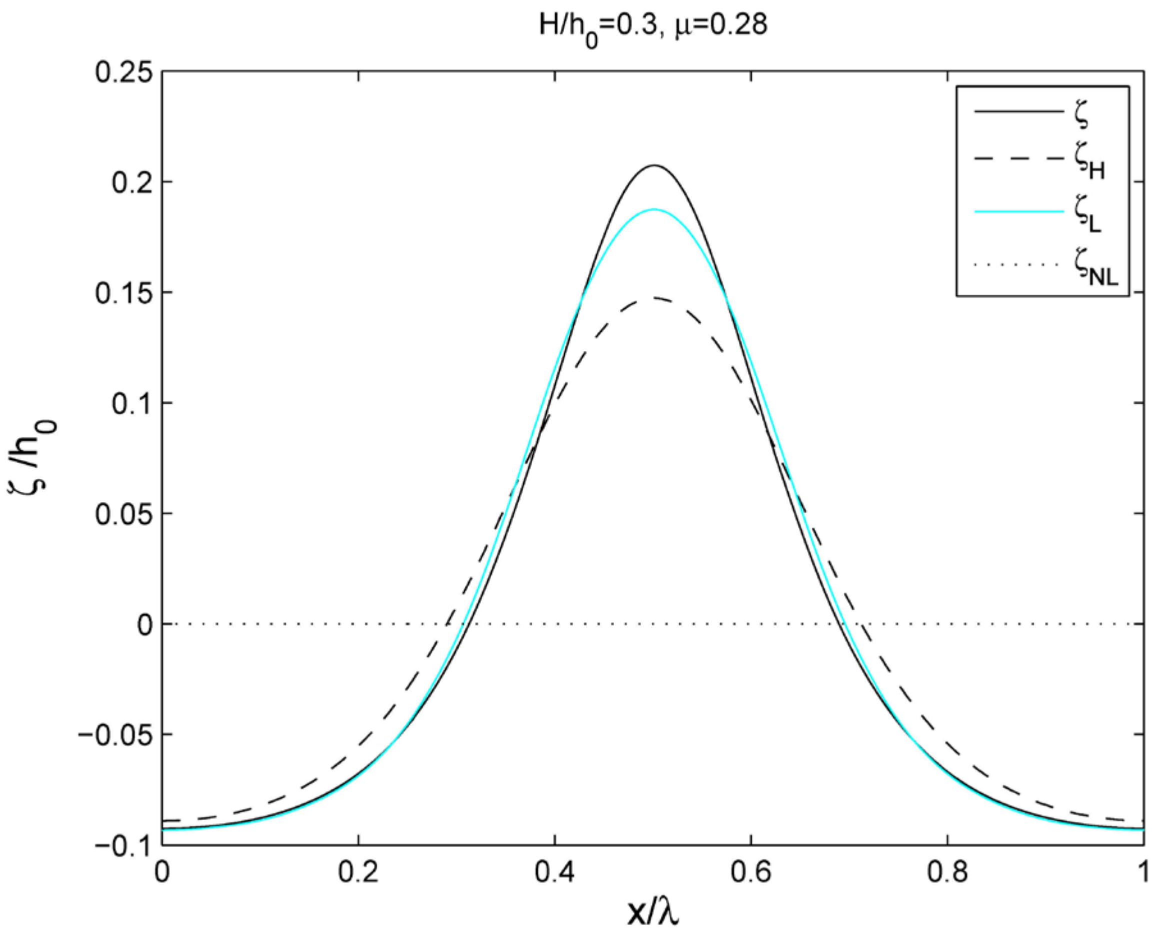
vagues de forme permanente

$$\zeta_H = \frac{P_b - P_a}{\rho_0 g} - h_0 \qquad\qquad \hat{\zeta}_L(k) = \cosh(h_0|k|)\,\hat{\zeta}_H(k)$$



vagues de forme permanente

$$\zeta_H = \frac{\mathrm{P_b} - \mathrm{P_a}}{\rho_0 g} - h_0 \qquad\qquad \hat{\zeta}_L(k) = \cosh(h_0|k|)\,\hat{\zeta}_H(k)$$



$$\phi = \phi_0 + \sigma\phi_1 + O(\sigma^2)$$

voir Lannes (Livre, 2013)

$$\boxed{\zeta = \zeta_L - \sqrt{\mu}\sigma\, \partial_t(\zeta_L \partial_t \zeta_L) + O(\sigma^2)}$$

$$\hat{\zeta}_L(k) = \cosh\left(\sqrt{\mu}|k|\right) \hat{\zeta}_H(k)$$

$$\phi = \phi_0 + \sigma\phi_1 + O(\sigma^2)$$

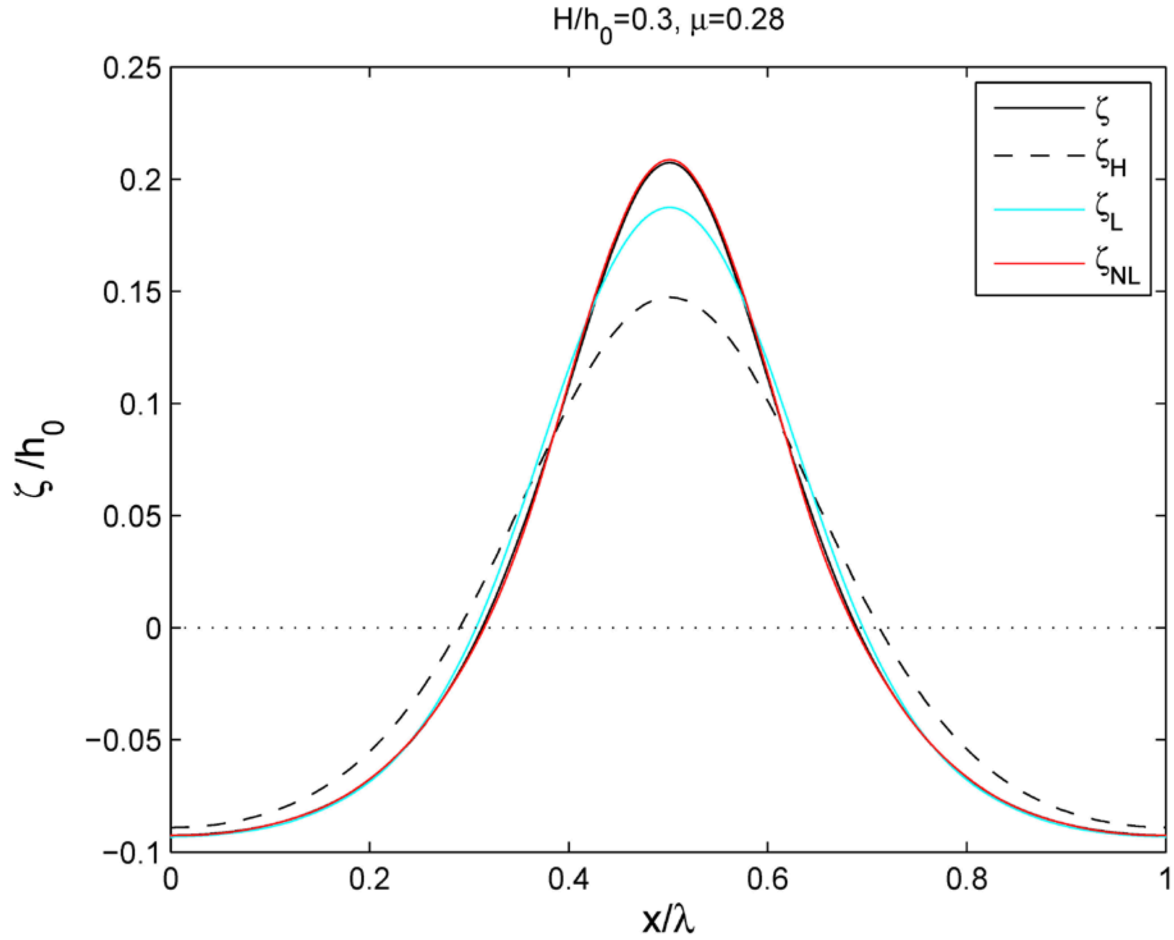
voir Lannes (Livre, 2013) et Bonneton et Lannes (JFM, 2017)

$$\boxed{\zeta_{NL} = \zeta_L - \sqrt{\mu}\sigma\, \partial_t(\zeta_L \partial_t \zeta_L)}$$

$$\hat{\zeta}_L(k) = \cosh\left(\sqrt{\mu}|k|\right) \hat{\zeta}_H(k)$$

$$\zeta_{NL} = \zeta_L - \sqrt{\mu}\sigma\, (\zeta_L \partial_t^2 \zeta_L + (\partial_t \zeta_L)^2)$$

$$\zeta_{NL} = \zeta_L - \sqrt{\mu}\sigma\left(\zeta_L \partial_t^2 \zeta_L + (\partial_t \zeta_L)^2\right)$$



$$\boxed{\begin{gathered}\zeta_{NL} = \zeta_L - \sqrt{\mu}\sigma\,\partial_t(\zeta_L\partial_t\zeta_L) \\ \hat{\zeta}_L(k) = \cosh\left(\sqrt{\mu}|k|\right)\hat{\zeta}_H(k)\end{gathered}}$$

→ nécessite de connaître

$$\zeta_H(x,t) = \frac{P_{b(x,t)} - Pa - 1}{\varepsilon}$$

en pratique on connait seulement $P_b(x_0, t)$

$\rightarrow$ comment reconstruire $\zeta(x_0, t)$ à partir d'une mesure localisée en x_0 ?

Vagues linéaires

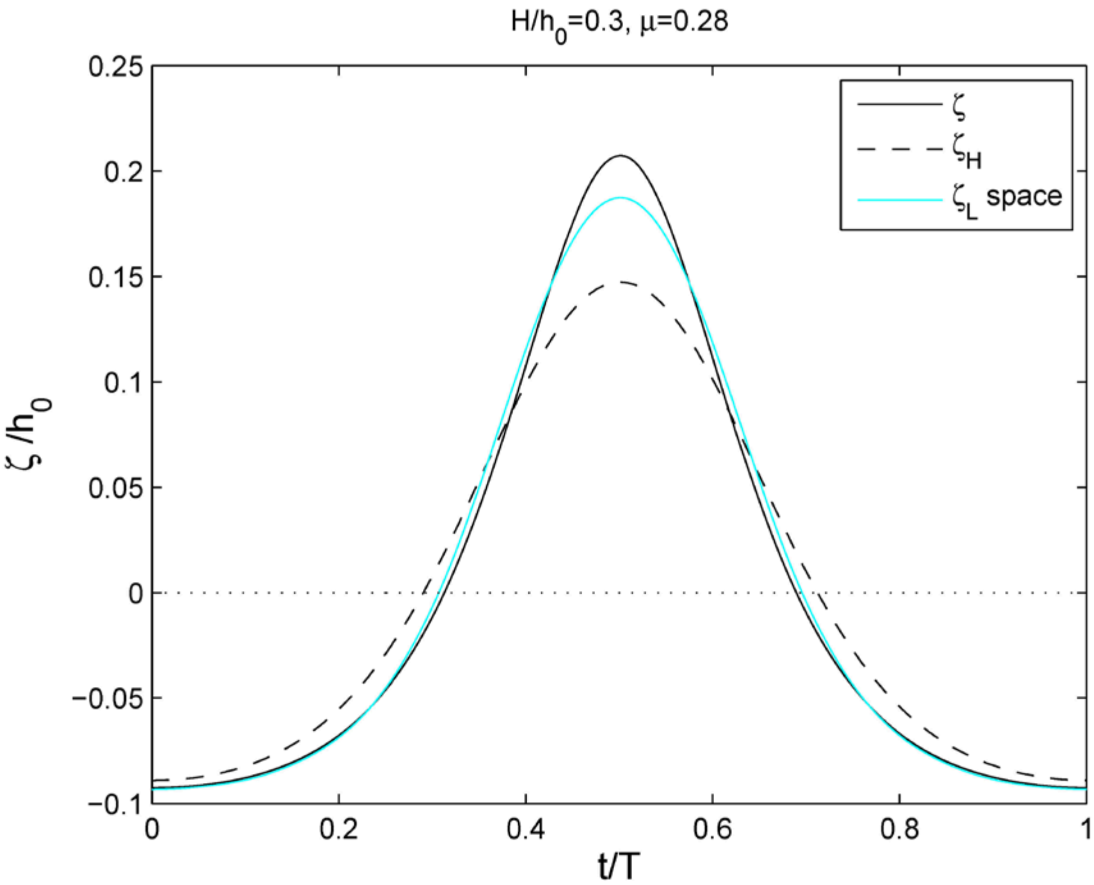
$$\boxed{\widehat{\zeta} = \cosh(\sqrt{\mu}|k|)\widehat{\zeta}_H}$$

$$\frac{\partial^2 \widehat{\zeta}}{\partial t^2} + \omega^2 \widehat{\zeta} = 0 \qquad \omega^2 = \frac{1}{\sqrt{\mu}}|k| \tanh(\sqrt{\mu}|k|)$$

$$\boxed{\tilde{\zeta}(\omega, x) = \cosh(\sqrt{\mu}|k(\omega)|)\tilde{\zeta}_H(\omega, x)}$$

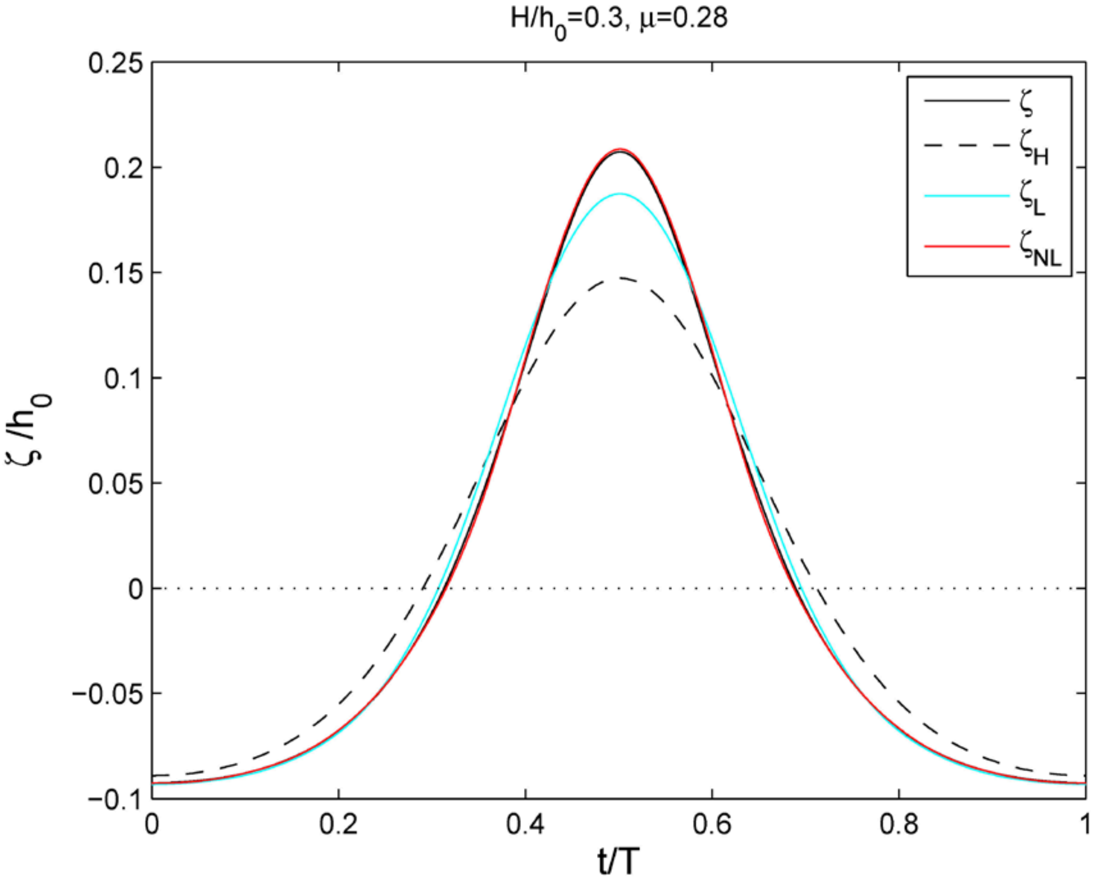
Vagues non-linéaires

<u>reconstructions linéaires</u> : spatiale et temporelle



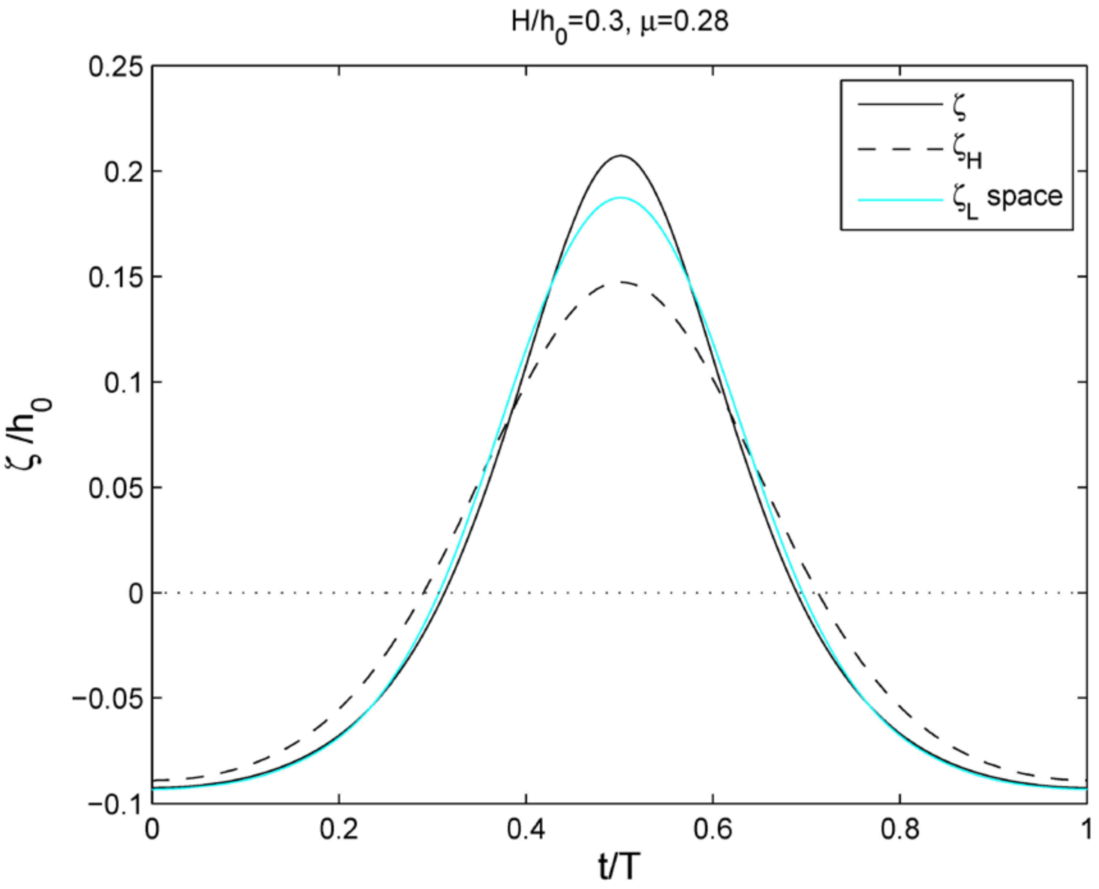
Vagues non-linéaires

reconstructions linéaires : spatiale et temporelle

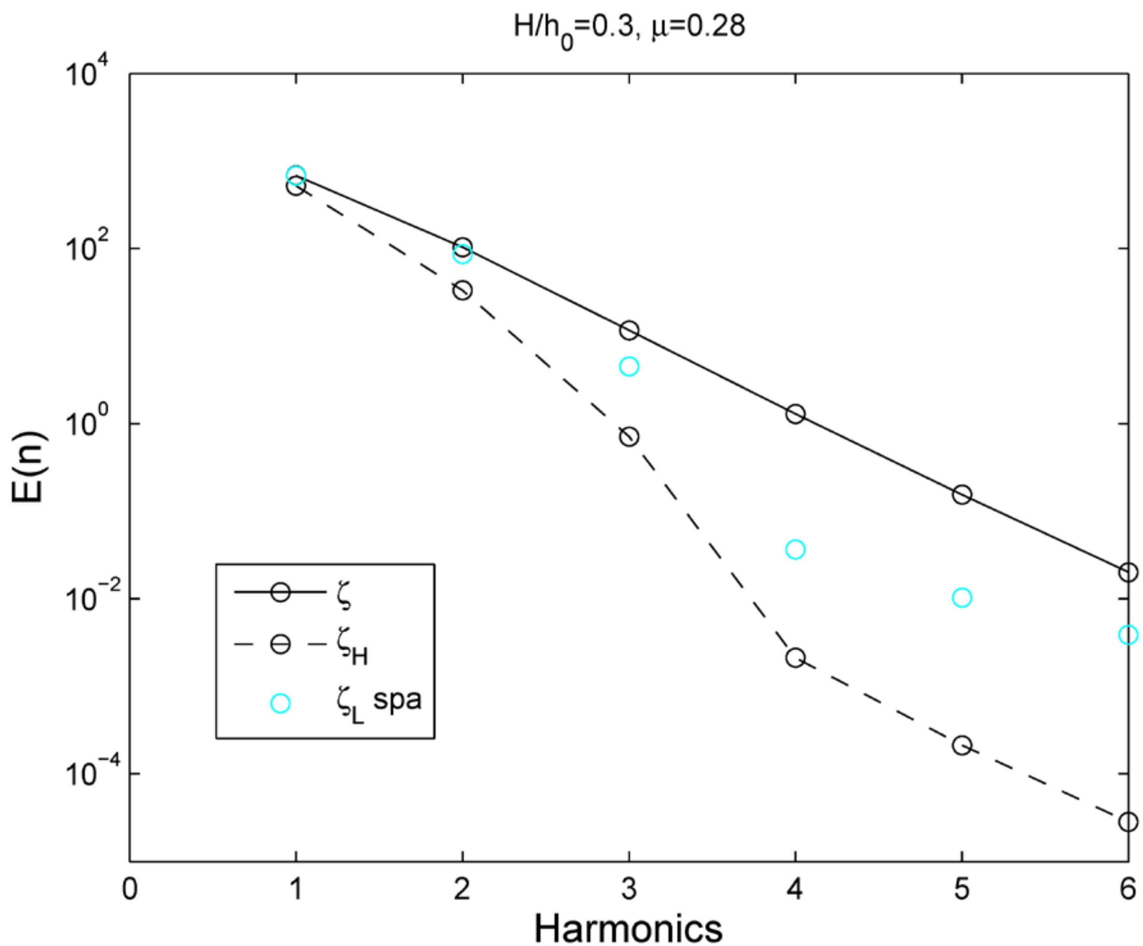


Vagues non-linéaires

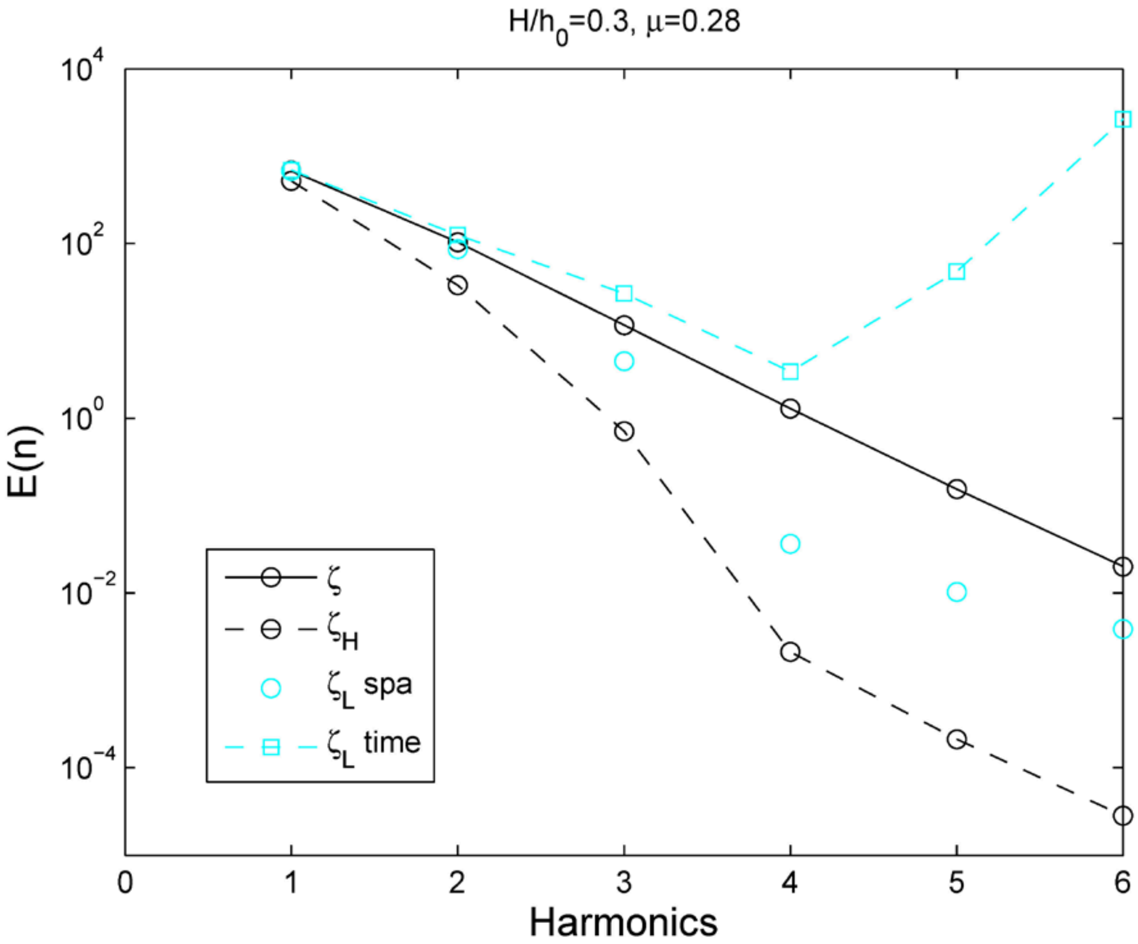
<u>reconstructions linéaires</u> : spatiale et temporelle



Vagues non-linéaires



Vagues non-linéaires

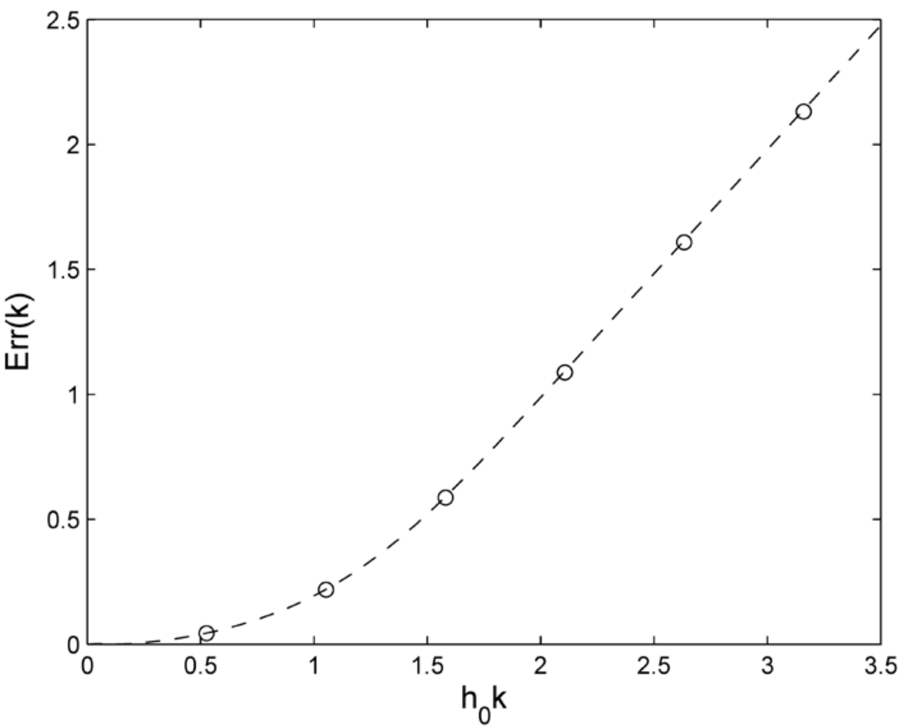


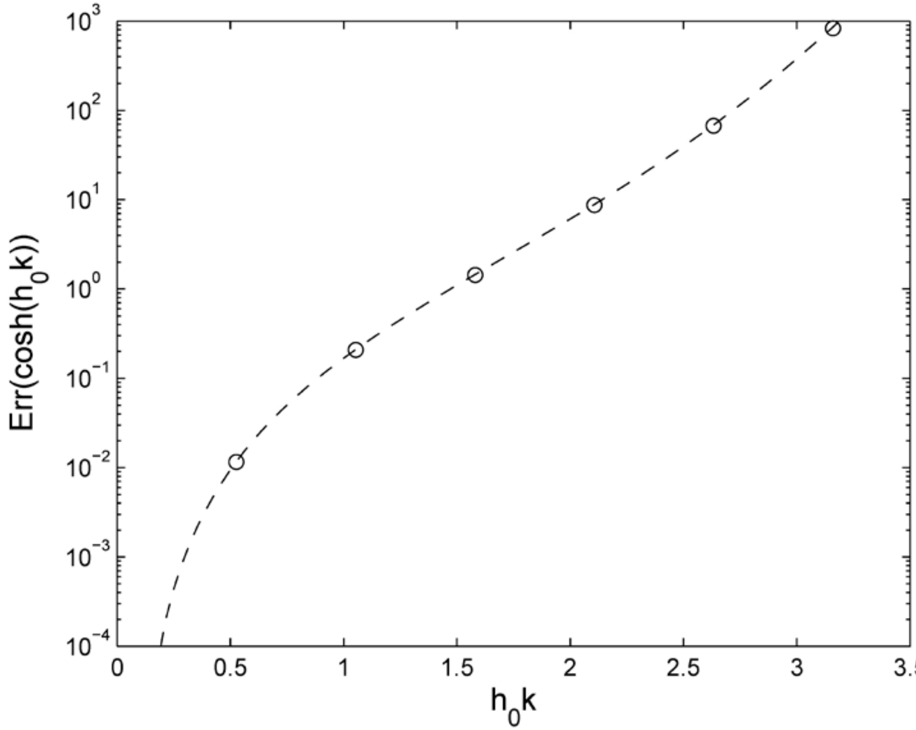
$$\tilde{\zeta}(\omega, x) = \cosh(\sqrt{\mu}|k(\omega)|)\tilde{\zeta}_H(\omega, x)$$

Vagues non-linéaires

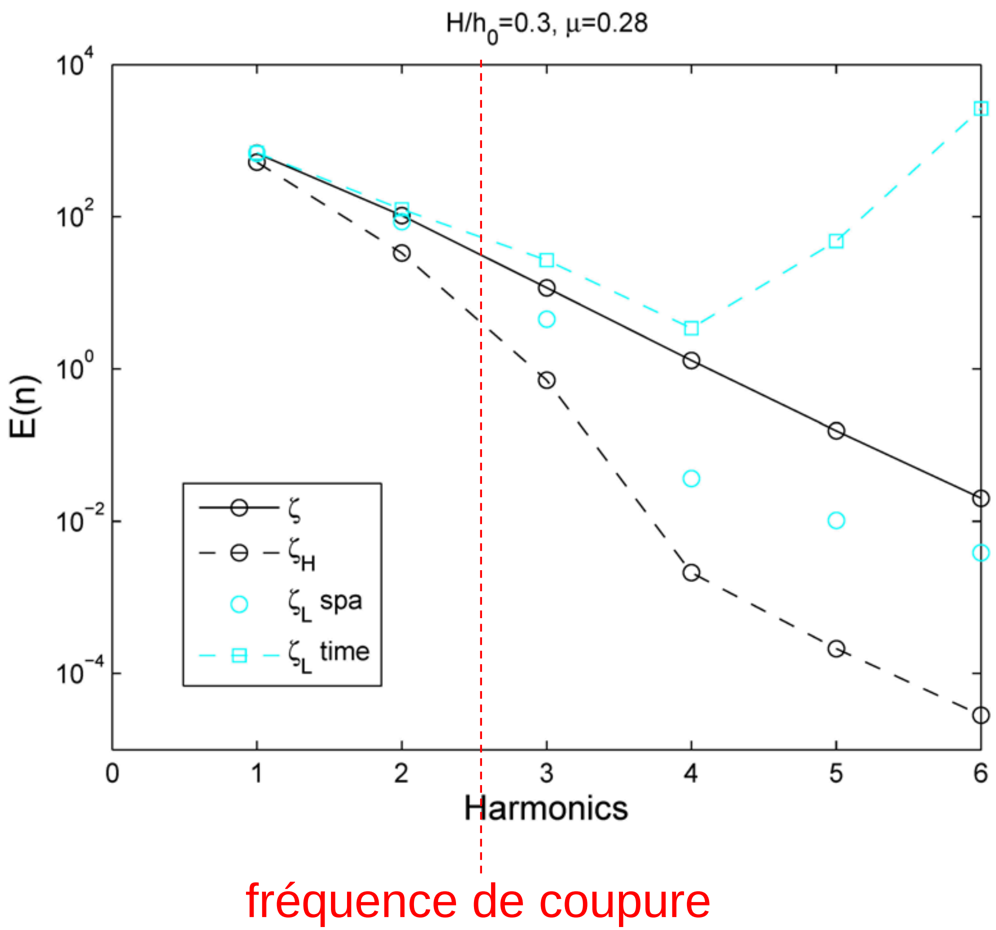
$$\tilde{\zeta}_L(\omega) = \cosh(h_0|k(\omega)|)\,\tilde{\zeta}_H(\omega)$$

$$\omega^2 = g|k|\tanh(h_0|k(\omega)|) \rightarrow c_\varphi = \sqrt{\frac{g}{|k|}\tanh(h_0|k|)}$$



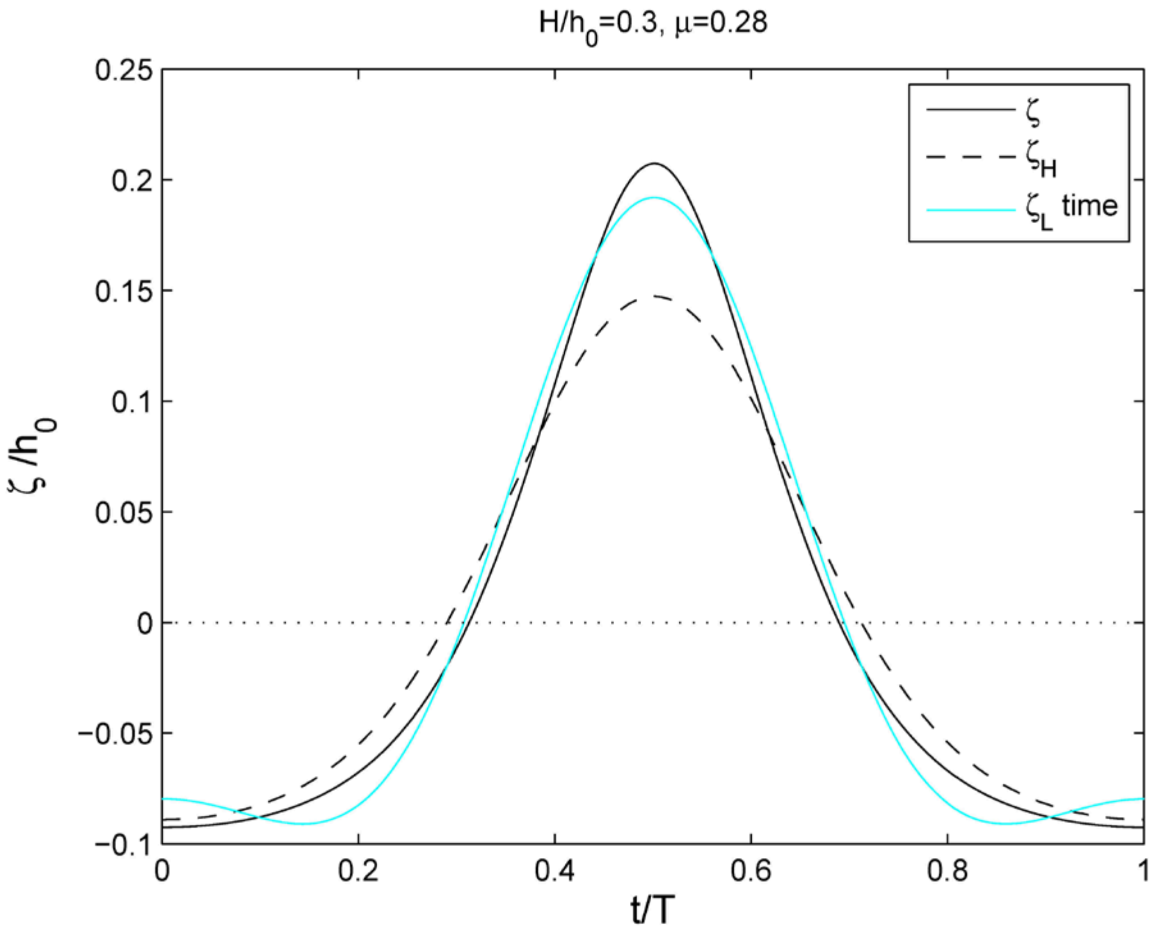


$$\tilde{\zeta}_L(\omega) = \cosh(h_0|k(\omega)|)\,\tilde{\zeta}_H(\omega)$$



Reconstruction linéaire temporelle

$$\tilde{\zeta}_L(\omega) = \cosh(h_0|k(\omega)|)\,\tilde{\zeta}_H(\omega)$$ & fréquence de coupure



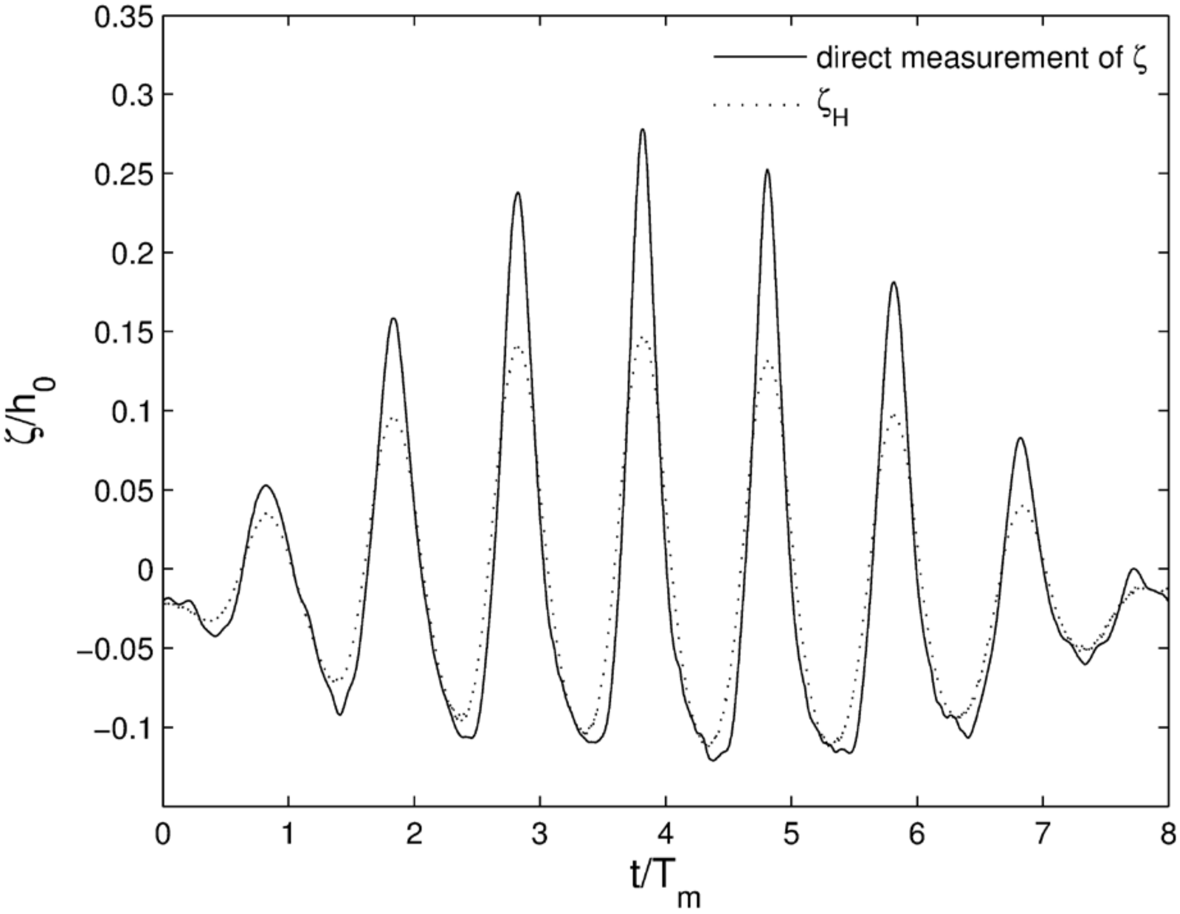
Reconstruction linéaire temporelle

$\tilde{\zeta}_L(\omega) = \cosh(h_0 |k(\omega)|)\, \tilde{\zeta}_H(\omega)$ & fréquence de coupure

$\rightarrow$ méthode classique en océanographie pour reconstruire ζ

Folsom (1947), Seiwell (1947), Hom-ma et al. (1966), Cavaleri et al. (1978), Guza et Thornton (1980), … Karimpour et Chen (2017)

Reconstruction linéaire temporelle



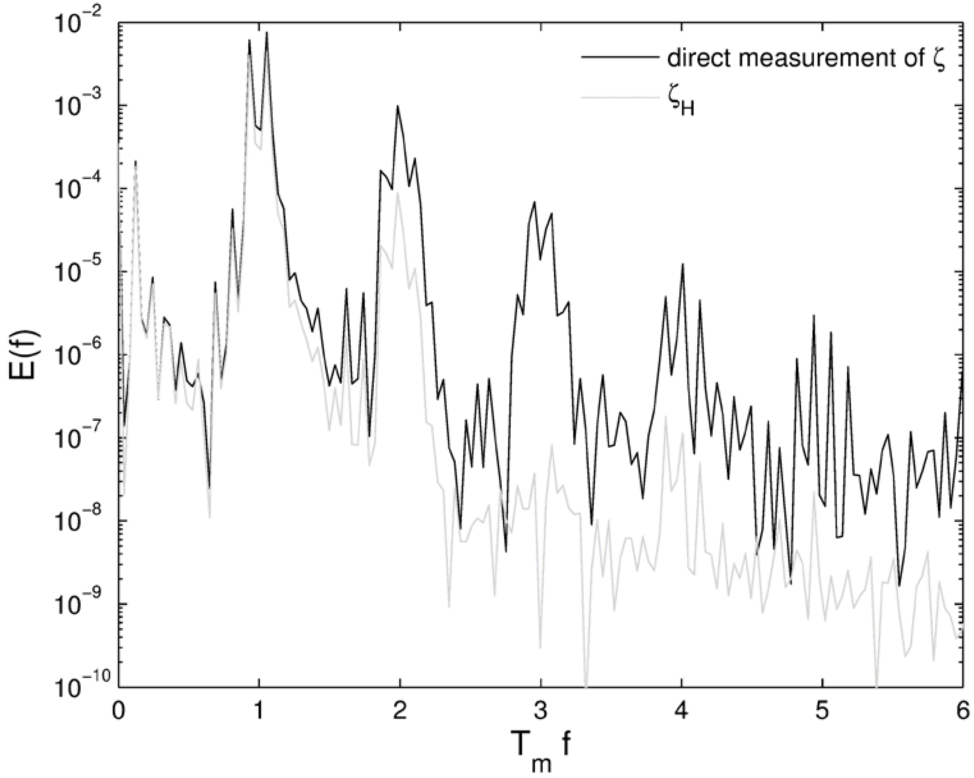
Vagues bichromatiques
Michallet et al. 2017

$$\zeta_H = \frac{P_b - P_a}{\rho_0 g} - h_0$$

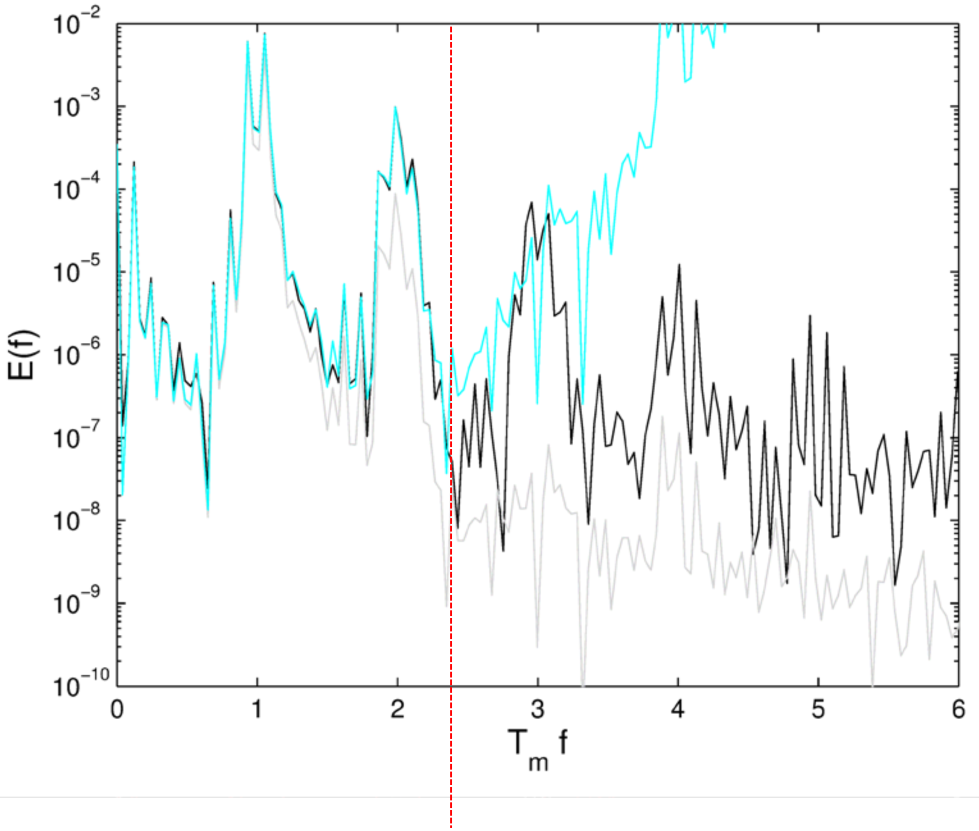
$$\tilde{\zeta}_L(\omega) = \cosh(h_0|k(\omega)|)\,\tilde{\zeta}_H(\omega)$$

$$\omega^2 = g|k|\tanh(h_0|k(\omega)|)$$

Reconstruction linéaire temporelle



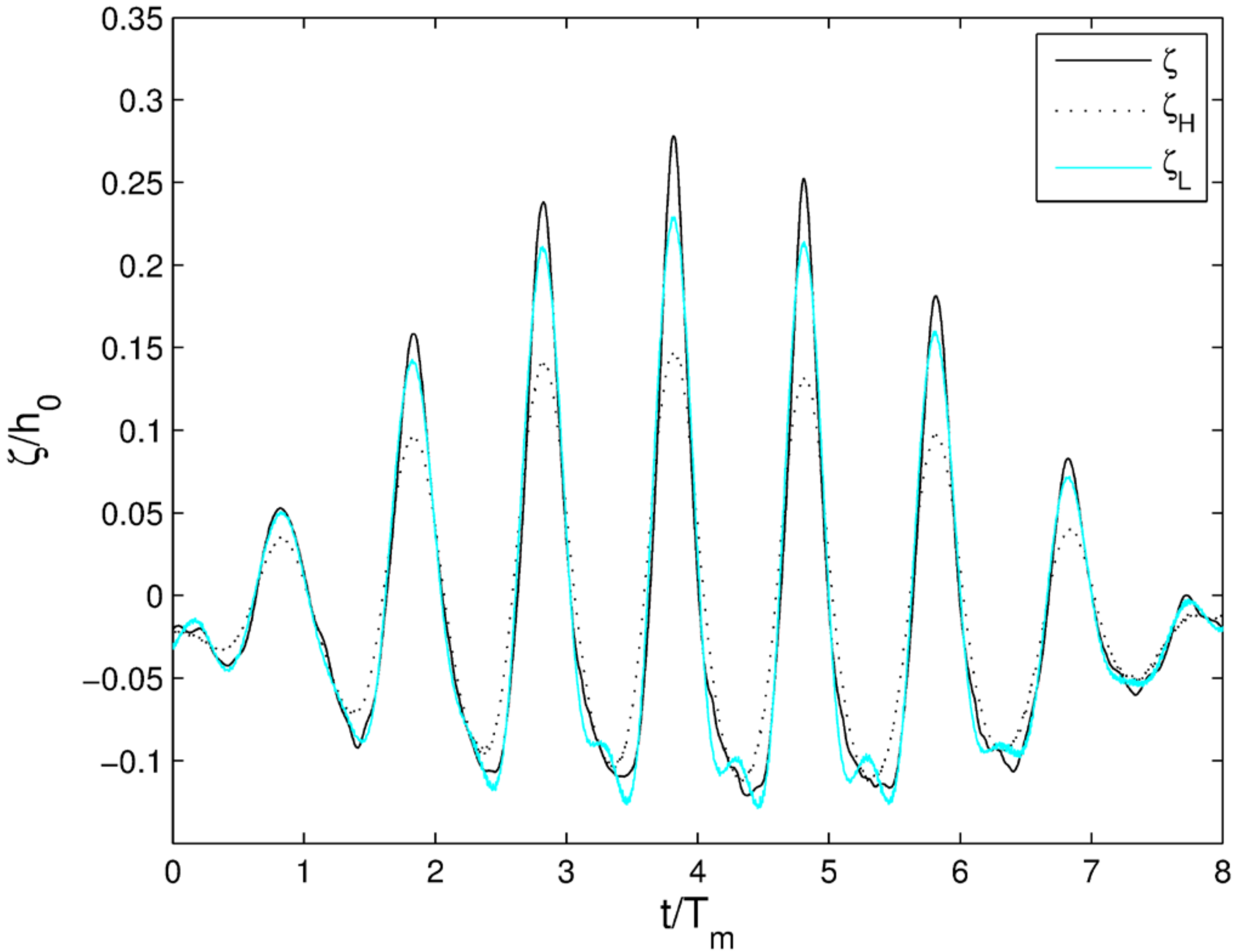
Reconstruction linéaire temporelle



f_c : fréquence de coupure

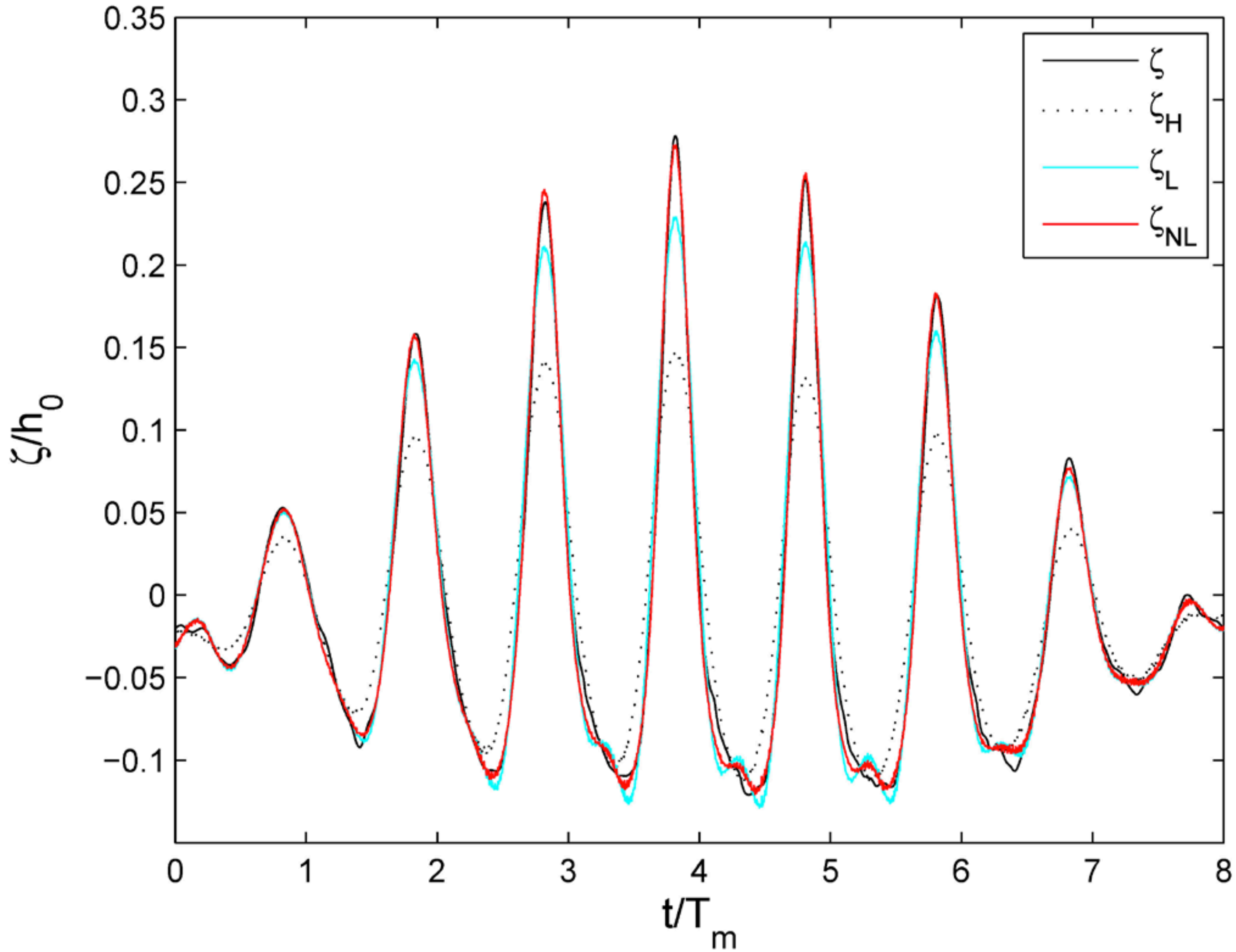
Reconstruction linéaire temporelle

$$\tilde{\zeta}_L(\omega) = \cosh(h_0|k(\omega)|)\,\tilde{\zeta}_H(\omega)$$ & fréquence de coupure



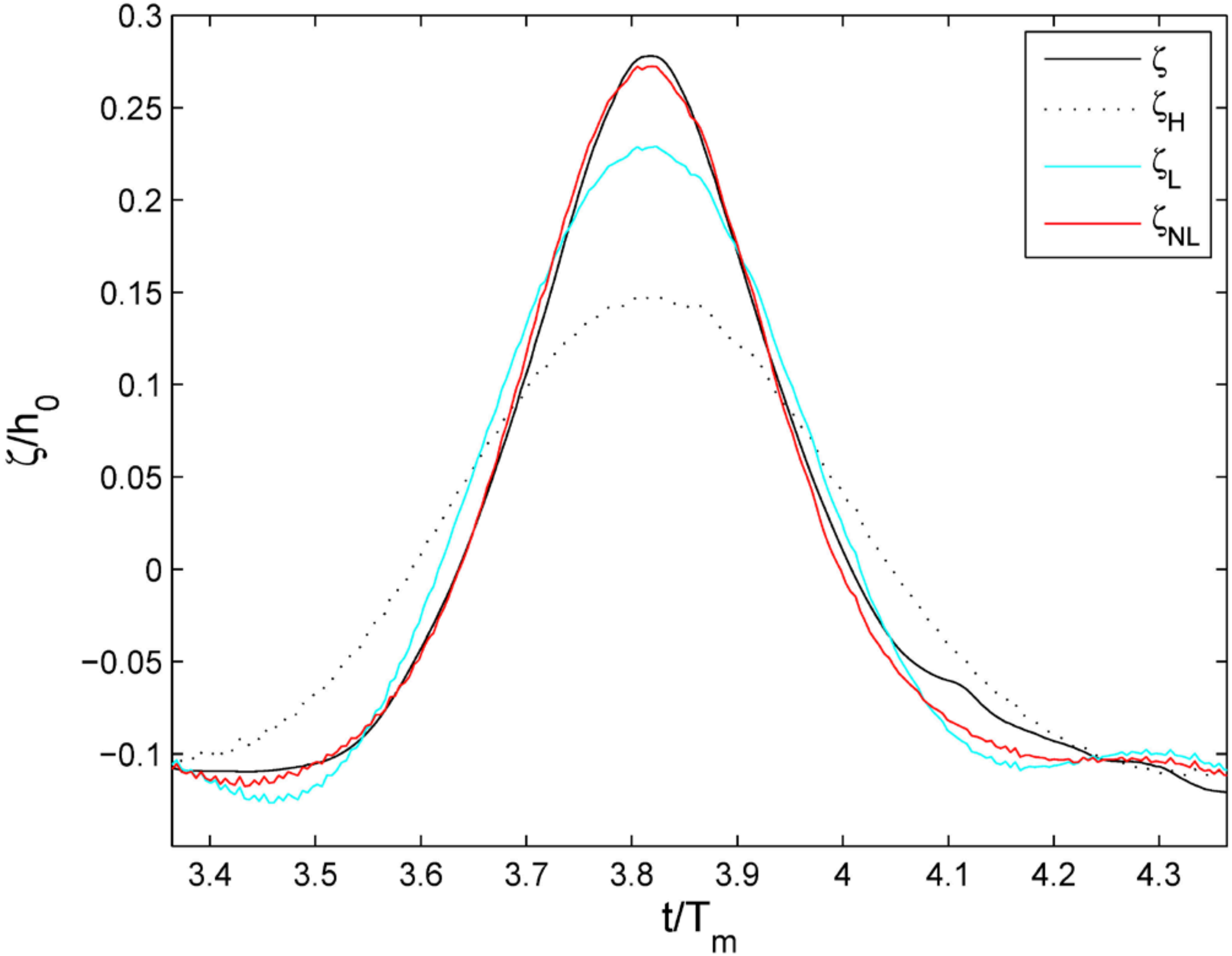
Reconstruction non-linéaire temporelle

$$\boxed{\zeta_{NL} = \zeta_L - \frac{1}{g}\,\partial_t\left(\zeta_L \partial_t \zeta_L\right)}$$



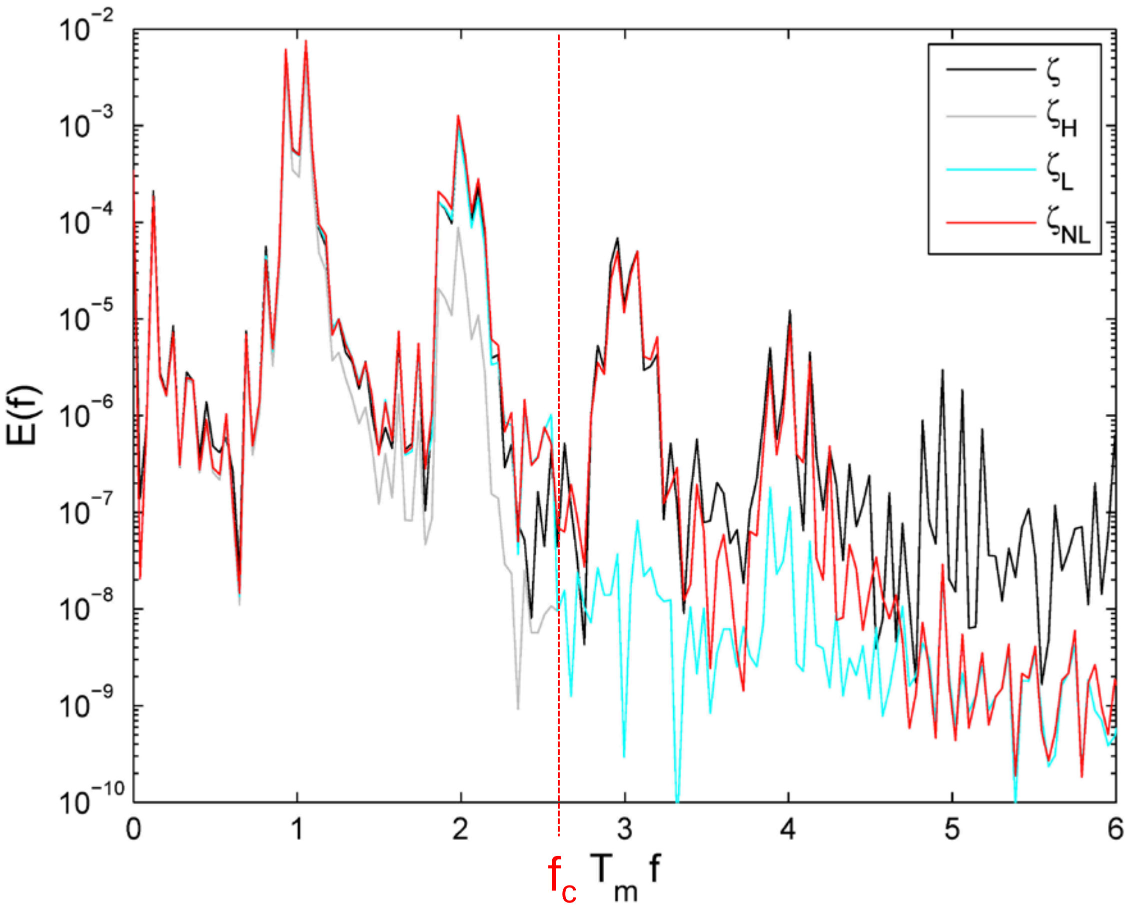
Reconstruction non-linéaire temporelle

$$\boxed{\zeta_{NL} = \zeta_L - \frac{1}{g}\,\partial_t\left(\zeta_L \partial_t \zeta_L\right)}$$



Reconstruction non-linéaire temporelle

$$\boxed{\zeta_{NL} = \zeta_L - \frac{1}{g}\,\partial_t\left(\zeta_L \partial_t \zeta_L\right)}$$



Reconstruction non-linéaire faiblement dispersive

Bonneton, P., Lannes, D, Martins, K. and Michallet, H. 2017. A nonlinear weakly dispersive method for recovering the surface wave elevation from pressure measurements. submitted to ***Coastal Eng***.

Reconstruction non-linéaire faiblement dispersive

les vagues sont fortement non-linéaires juste avant le déferlement

μ<<1 → méthode non-linéaire faiblement dispersive

Reconstruction non-linéaire faiblement dispersive

$$\underbrace{\varepsilon \left(\frac{\partial w}{\partial t} + \varepsilon u \frac{\partial w}{\partial x} + \frac{\varepsilon}{\mu} w \frac{\partial w}{\partial z} \right)}_{\Gamma} = -\frac{\partial P}{\partial z} - 1$$

$$\zeta = \zeta_H - \int_{-1}^{\varepsilon\zeta} \Gamma dz$$

Développement asymptotique par rapport μ pour trouver l'expression de Γ en fonction de ζ_H

Reconstruction non-linéaire faiblement dispersive

$$\Phi = \sum_{j=0}^{N} \mu^j \Phi_j = \Phi_0 + \mu\Phi_1 + O(\mu^2)$$

$$\begin{aligned} \mu\frac{\partial^2\Phi}{\partial x^2} + \frac{\partial^2\Phi}{\partial z^2} &= 0 & z \in [-1, \epsilon\zeta] \\ \frac{\partial\Phi}{\partial z} &= 0 & z = -1 \end{aligned}$$

$$\Phi = \psi - \frac{\mu}{2}\left((z+1)^2 - h^2\right)\frac{\partial^2\psi}{\partial z^2} + O(\mu^2)$$

$$avec \;\; \psi = \Phi_{|_{z=\varepsilon\zeta}}$$

$$\begin{aligned} u &= U - \frac{\mu}{2}\left((z+1)^2 - h^2\right)\frac{\partial^2 U}{\partial z^2} + O(\mu^2) \\ w &= -\mu(z+1)\partial_x U + O(\mu^2) \end{aligned}$$

Reconstruction non-linéaire faiblement dispersive

$$\begin{aligned} u &= U - \frac{\mu}{2}\left((z+1)^2 - h^2\right)\frac{\partial^2 U}{\partial z^2} + O(\mu^2) \\ w &= -\mu(z+1)\partial_x U + O(\mu^2) \end{aligned}$$

$$\Gamma = \frac{\partial w}{\partial t} + \varepsilon u \frac{\partial w}{\partial x} + \frac{\varepsilon}{\mu} w \frac{\partial w}{\partial z}$$

$$\Gamma = -\mu(z+1)\left(\frac{\partial^2 U}{\partial x \partial t} + \varepsilon U \frac{\partial^2 U}{\partial x^2} - \varepsilon(\frac{\partial U}{\partial x})^2\right) + O(\mu^2)$$

$$\zeta = \zeta_H - \int_{-1}^{\varepsilon\zeta} \Gamma dz$$

$$\zeta = \zeta_H - \frac{\mu h^2}{2}\left(\frac{\partial^2 \zeta}{\partial x^2} + 2\varepsilon(\frac{\partial U}{\partial x})^2\right) + O(\mu^2)$$

Reconstruction non-linéaire faiblement dispersive

$$\zeta = \zeta_H - \frac{\mu h^2}{2}\left(\frac{\partial^2 \zeta}{\partial x^2} + 2\varepsilon(\frac{\partial U}{\partial x})^2\right) + O(\mu^2)$$

- $\varepsilon = O(\mu)$

$$\boxed{\zeta_{SL} = \zeta_H - \frac{\mu}{2}\frac{\partial^2 \zeta_H}{\partial t^2}}$$

- $\varepsilon = O(\mu^{1/2})$

$$\boxed{\zeta_{SNL} = \zeta_{SL} - \varepsilon\mu\partial_t(\zeta_{SL}\partial_t\zeta_{SL})}$$

Reconstruction non-linéaire faiblement dispersive

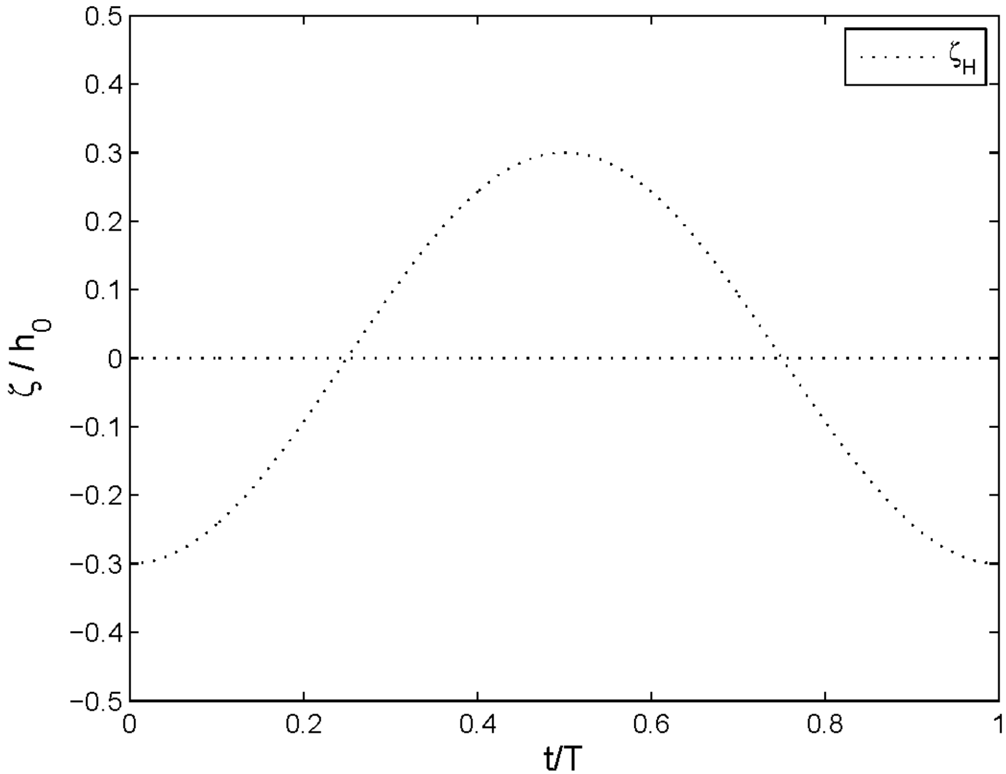
- $$\zeta_H = \frac{P_b - P_a}{\rho_0 g} - h_0$$
- $$\zeta_{SL} = \zeta_H - \frac{h_0}{2}\frac{\partial^2 \zeta_H}{\partial t^2}$$
- $$\begin{aligned} \zeta_{SNL} &= \zeta_{SL} - \frac{1}{g}\partial_t(\zeta_{SL}\partial_t\zeta_{SL}) \\ &= \zeta_{SL} - \frac{1}{g}\zeta_{SL}\partial_t^2\zeta_{SL} - \frac{1}{g}(\partial_t\zeta_{SL})^2 \end{aligned}$$

Reconstruction non-linéaire faiblement dispersive

$$\zeta_H = \frac{P_b - P_a}{\rho_0 g} - h_0$$

$$\zeta_{SL} = \zeta_H - \frac{h_0}{2}\frac{\partial^2 \zeta_H}{\partial t^2}$$

$$\zeta_{SNL} = \zeta_{SL} - \frac{1}{g}\zeta_{SL}\partial_t^2\zeta_{SL} - \frac{1}{g}(\partial_t \zeta_{SL})^2$$

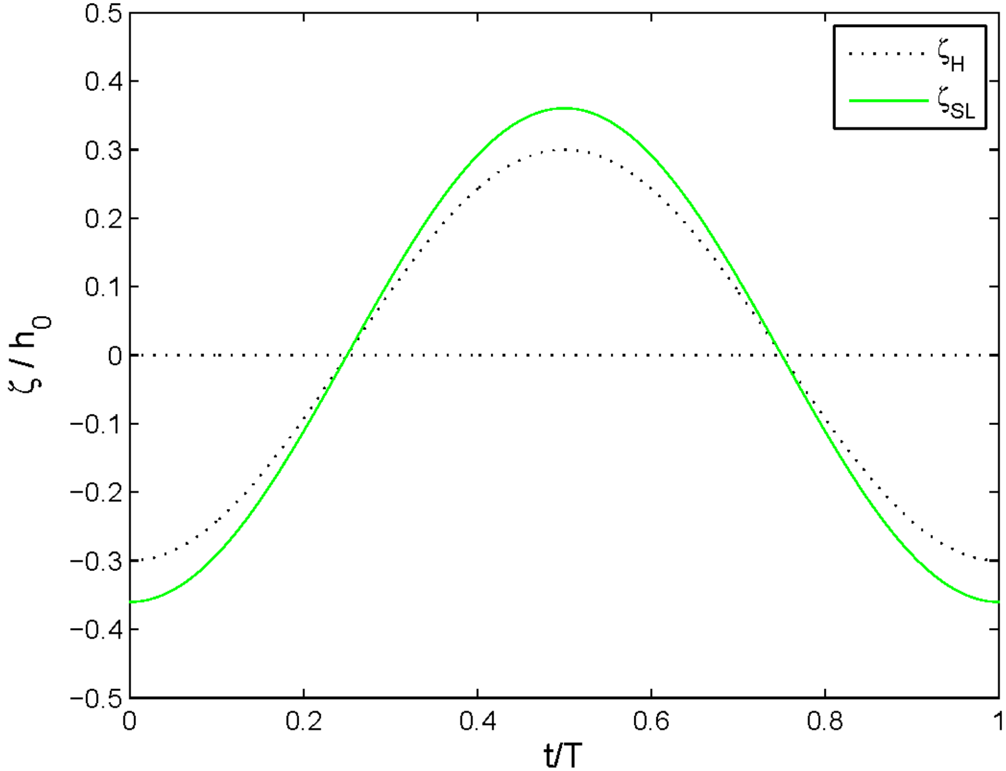


Reconstruction non-linéaire faiblement dispersive

$$\zeta_H = \frac{P_b - P_a}{\rho_0 g} - h_0$$

$$\zeta_{SL} = \zeta_H - \frac{h_0}{2}\frac{\partial^2 \zeta_H}{\partial t^2}$$

$$\zeta_{SNL} = \zeta_{SL} - \frac{1}{g}\zeta_{SL}\partial_t^2\zeta_{SL} - \frac{1}{g}(\partial_t \zeta_{SL})^2$$



Reconstruction non-linéaire faiblement dispersive

$$\zeta_H = \frac{P_b - P_a}{\rho_0 g} - h_0$$

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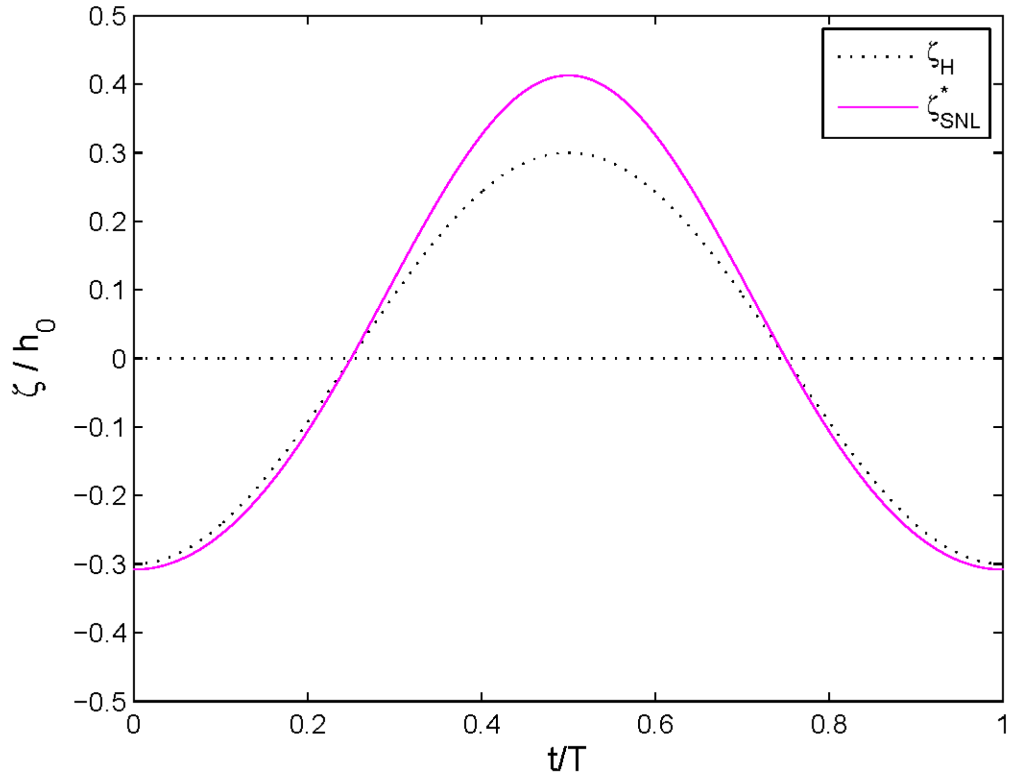
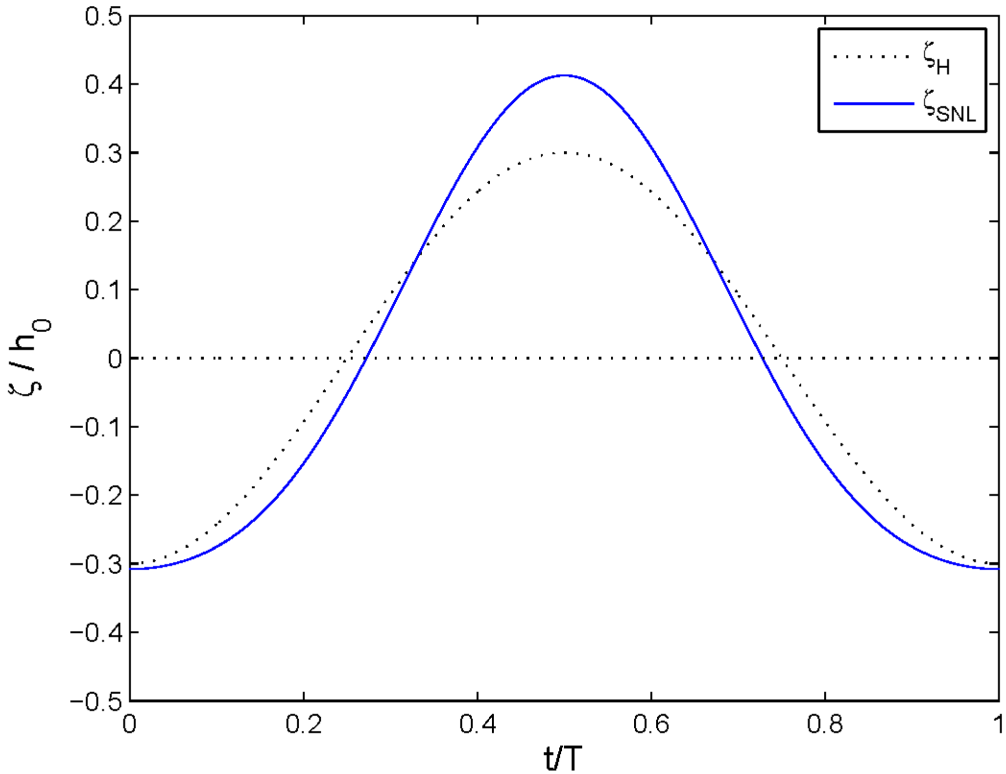


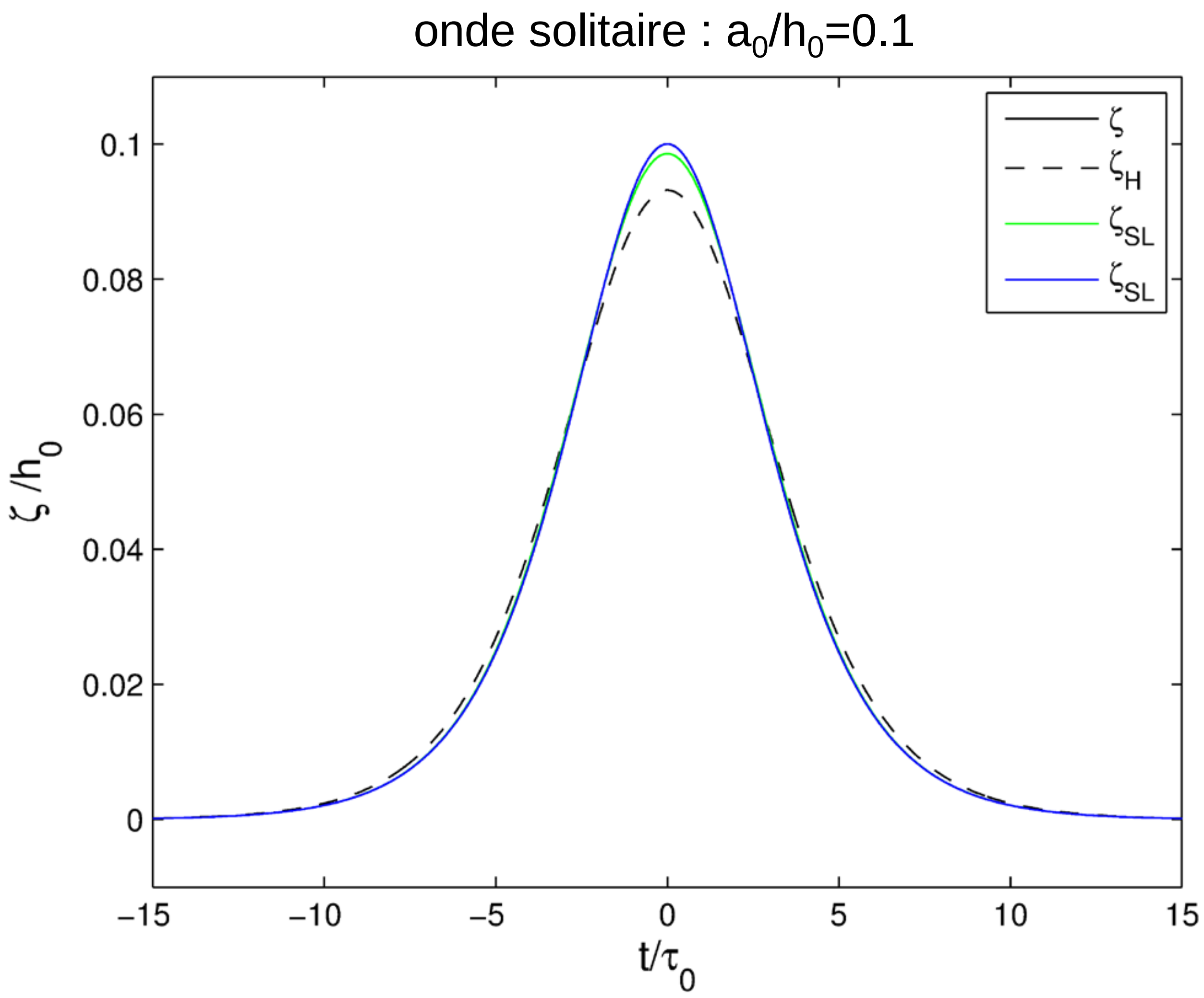
Reconstruction non-linéaire faiblement dispersive

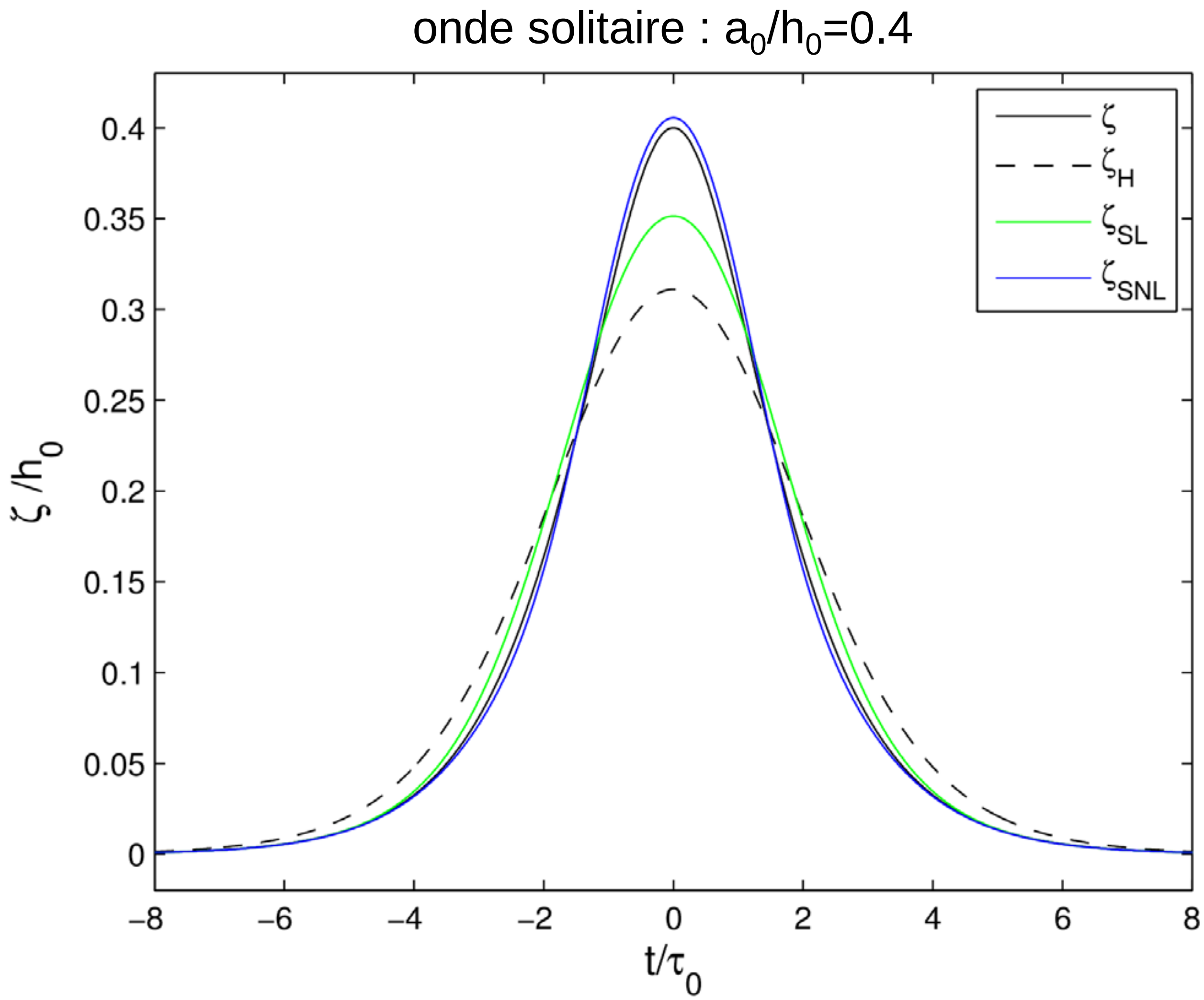
$$\zeta_H = \frac{P_b - P_a}{\rho_0 g} - h_0$$

$$\zeta_{SL} = \zeta_H - \frac{h_0}{2}\frac{\partial^2 \zeta_H}{\partial t^2}$$

$$\zeta_{SNL} = \zeta_{SL} - \frac{1}{g}\zeta_{SL}\partial_t^2\zeta_{SL} - \frac{1}{g}(\partial_t \zeta_{SL})^2$$




onde solitaire : a0/h0=0.1
ζ /h0
t/τ0
0.1
0.08
0.06
0.04
0.02
0
–15
–10
–5
0
5
10
15
ζ
ζH
ζSL
ζSL



	ζ_H	ζ_L	ζ_{NL}
Erreur RMS	22.5%	11.4%	3.5%

Mesures lidar juste avant le déferlement. Expériences Bardex II, Martins et al. 2017.

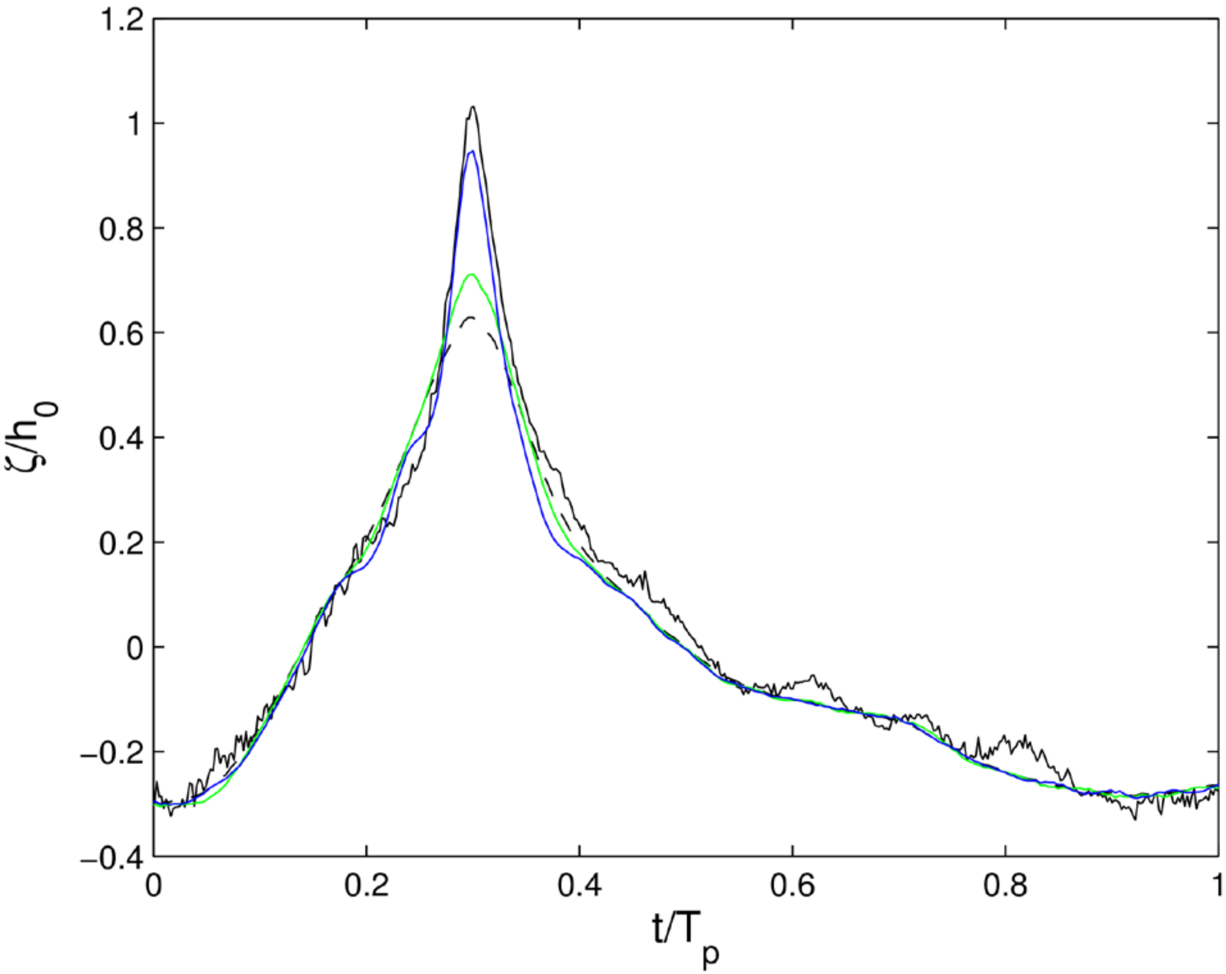


FIGURE 3: Surface elevation reconstruction of monochromatic waves. Zoom over one period of A7-mono test obtained during BARDEXII, $h_0 = 1.17$ m, $T_p = 12.1$ s and $\delta_m = 0.33$ m. Dimensionless cut-off frequency $T_p f_c = 20$. black line : direct LiDAR measurement of ζ ; dashed black line : hydrostatic reconstruction ζ_{H}, Eq. (11) ; green line : ζ_{SL}, Eq. (12) ; blue line : ζ_{SNL}, Eq. (13).

$$S_k = \frac{\langle(\zeta - \langle\zeta\rangle)^3\rangle}{\langle(\zeta - \langle\zeta\rangle)^2\rangle^{3/2}}$$

	ζ_H	ζ_L	ζ_{NL}
Erreur S_k	32.2%	22.5%	0.7%

Campagne de mesures au Wharf de la Salie, 13-14 avril 2017

mesures acoustiques et système vidéo

Bonneton N., Bonneton P., Castelle B., Detandt G., Marieu V., Poncet P-A.

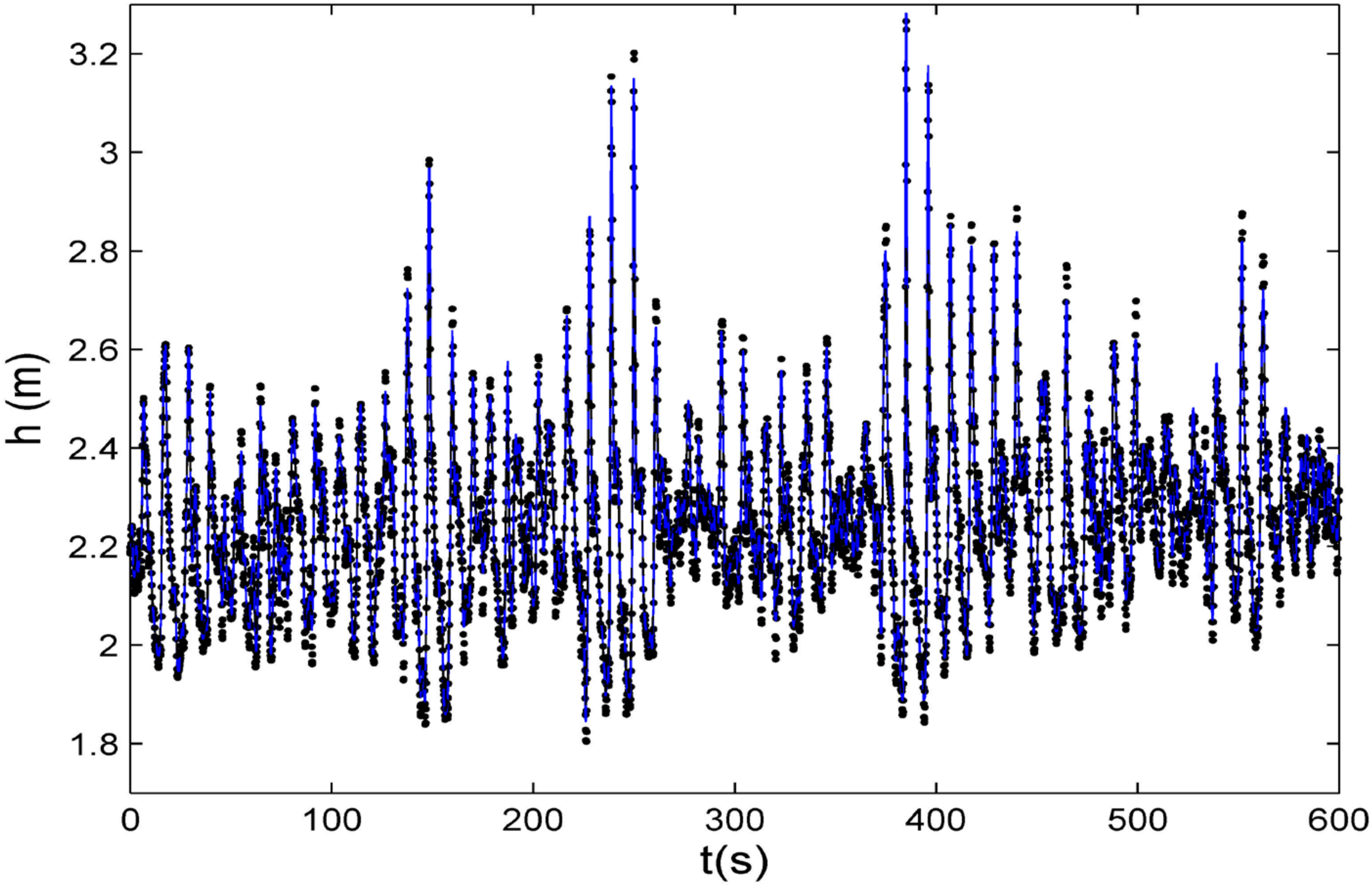


FIGURE 6: Reconstruction of water depth time series of waves observed in the field. Cut-off frequency $f_c = 1$ Hz, $\bar{h} = 2.25\,m$, $\delta_m = 0.69\,$m. dot : direct acoustic measurement of h ; blue line : $h_{\mathrm{SNL}} = \bar{h} + \zeta_{\mathrm{SNL}}$, Eq. (13).

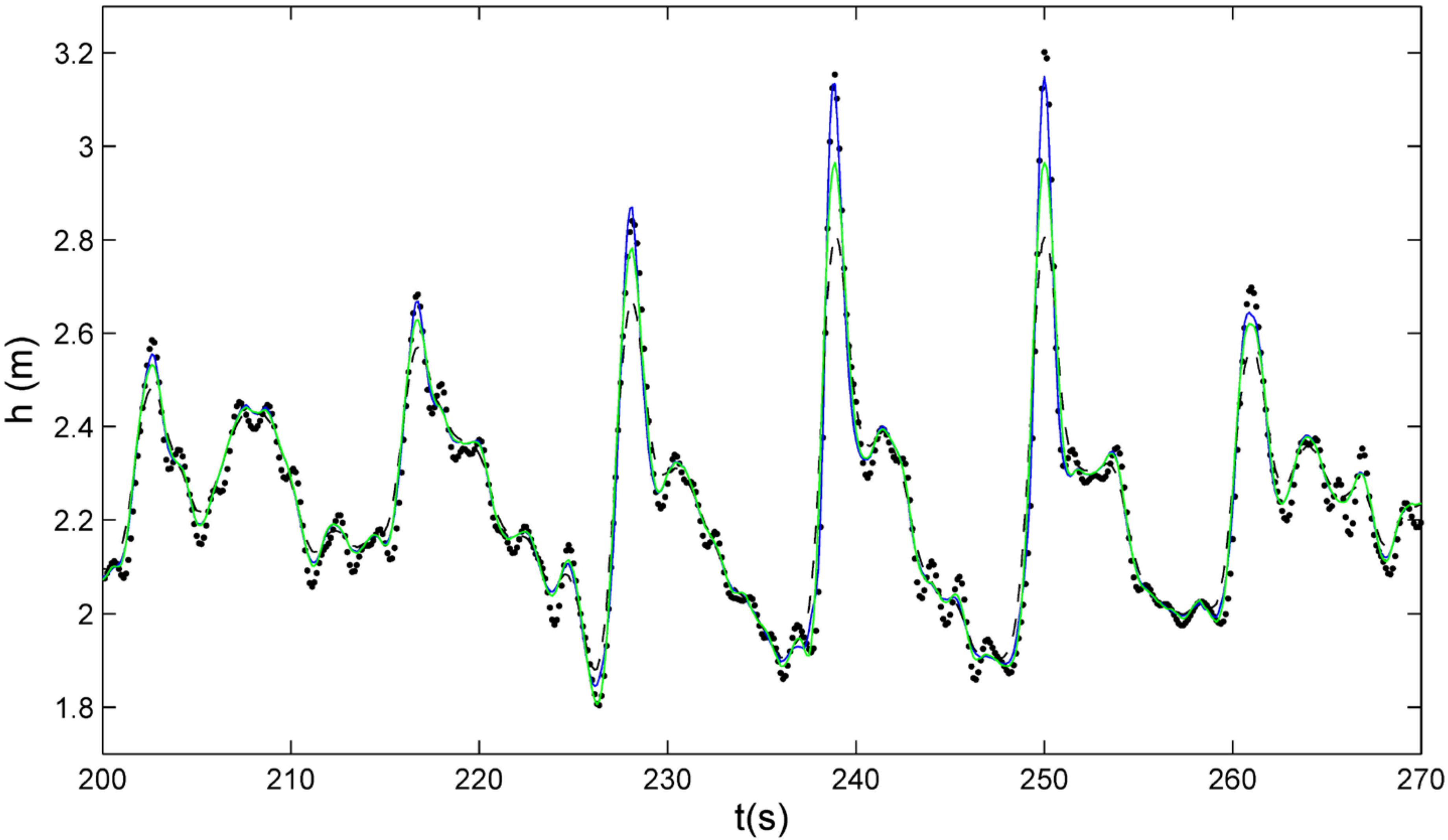


FIGURE 7: Reconstruction of water depth time series of a group of waves observed in the field. Cut-off frequency $f_c = 1$ Hz, $\bar{h} = 2.25\,m$, $\delta_m = 0.69\,\mathrm{m}$. dot : direct acoustic measurement of h ; green line : $h_{\mathrm{SL}} = \bar{h} + \zeta_{\mathrm{SL}}$, Eq. (12) ; blue line : $h_{\mathrm{SNL}} = \bar{h} + \zeta_{\mathrm{SNL}}$, Eq. (13).

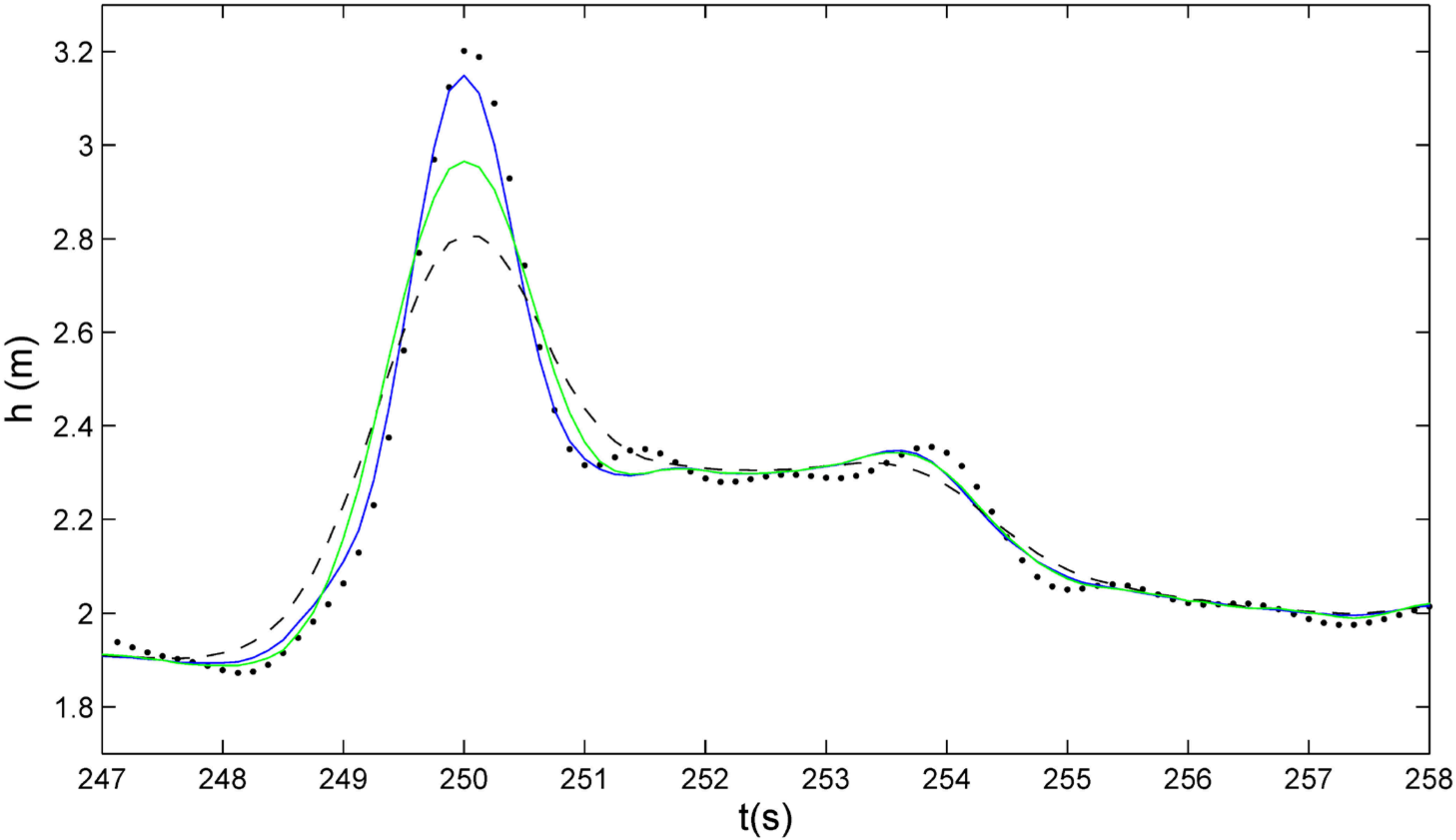


FIGURE 8: Reconstruction of the highest wave observed in a wave group. Cut-off frequency $f_c = 1$ Hz, $\bar{h} = 2.25\,m$, $\delta_m = 0.69$ m. dot : direct acoustic measurement of h ; dashed black line : hydrostatic reconstruction $\zeta_{\rm H}$, Eq. (11) ; green line : $h_{\rm SL} = \bar{h} + \zeta_{\rm SL}$, Eq. (12) ; blue line : $h_{\rm SNL} = \bar{h} + \zeta_{\rm SNL}$, Eq. (13).

Conclusion

$$\boxed{\zeta_{SNL} = \zeta_{SL} - \frac{1}{g}\partial_t\left(\zeta_{SL}\partial_t\zeta_{SL}\right)}$$

- une méthode efficace et simple à mettre en œuvre pour la reconstruction de l'élévation de vagues non-linéaires irrégulières à partir de la mesure de la pression au fond

- méthode locale en temps, pas besoin de transformée de Fourier, ni de fréquence de coupure

- bonne estimation des valeurs max de ζ et de l'asymétrie des vagues non-linéaires

- généralisation :
  effet d'un courant moyen ; pression mesurée au-dessus du fond

Perspectives

Revisiter la dynamique des vagues extrêmes

- Analyse de la densité de probabilité des vagues
  et modèle probabiliste de vague

- Méthode de reconstruction non-linéaire basée sur des mesures PUV

- Validation et amélioration des modèles de type Serre/Green Naghdi
  → code communautaire UHAINA (EPOC, IMB, INRIA, IMAG)

Projet « vagues extrêmes » 2018-2021

Région Nouvelle Aquitaine et SHOM

Thank you for your attention